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Is the STEM Approach Useful in Teaching Mathematics? Evaluating the Views of Mathematics Teachers

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ABSTRACT

The STEM approach, which has been included in the education literature with increasing value in the last decade, has also drawn researchers' attention to the process of learning and teaching mathematics. In this study, the views of mathematics teachers, who were involved in in-services STEM-training, were evaluated under the themes of integration with the curriculum, limitations in implementation, and attitude development. A qualitative case study was carried out with 36 secondary school mathematics teachers. Data were collected with a questionnaire form two different types of STEM tasks (engineering design sets and coding) and analyzed with descriptive statistics. The results of the study showed that the participants' views on the usefulness of STEM tasks in mathematics teaching are positive, but they have difficulties with linking the tasks to the mathematics curriculum. Participants find coding tasks more applicable than the engineering design and building tasks. Suggestions are made for teacher education and textbook development.

Keywords: STEM, mathematics teacher, coding tasks, engineering tasks

INTRODUCTION

One of the goals of education is to prepare individuals for the competencies needed in the 21st century and to train them well-equipped in this sense. Several revisions are made in different education systems around the world to improve skills such as creativity, critical thinking, problem-solving, and digital literacy (MoNE, 2016; NCTM, 2000). The STEM (Science, Technology, Engineering, and Mathematics) approach provides educational content that will enable future generations to be successful in STEM fields and helps the transition into digitalization and thinking on the basis of technology (NRC, 2011; Stohlmann et al., 2012; TUBITAK, 2016). Therefore, so as to obtain the competencies that the 21st century requires, training teachers for STEM education and preparing programs in accordance with the content required by interdisciplinary relationships are two important issues. The STEM-based curriculum not only aims to lead students to solve real-world problems but, thanks to their sufficient education and equipment in the field of STEM, also makes them future implementers of such curricula (Wang, 2013). Unlike the learning outcomes-based perspective of the traditional curriculum, the STEM education approach has an integrated skills-based philosophy in mathematics education (Bybee, 2010; NRC, 2011). Another key component that makes an educational approach or curriculum useful is how effectively this approach is used by teachers in their teaching practice. However, it remains unclear how much the STEM approach is adopted by the practitioner teachers in mathematics education and how well this approach is compatible with the current mathematics curriculum. Various studies in the related literature mainly consist of the developed scales and attitudes towards STEM education and in some other studies, science teachers' views are evaluated (El-Deghaidy et al., 2017; Li et al., 2020; Tseng et al., 2013). Among all these studies, there is limited research on mathematics, which is one of the stakeholders of STEM disciplines. However, it is important to consider the mathematics discipline, which students have difficulty in associating with daily life, but which also includes STEM skills such as modeling, measuring, and using numbers, within the STEM approach. For this reason, the aim of this study is to evaluate the views of mathematics teachers about using STEM tasks in their teaching practices. In the present study, answers to the following two questions were sought:

1. What are the views of mathematics teachers about the usefulness of STEM tasks in secondary school mathematics teaching?
2. Which mathematical skills can be improved with STEM tasks according to the views of mathematics teachers?

Conceptual Framework

What is STEM education?

STEM, which emerged as a product of the initiatives of some institutions and foundations in the early 1990s to solve various problems in the American workforce, has now found a place in education policies globally (NRC, 2011). STEM education has become more important as it is developed as an integrated effort that eliminates the traditional barriers between science, technology, engineering and mathematics, and attaches importance to innovative skills with the help of the contemporary technology (Kennedy and Odell, 2014). There are different definitions for STEM education in the literature. According to Bybee (2010), STEM education is an approach to improve the use of technology and designing products in science and mathematics teaching so as to increase students' understanding of how things work. Some other definitions of STEM education are: a multidisciplinary model that helps the development of skills in science, technology, engineering, and mathematics (Tsupros et al., 2009); the new generation curriculum for associating two or more STEM disciplines (Kelley and Knowles, 2016); simultaneous teaching of science and mathematics contents through the use of technology/engineering design (Kang et al., 2013). As stated above, although there are various definitions regarding STEM education, the common feature of these definitions is that they emphasize "interdisciplinary nature". Apart from other educational approaches, STEM education is skills-oriented and integrative.

Many studies in the literature examine the impact of STEM education on teachers' perceptions or/and students' skills (Bergsten and Frejd, 2019; Margot and Kettler, 2019; Park et al., 2016; Wang et al., 2011). The STEM approach, which finds a place in the field of education with a pragmatic agenda, has a claim to contribute to the development of skills that will be needed especially in the 21st century. These skills can be listed as critical thinking, collaboration, leadership, mathematical modeling, and productivity (Drake, 2012; Li et al., 2020; Stohlmann et al., 2012). According to Stohlmann et al. (2012), as the integration of STEM subjects into the curriculum increases, students can improve their critical thinking and problem-solving skills more effectively. Comparisons of international perspectives on the different policies and programs of each country show that many countries place STEM education in their systems with an increasing interest (Marginson et al., 2013). For instance, the Scientific and Technological Research Council of Turkey (TUBITAK), aims to create a "welfare society" that is literate in every subject of technology and science, and able to produce new technologies, use them consciously and transform the technological developments for the benefit of the greater society and economy (TUBITAK, 2016). To contribute to the training tasks of participants, some universities in Turkey have started to introduce STEM centers from which teachers and prospective teachers can benefit. Today, certificate programs are carried out in the Continuous Education Centers of more than 20 universities in Turkey to provide teachers with professional awareness and the workshop skills that they can use in their classrooms when it comes to STEM education. Although STEM terminology was not included directly in the mathematics curriculum of Turkey, attention is drawn to the interdisciplinary integration in the teaching process (MoNE, 2018). With the interest in STEM education in the field, researchers started to discuss the role of teachers in this approach.

Teachers' perception on STEM education

It is important to evaluate teachers' perceptions to understand the usefulness of an educational approach or method in classroom practice. STEM education research conducted with teachers' perceptions in the relevant literature can be grouped under two headings. These are STEM practices of teachers and teachers' attitudes and/or views on STEM education. In these studies, particularly the teaching of science concepts or the views of science teachers were considered as the central discipline in STEM education. In one of these studies, Wang et al. (2011) found that STEM professional development programs for teachers provided more opportunities and connections on how to use STEM integration for teaching their disciplines. El-Deghaidy et al. (2017), in their study about evaluating the science teachers' views regarding STEM pedagogy, found that teachers have concerns about their under-preparedness to enact STEM practices.

In recent years a considerable number of surveyed science teachers' attitudes towards STEM education, but few researchers have addressed the views of mathematics teachers in STEM environment (El-Deghaidy et al., 2017; Margot and Kettler, 2019; Tseng et al., 2013). In the literature concerning the processes and the evaluations of the STEM education approach in mathematics teaching, researchers generally have addressed the issues of students' mathematical achievement or mathematical modeling (Bicer et al., 2015; Stohlmann, 2017, Ozdemir et al., 2018). In one of the studies about academic achievement, Bicer et al. (2015) compare schools with and without STEM education in the USA in the context of 9th-grade mathematics achievement. The results of the study show that the mathematics achievement of 9th-grade students in schools applying STEM education is higher than those of the students at the same grade level in a school not practicing STEM. The contribution of STEM education to mathematics achievement is still discussed (English, 2016). Unlike other disciplines, mathematics is assessed by the legitimate principles of the discipline itself, while other disciplines are used as motivational contexts or application areas of mathematical methods (Bergsten and Frejd, 2019). Mathematics is already embedded in the process of evaluating disciplines such as science and engineering. A study revealing the contributions of the STEM education approach in terms of mathematical skills development has not been available in the reviewed literature.

STEM tasks and curriculum integration

The most important challenge encountered in STEM education is the problem of curriculum integration. Sometimes a new curriculum is developed to overcome this problem, but if STEM activities are integrated into the existing curriculum the current curriculum and the role of teachers needs to be monitored more closely (Bergsten and Frejd, 2019). The skills-oriented advantages of STEM education can benefit from teachers who are well-equipped in STEM education (Wang, 2013). The most important part with which teachers may have difficulties and prove inadequate during the implementation of STEM education would be the lack of content knowledge and attitudes towards integrability of STEM disciplines (Estapa and Tank, 2017; Park et al., 2016). Ozdemir et al. (2018) found that teachers have been incompetent in integrating and interpreting different disciplines, which is the most important part of STEM education. Wang et al. (2011), on the other hand, investigated teachers' beliefs about the use of integrated STEM from the perspective of branch teachers, and they determined that while science, mathematics, and engineering teachers have a common problem-solving process, STEM teachers in different disciplines have different perceptions about integrating STEM, thus emphasizing the variety of skills in applications.

The usefulness of STEM education also depends on the type of tasks or activities used in the integration process. Engineering design sets, or accessible materials may be used when developing a task in STEM learning environments. Another approach considered influential in teaching mathematics through STEM education is coding, as a result of which recently more attention has been given to coding education in STEM research. It is not yet known whether the coding tasks carried out within the framework of STEM education are effective for teaching mathematics. However, studies conducted with a coding program such as Scratch or Mblock can offer us an idea in this sense. Calder (2018) evaluated the effect of Scratch on 10-year-old students' mathematical skills and the findings showed that mathematical thinking, including geometry and problem-solving processes, was facilitated through these applications. In another study conducted with a similar purpose, Iskrenovic-Momcilovic (2020) examined the effectiveness of Scratch's application in mathematics in the study of basic geometric shapes and found that the coding tasks, which are added to the curriculum, have allowed mathematics to become more interesting to students. In the experimental research evaluating the coding tasks developed by STEM-trained preservice mathematics teachers, it has been determined that the participants tended to develop tasks for the domains of geometry and measurement and focused mostly on algorithmic thinking and visualization skills within the task (Ozdemir et al., 2018).

In summary, with the increasing interest of researchers in STEM education and the international recognition that this approach has gained, other questions that need to be answered are how these efforts are reflected in classroom practice and what teachers' views are about the usefulness of STEM education must. In this sense, research that examines how mathematics teachers, as the implementers of the curriculum and stakeholders of the STEM disciplines, practice their STEM education in teaching environments is crucial for a direct reflection on the learning-teaching processes.

Figure 1. Some parts of Fischertechnik engineering sets

METHOD

Research Model and Participants

This research focuses on a detailed and comprehensive examination of teachers' views and practices regarding an educational approach (STEM). The case study design was used in this research to understand the skills and mathematical subjects that teachers consider when using STEM tasks in their classroom practice. The case study is a detailed examination of a phenomenon with a holistic approach, and it is used by researchers to understand a situation using "how and why" questions (Yildirim and Simsek, 2013). Qualitative data from case studies must enable in-depth analysis and shed light on the contribution of other components that occur around the case. Unlike survey design, the case study design deals with a phenomenon occurring in and around a group of participants that is investigated in-depth and with multiple tools. The case in this study is the usefulness of STEM tasks in teaching practice.

For the opinions expressed by the participants about an educational approach to be representative of an authentic situation, the participants must be involved in this education beforehand. Therefore, the participants included in this study were chosen from among the mathematics teachers who participated in an in-service professional development program for STEM education. Purposeful sampling technique, which is appropriate to the qualitative research paradigm, was utilized in the present research because purposeful sampling provides rich data that can be analyzed in detail and used for the evaluation of situations (Creswell, 2009). The participants of this study are thirty-six secondary school mathematics teachers working in the Black Sea region of Turkey. For maximizing representativeness of the sampling in the study, each of the participants was selected from a different secondary school. As only a limited number of teachers can be provided with face-to-face STEM education within the framework of in-service training, this number represents a high regional participation. The participants were expected to have taken part in the previous two years in the in-service training programs, which were especially designed for the subject of STEM education under the name of Professional Development Program by the General Directorate of Teacher Training and Development of the Ministry of Education in Turkey. The in-service training program is carried out by academics who are experts in STEM Education and lasts for a week with the participation of teachers from different disciplines. The STEM training is carried out in two stages, basic and advanced. The basic level includes information about STEM education, recognizing STEM materials, understanding the teaching methods and techniques that can be used during STEM education and information about how STEM can be integrated into lessons, the advanced stage includes skills such as using a 3D printer, robotic coding, and workshop applications, and is organized for the teachers who are above basic level. Twenty of the teachers participating in the study received basic level STEM education, and the rest (sixteen participants) took the advanced level.

Data Collection Tools

In this study, questionnaires and interviews were used to collect data. The STEM-Usefulness Form was applied as a questionnaire to determine the participants' views on the integration of STEM tasks in the curriculum. The STEM-Usefulness Form includes items, tasks, and short answer questions to evaluate the views of secondary school mathematics teachers about the usefulness of STEM tasks. The form includes two types of tasks: three on Engineering Design and Building (EDB) tasks and three on coding. Thus, the usefulness of STEM contents in the teaching process according to the type of task was evaluated within the framework of the participants' views. The tasks in the STEM-Usefulness Form were selected from the "Secondary School STEM Task and Project Book" by Altun and Yildirim (2015).

The EDB tasks are the type of tasks in which students create a product using the plug-in parts (Fischertechnik) prepared for the STEM learning environment (**Figure 1**).

The EDB task: Our Security is in Your Hands

What I Will Learn: You will install electrical circuits in this project. You will use the electrical circuits you have installed for communication, and you will see the technological applications of science. Also, you will learn about cryptology (encryption), one of the fields of mathematics, and you will develop your encryption systems.

Duration: 5 hours

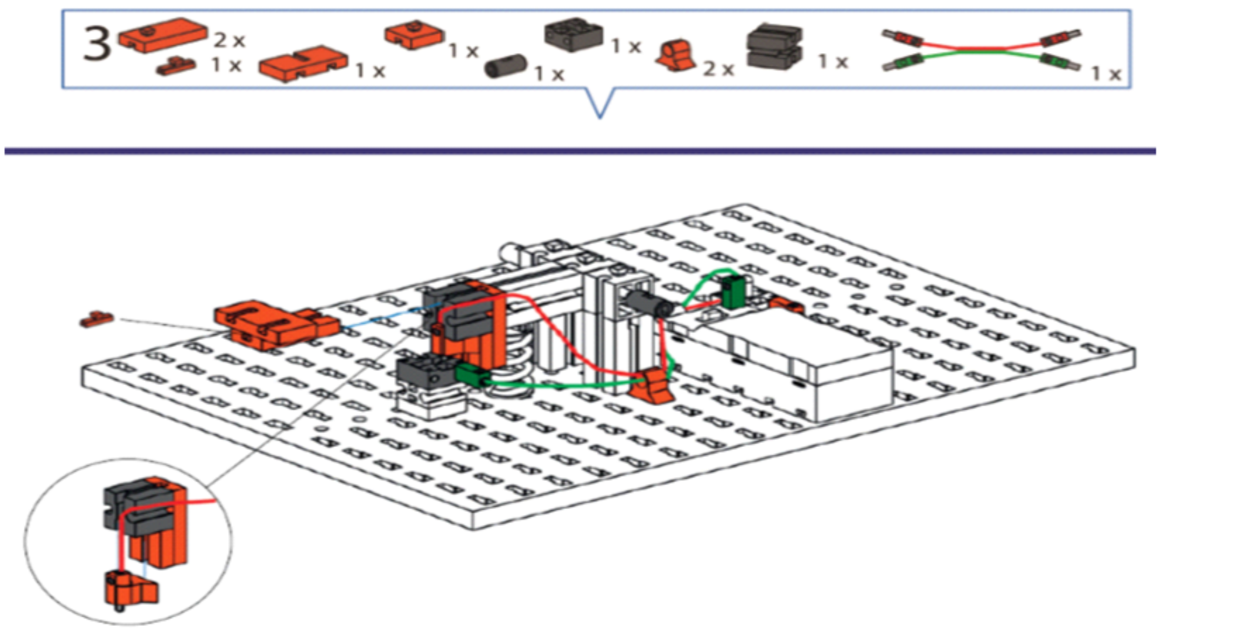

Figure 2. The Introduction to the 'Our Security is in Your Hands' task and the visual guide to assembling parts

Some stages of the task named 'Our Security is in Your Hands', which is one of the EDB tasks in the STEM-Usefulness Form, are presented in **Figure 2**. The task begins with a brief introduction to the purpose of the task, what kind of mathematical skills can be achieved at the end of it, and its duration (**Figure 2**).

The following sections describe what to do step by step, the topics of investigation, and which parts to use. The process of assembling the necessary parts and creating the product is also visually included in the tasks. The other two EDB tasks are "The Ferris Wheel" and "Producing the Domestic Car". The coding tasks, on the other hand, create products on traffic signals, wind turbines, and self-parking by adding an open-source microcontroller platform to the engineering sets via Mblock and Arduino programming.

According to Buyukozturk (2005), there are three critical stages when preparing a questionnaire. These are

a. obtaining expert opinion after writing the items,
b. revising the items according to the pre-application results, and
c. ensuring the internal consistency of the questionnaire.

In the process of preparing the questionnaire items in the form, first of all, the mathematics teachers involved in STEM education as a part of the pilot study were interviewed and as a result of these interviews, the draft form of the items was created. The positive and negative statements about the usefulness of the STEM tasks were placed in the form. The items in the form were selected from the prototype statements that question the usability of teaching material in the curriculum that have been used before. Six of the 14 questionnaire items related to integration in the curriculum, limitations of the implementation, and attitude development. Participants were expected to justify their answers. The form was examined by two experts with PhD in mathematics and science education. After the pilot study, the questions in the form took their final version.

After the application of the STEM-Usefulness Form to all participants, semi-structured interviews were conducted with ten teachers selected from the participant group to examine the problem which is investigated more deeply and to present the results more strongly. Participants were selected according to the level of STEM education they had received (five at the basic level, and five at the advanced level) and to represent the variety of responses in the STEM-Usefulness Form. In preparing the interview form, STEM-Usefulness Form questions were used for reference depending on the subject investigated, and the studies in the literature were utilized to enable the researcher to obtain more detailed information about the subject and ask more questions when necessary.

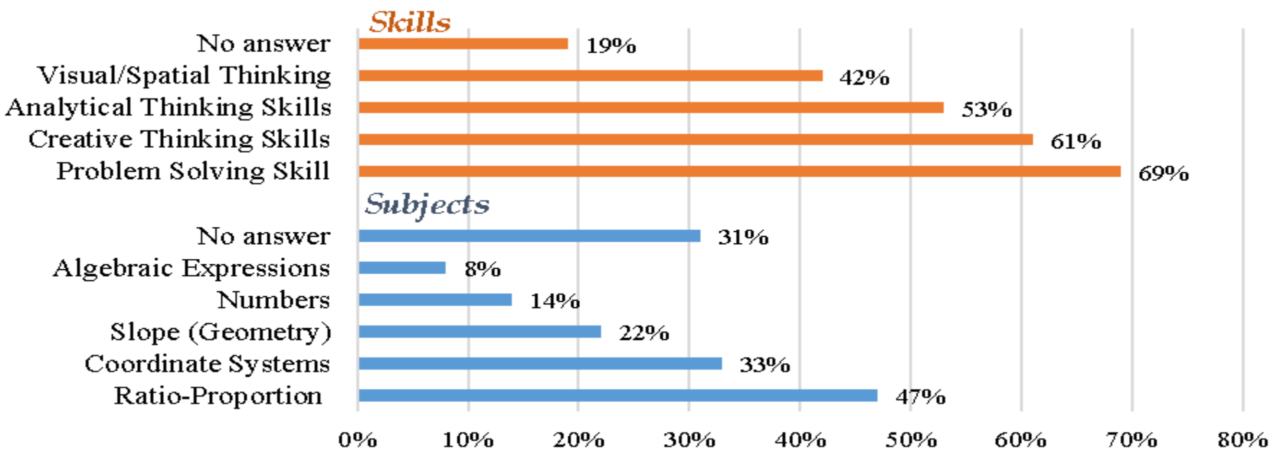

Figure 3. The distribution of subjects and skills integrated within STEM tasks

Data Analysis

Descriptive statistics and content analysis have been used to analyze the data obtained from the STEM-Usefulness Form and to evaluate the data from the semi-structured interviews respectively. In the STEM-Usefulness Form, there are Likert-type items of questionnaires and questions requiring short answers, along with spaces where participants can express their opinions for two types of tasks they have undertaken. The data from the STEM-Usefulness Form have been evaluated under the following labels: curriculum integration (1st and 2nd items along with short-answer question 7), limitations in the implementation (3rd and 4th items along with short-answer question 8), and developing positive attitude (5th and 6th items along with short-answer question 9). Comparisons have been made based on the participants' responses to the task type according to the STEM education level they received, and the findings are presented as percentages and frequency. In the content analysis the data were coded and grouped in categories according to the association of STEM tasks with specific mathematical subjects and mathematical skills (see **Figure 3**). Cronbach's alpha was calculated (α=.82) to determine the internal consistency of the application. After the interview, the transcription was read and confirmed by the participants, and false findings and comments were prevented.

RESULTS

The findings have been evaluated under the following headings:

1. The views on integration of the tasks in the curriculum,
2. The limitations of implementation of the tasks, and
3. The role of the tasks in the process of attitude development.

In this sense, the STEM-Usefulness Form and interview findings were integrated and presented under relevant headings.

The Views on the Integration of the Tasks in the Curriculum

When the responses to the first and second item in the STEM-Usefulness Form are examined, a majority of participants stated that both EDB and coding are suitable, but EDB tasks are considered to be more compatible with the mathematical skills in the secondary school curriculum compared to coding tasks (see **Table 1**). However, the percentage of participants considered to use these tasks in their mathematics course was lower for both task types (2nd item). For instance, 64% of the participants' state that EDB tasks are compatible with the curriculum, while the rate of participants who consider using these tasks in mathematics courses decreases. The data also show that the STEM tasks that include coding are more likely to be integrate into the mathematics curriculum than the EDB tasks. A large minority of participants, about 34%, think that both EDB and coding tasks may not be compatible with the mathematics curriculum. This is in agreement with the findings of the interviews, were seven of the ten participants stated that they have a positive attitude towards STEM tasks, whether coding or EDB, because they emphasize the interdisciplinary relations and contribute to the spiral quality of the curriculum, i.e., the relationship of the new learning with the old learning in different contexts. The first participant (P-1) stated that her awareness of the interdisciplinary approaches has increased as a result of the STEM teaching certificate that she received within the scope of in-service training, and that the tasks presented in this study have encouraged her to use mathematics in an interdisciplinary fashion.

Table 1. The frequency and percentage distribution of the data in the STEM-Usefulness Form

No	Questionnaire items	EDB tasks		Coding tasks	
		Yes	No	Yes	No
1	The task is suitable for the mathematical skills aimed at the secondary level mathematics curriculum.	23(64%)	13(36%)	28(78%)	8(22%)
2	I consider applying the task in my mathematics courses.	17(47%)	19(53%)	23(64%)	13(36%)
3	I may have time management problems during implementation of the tasks.	25(69%)	11(31%)	21(58%)	15(42%)
4	I may have a lack of material during implementation of the task.	24(67%)	12(33%)	23(64%)	13(36%)
5	I think the task will support students' mathematical development.	27(75%)	9(25%)	29(81%)	7(19%)
6	The task positively affects students' attitudes towards mathematics.	21(58%)	15(42%)	30(83%)	6(17%)

> **P-1:** The main purpose of STEM education is to present a product design by using mathematics, science, and technology together. Of course, while preparing the design of this product, some mathematical skills are necessary, so I think that tasks can be used in the curriculum ... Especially EDB tasks exemplify the interaction of mathematics with science discipline.

On the other hand, the participants who argued that the tasks may not be compatible with the mathematics curriculum put forward that, since the curriculum is learning objective-oriented, prioritizing the skills championed by the STEM approach may timewise prove difficult along with teaching the tasks required by the curriculum. For example, P-8 stated that it would be more appropriate to carry out STEM tasks outside the current mathematics course and referred to the subject-time relationship in the curriculum to support this view. P-4 likewise stated that it would be more convenient and beneficial to engage in STEM tasks with students who are willing and partly successful in this field, instead of applying them to all students in regular classes. Participants who argued that the tasks may not be compatible with the curriculum, jointly argued that STEM tasks could be given in out-of-school learning environments to students interested in them, as seen below:

> **P-8:** It can be used in teaching mathematics, but how efficient would it be? A STEM task takes four to five hours, but mathematics classes last an hour or two. So, it is a bit difficult with the current curriculum. But I think that including STEM tasks in a workshop environment or outside classes is very useful for teaching mathematics.

> **P-4:** I think that STEM education should not be employed for all children, but for the talented ones, who should be educated in out-of-school learning environments such as science and art centers. I think this training would be difficult for students who have displayed very poor performances.

Question 7 in the STEM-Usefulness Form asked participants which STEM tasks presented in the form could be integrated with which subjects and skills already existing in the mathematics curriculum. The answers to this question are presented in **Figure 3**. It was observed that the participants associated the given tasks most frequently with the subjects of ratio-proportion (47%) and the coordinate system (33%) in the curriculum. The participants had difficulty integrating STEM tasks with mathematics subjects because 31% of them did not answer the seventh question. The participants were less reluctant to associate STEM tasks with mathematical skills. 56% of the participants associated the tasks with more than one skill. More than half of the participants stated that the tasks presented in the form would contribute positively to the development of problem-solving (69%), creative thinking (61%), and/or analytical thinking skills (53%).

The Limitations in the Implementation of the Tasks

When the participants' responses to the STEM-Usefulness Form are evaluated within the theme of "limitations in the implementation", it becomes clear that approximately two-thirds of the participants were concerned about experiencing either time management issues or material shortages when using either EDB tasks or coding tasks in classroom practice (see **Table 1**).

To identify other constraints related to "material and time management" factors that limit the usefulness of EDB tasks in practice, question 8 inquired into other possible difficulties that might be experienced during the implementation of the tasks. The two most common reactions could be coded as the task being "difficult to design for each mathematical skill" (64%) and "requiring material setup or knowledge in software usage" (47%). Likewise, in the semi-structured interview findings, the participants emphasized that it would be difficult to develop a task suitable for each mathematical skill in the curriculum. Three participants stated that another difficulty in implementing STEM tasks in the mathematics classroom may be encountered during the course's assessment and evaluation process, illustrated by the following quotes:

> **P-7:** STEM tasks are mostly considered regarding science disciplines, but tasks that support problem-solving skills in mathematics could be designed, too. Therefore, I think they could be used in mathematics. But it is difficult to design a STEM task for each mathematical skill.

> **P-1:** Both the fact that our curriculum and examination system are not suitable for integrating STEM in it and that we lack time and materials cause difficulties for us in practice because of our deficiencies, not to mention the students'.

The Role of the Tasks in the Process of Attitude Development

The responses to the fifth and the sixth questionnaire items have been used to determine whether the tasks contributed positively to the process of attitude development. 75% (27 participants) and 81% (13 participants) of the participants stated that the EDB tasks and the coding tasks would support the mathematical development of students (see **Table 1**). The sixth item of the questionnaire evaluated the effects of the tasks on students' attitudes towards mathematics. 58% of the participants stated that EDB tasks may contribute to the process of developing positive attitudes towards mathematics, while 42% claimed the opposite. For coding tasks, this was much higher: 83% stated that students could develop a positive attitude towards mathematics.

In addition to the type of task, the level of the STEM education received by the participants in the in-service training program may also affect the attitudes towards the usefulness of the STEM tasks. Question 9 in the form asked the participants to evaluate the STEM education level they had received in terms of its utility in teaching mathematics. The basic level STEM education was found sufficient by approximately two-thirds of the participants (68%), while the advanced level by 85% of the participants. In the interviews, the participants who received STEM education at a basic level could describe what they needed more. Two remarks (from P-5 and P-6 below) indicate that they may need more practice and that an advanced level may be necessary to cover the whole mathematics curriculum.

> **P-5:** I cannot use [STEM] due to the first training I received, because we could not practice it. I know that STEM education will contribute to mathematics, but I have not been able to move on to the implementation phase in my teaching practices yet. I consider [implementing STEM] once I receive further education.

> **P-6:** Since the education I received was at the basic level, I could not use it a lot, only a little in mathematics applications.

Participants who had received an advanced level STEM education were more willing to implement the tasks included in the form into classroom practice. P-10 illustrated how EDB tasks can be used in classrooms in cooperation with the subject of ratio-proportion and for the development of creative thinking skills. P-8 stated that using coding tasks in mathematics classes would offer the opportunity to associate mathematics with real-world problems, therefore contributing positively to the students' attitude towards mathematics.

> **P-10:** I worked with seventh-grade students at school and carried out a practice about the ratio-proportion that included wheels. I gave the children wheels with different diameters, introduced the engineering sets, and then gave the instructions and waited for the children to do it. It proceeded as a group investigation, resulting in many authentic ideas and discussions. We thus had a practice related to other disciplines, especially science.

> **P-8:** I would like to mention my STEM task as an example. We performed a task of pudding-making for diabetes patients with my seventh-grade students. When cooking the desert, they made a cup with a 3D printer. They were very interested and were informed about diabetes. Using mathematics, they calculated how much sugar they should put in. With this, they also saw that mathematics is used in daily life.

DISCUSSION

The main problem for which the answer is sought in this study is to evaluate views of mathematics teachers about the usefulness of STEM tasks in secondary school mathematics teaching. The findings in the present study demonstrated that the STEM education approach is considered important by the participants, but they still see difficulties for using STEM tasks in the classroom. We can conclude that the support in theory is higher than the support in practice. An important constraint is linking STEM tasks to specific content or skills of the mathematics curriculum (31% of the participants did not answer question 7). The lack of explicit indications for STEM education in the mathematics curriculum may also negatively affect the motivation of teachers who are the executives of the curriculum. Wang (2013) emphasized that teachers' biggest problems are time constraints and material and technological deficiencies during STEM applications, which cause disadvantages in the implementation of STEM tasks in lessons. Although some materials for designing and implementing STEM tasks can be obtained easily, other technological components remain difficult to find or manufacture specifically.

The participants who stated that STEM tasks would develop a positive attitude for mathematics emphasized establishing interdisciplinary relationships and using mathematics in daily-life problems. Indeed, in other research evaluating the effectiveness of the STEM approach with groups of teachers teaching different subjects, it has been pointed out that if students create a product by applying their knowledge of different subjects do daily-life problems, they can develop self-confidence, which will increase their motivation towards the STEM subjects (Kim et al., 2015). Likewise, the researchers are aware that the STEM approach is an integrated field and a product-oriented, pragmatist education approach that merges the power of disciplines, rather than favoring one over the other.

It is natural that the teaching habits or experiences of teachers may cause resistance towards a new approach. This study related enthusiasm or resistance to the type of task. Mathematics teachers perceive coding tasks to be more clearly linked to the contents of the mathematics curriculum than EDB tasks. This could be partly explained by the fact that coding and robotics training was part of the advanced in-service training. Or, it may take experience to appreciate the contribution that science or engineering tasks can make to mathematics. Park et al. (2016), is a similar study, found that experienced Korean teachers have a positive view on the role of STEAM education. Other researchers argue that the contribution of mathematical knowledge and/or skills to other learning outcomes should be made more explicit to support STEM integration in the curriculum (English, 2016; Shaughnessy, 2013). Mathematical modeling of daily-life problems, which already has a place in the secondary mathematics curriculum of Turkey (MoNE, 2018), may be a good starting point for STEM integration. Modeling can be one of the most powerful tools of mathematics in interdisciplinary integration (Stohlmann, 2017). We observed that the mathematics teachers in this study associate STEM tasks with mathematical skills and generally prioritize problem-solving skills. Better, more creative and more compatible products may be obtained as a result of the integration of mathematical modeling with design and technology.

Our study confirms what similar studies have also shown, namely that STEM tasks are time-consuming compared to other mathematical tasks (Ozdemir et al., 2018). The fact that the participants who had not received support for a STEM education approach during their undergraduate education voluntarily wanted to receive STEM education within the scope of in-service training shows that the interest in this issue has increased.

Professional development on STEM education provided at a basic level raises awareness, but teachers apparently still need advanced level training and be educated in coding and robotics for using STEM tasks which are made up of engineering sets, e.g., plug-in parts, in classroom practice. Other studies also indicate that coding activities through interactive software such as Scratch can increase both student attitude and skills (i.e., problem-solving, geometrical thinking) in mathematics teaching (Calder, 2018, Iskrenovic-Momcilovic, 2020). This study confirms that coding tasks that are embedded in STEM education are found more interesting to teachers. Therefore, we suggest to include this topic in pre-service teacher education courses, preferably at an advanced level STEM education with regard to their branches, so that coding can be integrated in the curriculum.

In this study, participants stated they had difficulty in establishing a relationship between STEM tasks and mathematical skills. As mathematics teachers, they naturally prefer tasks to use in their teaching that fit the mathematics curriculum. The literature shows that coding tasks used in mathematics contribute to algorithmic thinking, geometrical thinking or reasoning (Calder, 2018; Iskrenovic-Momcilovic, 2020; Ozdemir et al., 2018). These skills are also important in STEM education in general (Bybee, 2010) and in the engineering design tasks derived from the Fischer Technik sets (Yildirim and Altun, 2015). Estapa and Tank (2017) state that content knowledge and beliefs are important for teachers that make decisions about integrated STEM in engineering challenges. However, the participants thought that the tasks could be used for only a few subjects, such as ratio and proportion or coordinate system. Almost one-third of the participants did not answer the question regarding the subjects in secondary school mathematics curriculum that may be compatible with STEM tasks. Furthermore, the interviews show participants believing that STEM tasks are mostly related to subjects in the science curriculum, thus leaving mathematics out. This mindset may be a cause for the difficulties with integrating STEM tasks with the skills in the secondary school mathematics curriculum. In the Turkish secondary education level, STEM education has been placed in the science curricula (MoNE, 2018). The fact that STEM tasks are not included in the curriculum and in mathematics textbooks may cause teachers not to be open for the idea of interdisciplinary integration in their teaching practice. Considering these findings, providing STEM education to teachers by itself is not sufficient for the implementation of this educational approach in the teaching practices. The mathematics curriculum and textbooks should be updated as well.

CONCLUSION

This study shows that mathematics teachers' opinions on integration are related to the task types. Mathematics teachers favor coding tasks over EDB tasks. Although the mathematics teachers in our study have a positive attitude towards teaching integrated STEM, they have a lower motivation to use these tasks in their classroom practices. They feel constraint by lack of material knowledge and time limitations in the curriculum. Although mathematics can be applied in many STEM tasks, the mathematics curriculum and textbooks do not make this explicit, which hinders teachers to recognize the contribution of STEM tasks to mathematics skills development.

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REFERENCES

Altun, Y. and Yildirim, B. (2015). *Ortaokul STEM etkinlik ve proje kitabı* [*Middle school STEM activity and project book*]. Teoriden pratiğe STEM eğitimi serisi [STEM education series from theory to practice]. Eduplay: Istanbul.
Bergsten, C. and Frejd, P. (2019). Preparing pre-service mathematics teachers for STEM education: An analysis of lesson proposals. *ZDM–Mathematics Education,* 51(1), 937-953. https://doi.org/10.1007/s11858-019-01071-7
Bicer, A., Navruz, B., Capraro, R. M., Capraro, M. M., Oner, A. T. and Boedeker, P. (2015). STEM schools vs. nonSTEM schools: Comparing students' mathematics growth rate on high-stakes test performance. *International Journal on New Trends in Education and Their Implications,* 6(1), 138-150.
Buyukozturk, S. (2005). Anket geliştirme [Survey development]. *Türk Eğitim Bilimleri Dergisi* [*Turkish Journal of Educational Sciences*], 3(2), 133-151. Available at: https://dergipark.org.tr/tr/pub/tebd/issue/26124/275190
Bybee, R. W. (2010). *What is STEM education?* New York: American Association for the Advancement of Science. https://doi.org/10.1126/science.1194998
Calder, N. S. (2018). Using Scratch to facilitate mathematical thinking. *Waikato Journal of Education,* 23(2), 43-58. https://doi.org/10.15663/wje.v23i2.654
Creswell, J. W. (2009). *Research design, qualitative, quantitative, and mixed methods approaches.* Thousand Oaks, CA: SAGE.
Drake, S. M. (2012). *Creating standards-based integrated curriculum: The common core state standards edition.* Thousand Oaks, CA: Corwin Press.
El-Deghaidy, H., Mansour, N., Alzaghibi, M. and Alhammad, K. (2017). Context of STEM integration in schools: Views from in-service science teachers. *Eurasia Journal of Mathematics, Science, and Technology Education,* 13(6), 2459-2484. https://doi.org/10.12973/eurasia.2017.01235a
English, L. (2016). STEM education: Perspectives on integration. *International Journal of STEM Education,* 3, 3. https://doi.org/10.1186/s40594-016-0036-1
Estapa, A. T. and Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A professional development approach centered on an engineering design challenge. *International Journal of STEM Education,* 4, 6. https://doi.org/10.1186/s40594-017-0058-3
Iskrenovic-Momcilovic, O. (2020). Improving geometry teaching with Scratch. *International Electronic Journal of Mathematics Education,* 15(2), em0582. https://doi.org/10.29333/iejme/7807
Kang, M., Kim, J. and Kim, Y. (2013). Learning outcomes of the teacher training program for STEAM education. *Korean Journal of the Learning Sciences,* 7(2), 18-28.
Kelley, T. R. and Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education,* 3, 11. https://doi.org/10.1186/s40594-016-0046-z
Kennedy, T. J. and Odell, M. R. L. (2014). Engaging students in STEM education. *Science Education International,* 25(3), 246-258.
Li, Y., Wang, K., Xiao, Y. and Froyd, J. E. (2020). Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education,* 7, 11. https://doi.org/10.1186/s40594-020-00207-6
Marginson, S., Tytler, R., Freeman, B. and Roberts, K. (2013). *STEM: Country comparisons.* Report for the Australian Council of Learned Academies. Available at: www.acola.org.au
Margot, K. C. and Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education,* 6, 2. https://doi.org/10.1186/s40594-018-0151-2
Ministry of National Education in Turkey. (MoNE, 2016). *STEM eğitimi raporu* [*STEM education report*]. Available at: http://yegitek.meb.gov.tr/STEM_Egitimi_Raporu.pdf

Ministry of National Education in Turkey. (MoNE, 2018). *Matematik dersi öğretim programı* [*Mathematics course curriculum (1-8 grade)*]. Available at: http://mufredat.meb.gov.tr/

National Council of Teachers of Mathematics. (NCTM, 2000). *Principles and standards for school mathematics*. Available at: http://www.nctm.org/uploadedFiles/Standards_and_Positions/PSSM_ExecutiveSummary.pdf

National Research Council. (NRC, 2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics. Committee on highly successful science programs for K-12 science education.* Washington, DC: The National Academies Press.

Ozdemir, A. S., Sevimli, E., Aydin, E. and Derin, G. (2018). *Examining the opinions of mathematics teacher candidates on the effectiveness of coding activities in the teaching-learning process* [Paper presentation]. British Society for Research into Learning Mathematics, King's College, London, UK.

Park, H., Byun, S. Y., Sim, J., Han, H. and Baek, Y. S. (2016). Teachers' perceptions and practices of STEAM education in South Korea. *Eurasia Journal of Mathematics, Science & Technology Education,* 12(7), 1739-1753. https://doi.org/10.12973/eurasia.2016.1531a

Shaughnessy, M. (2013). By way of introduction: Mathematics in a STEM context. *Mathematics Teaching in the Middle School,* 18(6), 324-326. https://doi.org/10.5951/mathteacmiddscho.18.6.0324

Stohlmann, M. S. (2017). Mathematical modeling with middle school students: The robot art model-eliciting activity. *European Journal of STEM Education,* 2(2), 4. https://doi.org/10.20897/ejsteme.201704

Stohlmann, M., Moore, T. and Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research,* 2(1), 28-34. https://doi.org/10.5703/1288284314653

Tseng, K. H., Chang, C. C, Lou, S. J. and Chen W. P. (2013). Attitudes towards STEM in a project-based learning environment. *International Journal Technology Design Education,* 23(1), 87-102. https://doi.org/10.1007/s10798-011-9160-x

Tsupros, N., Kohler, R. and Hallinen, J. (2009). *STEM education: A project to identify the missing components.* Intermediate Unit 1: Center for STEM Education and Leonard Gelfand Center for Service Learning and Outreach, Carnegie Mellon University, Pennsylvania.

TUBITAK. (2016). *Bilim ve Teknoloji Yüksek Kurulu kararları ve gelişmeleri* [*Decisions and developments of the Supreme Council of Science and Technology*]. Available at: https://tubitak.gov.tr/sites/default/files/btyk29_web_2.pdf

Wang, H., Moore, T. J., Roehrig, G. H. and Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research,* 1(2), 2-23.

Wang, X. (2013). Why students choose STEM majors: Motivation, high school learning, and postsecondary context of support. *American Educational Research Journal,* 50(5), 1081-1121. https://doi.org/10.3102/0002831213488622

Yildirim, A. and Simsek, H. (2016). *Sosyal bilimlerde nitel araştırma yöntemleri* [*Qualitative research methods in the social sciences*]. Ankara: Seçkin Yayıncılık [Seckin Publishing].

Yildirim, B. and Altun, Y. (2015). STEM eğitim ve mühendislik uygulamalarının fen bilgisi laboratuar dersindeki etkilerinin incelenmesi [Investigating the effect of STEM education and engineering applications on science laboratory lectures]. *El-Cezerî Fen ve Mühendislik Dergisi* [*Al-Jazari Journal of Science and Engineering*], 2(2), 28-40.

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Pre-Service Teachers' Experiences on the Development of Educational Science Board Games

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ABSTRACT

The expectation is that pre-service teachers that are specializing in the teaching of primary school natural science, ought to make use of teaching approaches that will allow them to engage learners in a joyful yet meaningful science learning experience. One such teaching approach to be considered is regarded as board game-based teaching. This paper investigated how natural science pre-service teachers experienced the development of educational science board games. This study draws on a conceptual understanding of game-based education, which allows for the integration of topics within board game mechanics, board game aesthetics and board game thinking. This qualitative case study considered a focus-group discussion and photo-voice methodology as data collection techniques to capture the pre-service teachers' experiences on the development of educational science board games. Findings from the study revealed how their engagement in the development of educational science board games had an impact on their personal skill development, their professional teacher development, their development of pedagogical content knowledge, as well as their development of applicable assessment methodology that relates to the teaching of the subject natural science. On the other hand, issues surrounding the learning objectives, the complex design processes, and the lack of relevant materials available to develop the educational science board games were viewed in a less positive light. Findings from the study suggest that science teacher education programmes should be intentional in shaping pre-service teachers' skills to develop educational board games that would complement the quality of their science teaching practice.

Keywords: educational science board games, board game-based teaching approach, natural science education, natural science pre-service teachers, natural science pre-service teacher development

INTRODUCTION

Given the popularity of game playing among individuals young and old, researchers in the field of science education are convinced that the use of educational science board games adds value to a science learning experience (Li and Tsai, 2013; van Roy and Zaman, 2018; Young et al., 2012). Although learners are drawn to games for enjoyment and entertainment, the engaging learning experience of playing an educational board game is a product of the board game approaches that are set out to facilitate positive learning outcomes (Tsai et al., 2019; Yien et al., 2011). Amongst these positive outcomes, is the ability of learners to draw on their intellectual skills such as memorising, comprehending, reasoning and analysing information (Taspinar et al., 2016). Other positive outcomes also include learners being able to communicate information both verbally and non-verbally, using cognitive strategies to engage in problem-solving tasks and activities, employing motor skills to perform tasks and finally expressing attitudes. The learning outcomes identified here are a product of the different types of learning couched within a board game-based teaching approach. From the literature, one finds that a board game-based teaching approach promotes active learning, cooperative learning, collaborative learning, learning through problem-solving and learning through role-playing, to name but a few (Gagné, 1985; Sousa and Rocha, 2019).

However, these pedagogical principles solely do not constitute an interesting and attractive educational board game that will necessarily motivate learners to play. Li and Tsai (2013) explain that features such as game rules, game instructions, game design, game interactivity, game feedback and game challenges are key towards eliciting an immersive board game-based learning experience. By drawing on these board game features and pedagogical principles, educators will be in a position to expose learners to a joyful, yet meaningful learning experience. The effectiveness of board game-based learning, specifically in the context of natural science education, has been well documented in recent years (Rowe et al., 2017). A study conducted by Hussein et al. (2019) documented how learners who were exposed to board game-based science learning showed improved cognitive gains in the mastering of topics related to life and living, matters and materials, energy and change and earth and beyond, compared to those learners who received traditional instruction. Work done by Tsai et al. (2019) described how learners' engagement in board game-based learning positively affected their motivation and attitudes to learning topics that relate to the natural science school syllabus.

Given the learning benefits offered by the board game-based teaching approach, some researchers predict that the use of educational science board games is likely to become more mainstream in the coming years, especially in the primary education schooling context (Berland and Lee, 2011). Consequently, the capability of board game-based teaching raising learners' motivation and interest in learning natural science, has drawn the attention of curriculum planners and developers in the field of initial teacher education (Tsai et al., 2019). For this reason, teacher development programmes are intentional in exposing pre-service teachers in development to the features and pedagogical principles of the board game-based teaching approach (Kaimara et al., 2021). It is against this background, that the School of Education at a selected South African university strives towards creating awareness amongst natural science pre-service teachers in applying features and pedagogical principles of the board game-based teaching approach in their teaching practicum, as part of their teacher development. In the School of Education, the natural science pre-service teachers are made aware of the educational benefits of game-based learning in their teaching didactic modules. The expectation is that the natural science pre-service teachers be able to design and develop their own educational science board games that are underpinned by the pedagogical principles of board game-based teaching. In doing so, the natural science pre-service teachers are not only required to learn theory and understand why theory is important but also learn to apply theory in their teaching practice, hence the phrase from theory to practice (Epstein, 2019). However, given this task, it will be interesting to unravel how the natural science pre-service teachers experienced the process of developing educational science board games. It is for this reason that this study sought to investigate how the natural science pre-service teachers experienced the development of educational science board games.

Conducting this study is important for several reasons. In the first instance, the study amplifies the pre-service teacher-voice in their quest to develop educational science board games. As teacher educators in a school of education, we also intend to learn from the subjective experiences offered by the pre-service teachers in terms of developing educational science board games. Their rich experiences will come in handy to make us realise how we can better structure our teacher developmental material to cater for a board game-based teaching approach. In addition, their experiences will also come in handy to experiment how the ideals of board game-based education might reflect in other subject specialisations, such as mathematics, technology, and social science education.

RATIONALE FOR THE STUDY

The School of Education at a selected South African university is intentional in its drive to expose natural science pre-service teachers in development to creative and innovative teaching approaches. One such teaching approach, is referred to as board game-based teaching. In exposing natural science pre-service teachers to the aspects of board game-based teaching, they are made aware of the implications, educational benefits and limitations regarding board game-based education. In addition, the natural science pre-service teachers in School of Education are also tasked to design and develop their own educational science board games. In doing so, the natural science pre-service teachers are required to apply their knowledge and understanding of board game-based education into real-life teaching practice. However, given this task, little to no effort had been made by us as teacher educators in the School of Education to unravel how the natural science pre-service teachers ultimately experienced the process of developing educational science board games. It is with this argument in mind that this paper investigates how the natural science pre-service teachers experienced the development of educational science board games.

GAME-BASED EDUCATION

Over the last couple of decades, the use of game-based education has gained momentum as a useful teaching approach (Boghian et al., 2019; Bidarra and Rusman, 2017). Apart from eliciting a joyful learning experience, game-based education provokes what Greenhalgh et al. (2019) refer to as a "deep and engaging learning experience". The authors explain, that game-based education enables an educator to make use of interactive game-based material in order to stimulate the higher-order thinking of learners (Greenhalgh et al., 2019). Game-based education allows learners to engage in learning activities that require a level of recalling, analysis, application and evaluation of knowledge (Coil et al., 2017).

Some scholars are of the view, that a game-based education allows educators to create educational exercises that are tailored to achieve the requirement of a particular learning outcome (Bidarra and Rusman, 2017). For example, an educator can select a lesson topic and integrate the topic within particular game feature designs such as simulations, role-playing, educational card games and educational board games, to mention a few. Educational board games, in particular, is considered a highly versatile and flexible medium that enables learners to engage in tasks that stimulate learners' cognitive domain (for example, learners' development of knowledge and intellectual skills and abilities), affective domain (for example, learners' shaping of feelings, attitudes, and emotions) and psychomotor domain (for example, learners' physical movement, coordination, and use of motor-skills) (Noda et al., 2019).

Targeting these domains also requires learners to draw on their five senses, which includes learners' ability to see, hear, smell, touch, and move (Chiarello and Castellano, 2017). This echoes the view of Higgins and McFeetors (2019) when they refer to the diverse manner through which learners learn and express themselves in a learning situation. Bidarra and Rusman (2017) add, that the use of educational board games allows educators to formulate lesson goals that are aligned to the instructional objectives of the board game. In following these instructional objectives, learners are motivated to acquire knowledge through engaging in the educational board gameplay. This approach, according to Chiarello and Castellano (2017), serves as a means to initiate learners' creative thought processes.

In addition, it has been suggested that the use of educational board games is key in simplifying learners' understanding of subject-content material (Eriksson et al., 2021). Noda et al. (2019) explain that learners' engagement in educational board games fosters their development of non-cognitive attitudinal skills such as the ability to persevere in a task, be conscientious, and work together as a team by communicating and respecting each other's viewpoints. Another benefit that relates to the learners' engagement in educational board gameplay deals with their development of cognitive skills such as their ability to think, read, learn, remember, reason, and pay attention (Bayeck, 2018). It is for this reason that the use of educational board games is considered valuable in eliciting interactive, cooperative and collaborative learning in the classroom (Higgins and McFeetors, 2019). Boffa et al. (2020) add that learners' engagement in educational board gameplay further results in an element of competitiveness. The latter, in turn, serves to motivate and encourage learners to commit and participate in the educational experience (Hallifax et al., 2019).

Finally, the use of educational board games further allows educators to draw on different types of knowledge. This particular feature creates the possibility for educators to integrate ideas and concepts from other subject disciplines into what Bidarra and Rusman (2017) refer to as a cohesive "world picture". This multi- or transdisciplinary exercise is particularly valuable in making learners aware of the cross-curricular nature of knowledge that informs the school syllabus.

RESEARCH METHODOLOGY

This study was qualitative in nature and followed a case study research design. The case included that of 7 final-year natural science pre-service teachers and their experiences regarding the development of educational science board games.

Data Collection and Procedures

The study made use of two data collection techniques, namely a focus group discussion and photo-voice methodology. Data collection for the study took place over a period of two days within the academic programme of the pre-service teachers. In order to achieve the aim of the study, which was to investigate how natural science pre-service teachers experienced the development of educational board games, a series of research questions were considered. These questions were, as follows:

1. Which skills did the natural science pre-service teachers attain by engaging in the development of educational science board games?

2. What were the natural science pre-service teachers' most enjoyable experiences in developing educational science board games?
3. What were the natural science pre-service teachers' least enjoyable experiences in developing educational science board games?

The purpose for making use of a focus group discussion was two-fold. In the first instance, the focus group discussion allowed the natural science pre-service teachers to respond to the three research questions of the study. In the second instance, the focus group discussion enabled the natural science pre-service teachers to present their education board games that they have developed to their fellow peers. Characteristic of the focus group discussion, was the free flow of information sharing that commenced through open dialogue and narratives between the researcher and the participants (Gawlik, 2018). In following the focus-group discussion, the pre-service teachers had the freedom to share their subjective views and opinions that relate to the three research questions posed. In following the focus group discussion, my role as researcher was merely to stimulate and facilitate discussions that centred around the three research questions. The verbal responses that derived from the focus group discussion was audio recorded. The audio recording of the focus-group discussion was made secure and password protected. None of the names of the participants where mentioned, instead pseudonyms where used to ensure anonymity in the study. The qualitative data that derive from the focus group discussion was analysed through the use of thematic content analysis whereby the data was verbatim transcribed, thematically coded and categorised as themes.

Apart from the focus group discussion, a photo-voice methodology was also employed as a means to capture rich qualitative data in the form of photographic evidence. Photo-voice methodology is a visual data collection method that allows research participants to make use of photographs to support their individual views and opinions (Wang and Burris, 1997). For this study, the natural science pre-service teachers where encouraged to use photographic evidence of their educational board games that they have developed to support their individualised responses to the three research questions posed. In doing so, a correlation was established between the verbal responses from the focus group discussion and the visual photographic evidence offered by the pre-service teachers. This approach allowed for an in-depth exploration and interpretation of the participants' responses, which promoted the aspect of triangulation in the study.

Trustworthiness in the Study

Methodological rigor in the study was considered through drawing on measures such as "confirmability", "credibility" and "neutrality" (Creswell and Creswell, 2017). Confirmability, which is the degree to which findings of the study can be confirmed by others, was established through the open-dialogue that surfaced between the researcher and the pre-service teachers during the focus group discussion. The use of photo voice methodology, as another data collection technique, further promoted the confirmability of the data. Credibility and neutrality were confirmed through the researchers' prolonged interactive engagement with the 7 pre-service teachers in the focus group discussion that took place over the course of a day. Also, the findings of the study were also shared with the team of pre-service teachers to ensure that the data were accurately identified, interpreted and described.

Research Setting and Participants

The research site was situated in a school of education at a selected South African university. The School of Education offers a Bachelor of Education degree with areas of programme specialization in primary and secondary school teaching. From this research site, the population of the study included pre-service teachers who studied for a Bachelor of Education degree. From this population, a purposive sample of 7 final-year pre-service teachers who specialised in the teaching of the subject natural science, opted as participants for the study. All 7 participants identified specialised in primary school teaching.

Positionality of the Researcher

Positionality "reflects the position that the researcher has chosen to adopt within a given research study" (Savin-Baden and Major, 2013:71). Positionality requires the researcher to acknowledge and locate their views, values, and beliefs in relation to the research process (Goacher et al., 2017). Positionality is normally identified by locating the researcher in terms of the subject under investigation, the research participants and the research context.

In this study, I acknowledged my combined roles as researcher and module lecturer of the 7 final year natural science pre-service teachers. Given these combined roles, I was aware of potential power imbalances that might have existed between myself as module lecturer and researcher and my students whom served as the research participants of the study. With this in mind, I was prompted to be cautious of power-dynamics and forms of intimidation that could have existed between myself and the research participants. By no means did my role as module lecturer affect the ethical processes in this study. In addition, my role as module lecturer also did not influence the participants to partake in this study since the participants had the right to form part of the study on a voluntary basis.

Ethics

Permission for this study was granted by the Postgraduate Research Ethics Committee of the University of the Free State (Ethical clearance number-UFS-HSD2018/0073). The natural science pre-service teachers, who from now onwards will be referred to as the research participants of the study, were consulted in advance to give their consent to participate in the study. The participants were assured confidentiality throughout the study and they were also allowed the right to withdraw from the study at any time. A consent form was drawn up and each of the participants signed the consent form. All of the signed consent forms were archived for record purposes.

RESEARCH RESULTS

The verbal responses from the focus group discussion and the photographic evidence of the educational science board games that the pre-service teachers developed, yielded rich qualitative data. **Table 1** provides a synopsis of the main themes with supportive categories that emerged from the data. The table further aligns the themes and corresponding categories with the three research questions of the study. Following this synopsis, an in-depth interpretation and description of the empirical data will be provided.

Table 1. Synopsis of the themes and categories that emerged from the three research questions

Research questions	Themes	Categories
1. Which skills did the natural science pre-service teachers attain by engaging in the development of educational science board games?	1.1. Skills related to individual development	Practices related to creativity & improvisation
		Practices related to planning & organisation
	1.2. Skills related to professional teacher development	Displaying patience & commitment in designing the board game
		Selecting appropriate natural science content for the board game
		Formulating applicable questions to test learners' understanding of natural science subject content knowledge
2. What were the natural science pre-service teachers' most enjoyable experiences in developing educational science board games?	2.1. Physical design of board game	Following a hands-on design approach
		Improvisation with recycled goods
	2.2. Pedagogical content knowledge development	Setting instructions
		Structuring questions
		Evaluating learners' practical process skills
		Establishing an inquiry-based teaching and learning experience
	2.3. Prototyping the educational science board game	Testing the functionality of the board game with peers
3. What were the natural science pre-service teachers' least enjoyable experience in developing educational science board games?	3. Issues associated with the design and implementation of the educational science board game	Unavailability of resources to develop the board game
		Inability to use the board game in an authentic "real-life" teaching setting

Responding to the Research Question 1-Which Skills Did the Natural Science Pre-Service Teachers Attain by Engaging in the Development of Educational Science Board Games?

The first research question sought to determine "Which skills did the natural science pre-service teachers attain through engaging in the development of educational science board games?" In posing this question to the 7 participants in the focus group discussion, two themes emerged. These themes were identified as "skills related to individual development" and "skills related to professional teacher development". These two themes are briefly described next.

Theme 1.1. Skills related to individual development

An analysis of the verbal responses of the participants during the focus group discussion revealed that they encountered a level of personal skill development. To be specific, the research participants reported that their involvement in the development of educational science board games enabled them to practice aspects of "creativity" and "improvisation" in terms of the actual design and development of the educational board game. This can be found in the following response:

> A teacher should have various skills in their teaching toolbox, one including being creative. By planning and making the board game I tapped into my creative skill as well as developed my creative skill. I am now aware of much more creative and interesting ways to teach/assess learners' knowledge informally as well as formatively (Participant 3).

Another participant mentioned the following:

> I learned the skill of improvising and planning, using what I have to my disposal to create the board game, for example, using old boxes and cheap affordable materials to create the board game. I also developed an artistic skill of creatively using old materials to make the board game (Participant 5).

Both responses by participants 3 and 5 suggest that the task to develop an educational science board game required a level of creativity, improvisation, planning and organization. In support of these verbal responses, photographic evidence of a board game developed by participant 7 resembles the level of creativity, improvisation, planning and organisation that the task required (**Figure 1**).

Figure 1. "SCIENCE 360"-A board game developed by research participant 7

In support of the photographic evidence provided by the participant, the description below depicts the level of creativity, planning, improvisation and organisation that were required to design and develop the board game of participant 7. The educational science board game titled "SCIENCE 360" shown here requires learners to compete cooperatively in pairs. The game requires learners to throw a die to determine the number of space/s their team token should move on the board game. Once moved to a certain spot, learners are expected to engage with game cards that contain a variety of questions that tests their knowledge on various natural science topics. To be specific, a closer look at the centre of the board game reveals interesting game cards with catchy labels such as "What am I?", "danger zone!", "picture perfect" and "let's hit the lab". What adds to the creativeness of the game, is that when the game token lands on for instance the question mark icon, then learners are expected to pick up the "what am I?" card. The particular set of cards that form part of the "What am I?" category, requires learners to provide the correct biological term for various biological definitions, thus testing the learners' content knowledge of the subject natural science. Moreover, if the token lands on the "danger zone!" icon, then learners are expected to explain certain scientific phenomena in a more descriptive manner, hence allow for the testing of learners' deeper understanding of natural science content knowledge. The opportunity also exists for pairs to land on the "picture perfect" icon. By landing on this icon would require learners to engage in scientific drawings, thus testing the learners' ability to make accurate visual drawings of relevant science topics with complementary labels. Finally, the board game also allows learners to land on the "let's hit the lab" icon. By landing on this icon, learners will be required to draw graphs and tables and interpret scientific data.

Theme 1.2. Skills related to professional teacher development

The participants' responses to the first research question further suggested that they encountered a level of professional teacher development. In particular, it was reported that their engagement in the task enabled them to display a level of "patience", "commitment" and "dedication" in developing an educational science board game that is "presentable" and would allow learners to "engage in a meaningful learning experience". This can be found in the following two responses.

> I had to be very patient in making this game to ensure that everything comes together, and the game looks presentable, from drawing the background to finally pasting the rest of the game (Participant 1).

A similar response was shared by another participant when it was mentioned that:

> I had to be very committed in developing the board game. There is a lot of thinking that went into the board game so I had to be dedicated in making the best possible board game that will engage my learners in meaningful learning (Participant 7).

In addition, their responses to the first research question further revealed how their involvement in the development of educational science board games complemented the development of pedagogical content knowledge as a professional teacher skill. Participants 2 and 7 recalled how the task to develop educational science board games challenged them to select topics and formulate questions that are relevant to the subject-syllabus of natural science. This is supported by the following views:

> I had to summarise the whole two term's work into 20 short questions and I believe that my summarising skills were developed in the process (Participant 2).

This was similarly the case with participant 7, when it was mentioned that:

> I had to make certain judgements on which type of content I should use that would suit the board game and also make judgements in between the kind of questions to ask from the content. (Participant 7).

To support the verbal responses provided by participants 2 and 7, photographic footage of the educational science board game developed by participant 5 was considered. A closer look at the board game titled "Caught in the web" (see **Figure 2** and **Figure 3**) confirms that the participant selected content topics that related to "plants", "animals" and "insects". These topics inform the natural science syllabus at primary school level. One further finds that participant 5 formulated written questions such as "If a plant did not have a stem, would it be able to grow upright?" and "In which habitat is this specific insect found?"

Figure 2. "Caught in the Web" board game instructions

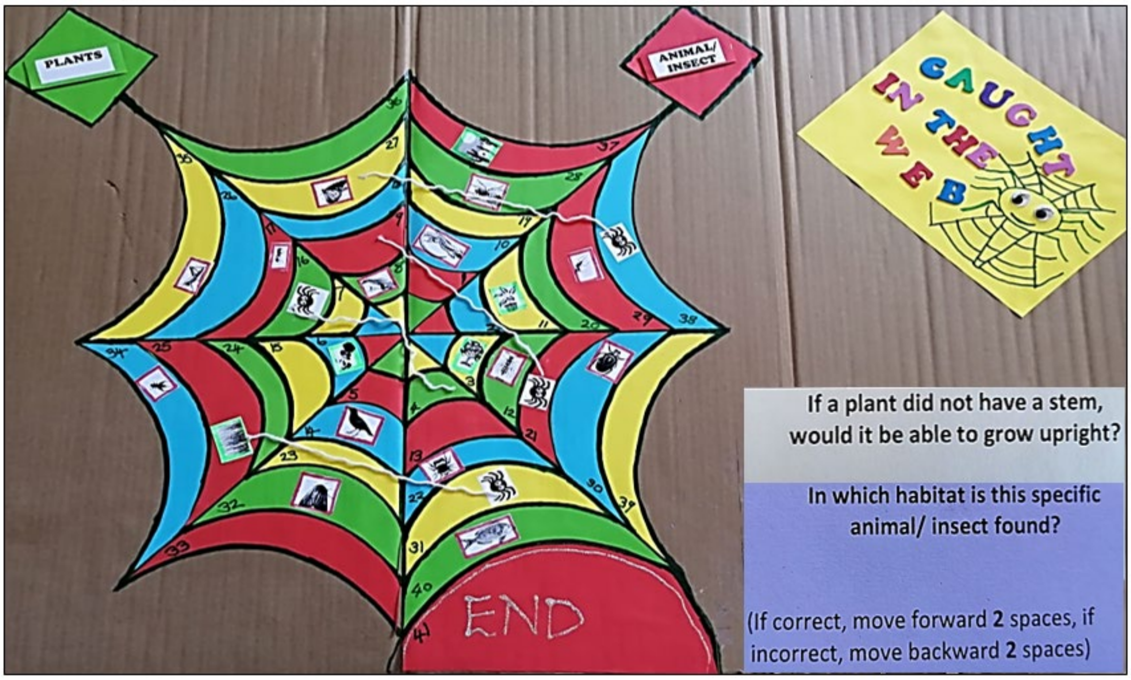

Figure 3. "Caught in the Web" board game

The verbal responses provided by participants 2 and 7, as well as photographic footage provided by participant 5 suggest, that their engagement in the task to develop and educational science board game challenged their ability to select relevant topics and formulate written questions that are associated with the natural science subject syllabus. The latter is considered a key teacher attribute that a natural science educator should possess.

More photographic evidence was provided by participant 3 that demonstrates the participant's ability to formulate different question types such as completion questions (for example, "fill in the missing word that related to the picture"), short response questions (for example, "is the shelter shown in no. 34 a natural or a man-made object?") and explanation questions (for example, "look at the picture and explain what is mean by the word predator") (**Figure 4**).

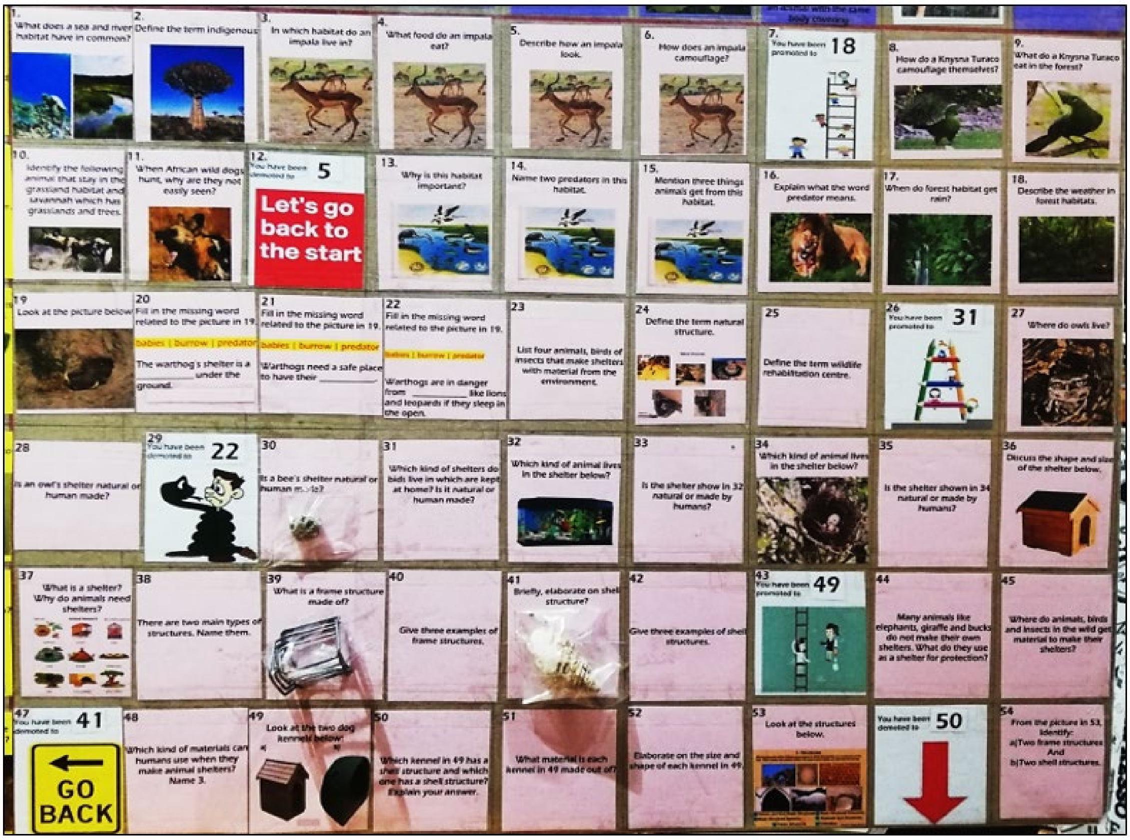

Figure 4. An education science board game inspired by "snakes and ladders"

Responding to the Research Question 2-What Were the Most Enjoyable Experiences in Developing Educational Science Board Games?

The purpose of the second research question was to establish the participants' most enjoyable experiences in developing educational science board games. In posing this question to them, four themes emerged from the focus group discussion. Positive experiences, in this regard, were linked to themes that dealt with the "physical design of the science board game", "developing pedagogical content knowledge" and finally "prototyping the science board game with their significant others".

Theme 2.1. Positive experiences related to the physical design of the board game

The processes involved in the physical design and development of the board games were seen in a positive light, as witnessed in the following response:

> The most enjoyable aspect of the game was searching for pictures about the topics and look for interesting/fun facts, learning more about natural sciences and also creating the game, cutting and pasting pictures and designing a game that I would like to play and making the cards (cutting out the cards) (Participant 6).

Participant 5 was also able to share his/her positive experience regarding the physical design of the board game, as witnessed below:

> It was also nice being able to use all the papers, magazines and cartons even old plastic milk bottles that I have not gotten rid of so I kind of turned it into something useful (Participant 5).

These two responses depict the level of creativity and improvisation that the participants had to display in their attempt to develop board games from recycled materials. From these responses, the assumption can be made that the participants were challenged to use existing information to create new knowledge, as participant 6 mentioned that he/she had to "search for pictures about topics" while also "looking for interesting fun facts". Apart from the task to use existing knowledge to create new knowledge, the physical "hands-on" design approach of the board game enabled participant 6 to utilise fine motor skills which required her to "cut and paste pictures" while also "cutting out cards for the game". The aspect of improvised thinking also came into play when participant 7 mentioned that he/she was able to make use of "papers, magazines, cartons and old plastic milk bottles" to design the board game.

Theme 2.2. Positive experiences related to the development of pedagogical content knowledge

Another positive experience that was reported on dealt with the participants' on-going development of pedagogical content knowledge. Participants 1 and 6 mentioned how the project impacted their ability to "create instructions", "develop questions", "evaluate learners' development of science process skills" and "promote the idea of scientific reasoning". Participant 6 had the following to say:

> I enjoyed the fact that I could set my own instructions for the questions and design relevant NS questions with answers for the cards. There are easy ones and tricky ones. So my board game will test learners' different intelligences so that no learner is left behind. They will really enjoy it, even the dice is large and spongy, it's an unusual dice and might make learners laugh but it will work well (Participant 6).

In the same vein, participant 1 similarly expressed that:

> The most enjoyable aspect is that although it is a board game, the learners will still be engaged in things like hypothesis testing, establishing variables, making calculations and drawing conclusions. So it's basically a mix of fun and scientific reasoning (Participant 1).

Both these responses suggest that the participants had to draw on their pedagogical content knowledge in order to develop the education board game. In the first instance, participant 6 confirmed that the development of the board game allowed her to apply her mind in terms of "structuring relevant instructions on how to play the board game". In addition, participant 6 also had to brainstorm applicable questions to test the learners' content knowledge of the subject natural science. Participant 6 further explained, that some questions of her board game were "easy ones" while other questions "were tricky ones".

This particular response makes it apparent that participant 6 is cognisant of the different levels of questioning as pronounced in Bloom's taxonomy. Participant 1 also made claims about pedagogical content knowledge when she mentioned how she intend to engage learners in scientific reasoning through "hypothesis testing", "clarifying variables", "making calculations" and "drawing conclusions". His/her reference to these aspects of scientific-reasoning makes one belief that the participant wishes to promote inquiry-based learning amongst the learners.

Theme 2.3. Positive experiences related to the prototyping of the board game

Another positive experience that was captured dealt the ability of the participants to test the functionality of the board game with their fellow peers and significant others. This was confirmed when participant 3 mentioned that:

> Playing a game with my siblings was quite cool. This made me check if the questions asked on the game clear enough for learners to attempt them (Participant 3).

Participant 2 similarly felt that:

> This project allowed me to brag a bit with my hard work since I could play the game with my roommate just to check if it works (Participant 2).

Both participants 2 and 3 elaborated on the extent to which they were able to "pilot" the functionality of their educational science board game with their peers and significant others. Surprisingly, the piloting of the board game also had a positive impact on their teacher image. This is supported by the phrases "was quite cool–participant 6" and "I could brag a bit with my hard work–participant 2".

Responding to the Research Question 3-What Were the Least Enjoyable Experiences in Developing Educational Science Board Games?

In order to portray a comprehensive picture of the participants' experiences further required a reflection on the least enjoyable experiences regarding the board game development process. Their responses to this question pointed to a prominent theme titled "issues associated with the design and testing of the board game".

Theme 3.1. Issues associated with the design and testing of the board game

Initially, the participants perceived the physical design of their board games from recycled goods in a positive light. However, this was not the case with all of the participants. Some of the participants expressed their frustration with the practical design of the board game due to the unavailability of relevant materials, as witnessed in the extract below:

> At the start I had nice ideas to develop the game. But I was also caught off-guard by not having all the stuff needed to make the board game as creative as possible (Participant 5).

The response provided by participant 5 suggests that a shortage of materials restricted his/her ability to develop the board game in a creative manner. Apart from the issue associated with the lack of materials to design the board game, another participant vented his/her frustration in not being able to use the board game in an authentic teaching setting, as witnessed below:

> I really wanted to test the board game out during my teaching practice. I mean it was such a mammoth task to create the thing, why not test it? (Participant 1).

DISCUSSION OF FINDINGS

In the context of natural science teacher education, the expectation is that pre-service teachers that are specializing in the teaching of primary school natural science, ought to make use of a teaching approach that will allow them to engage learners in a joyful yet meaningful science learning experience (Bidarra and Rusman, 2017; Hoy, 2018). One such teaching approach to be considered is referred to as board game-based education (van Roy and Zaman, 2018). Board game-based education in the context of natural science education, allows the educator to teach relevant topics associated with the subject syllabus of natural science through engaging learners in interactive learning materials such as educational science board games (Muell et al., 2020; Huizenga et al., 2017).

As a teaching approach, the use of educational science board games is characterised by different forms of learning namely cooperative learning, cooperative learning and problem-based learning (Ladur et al., 2018). In exposing learners to such forms of learning results in what Higgins and McFeetors (2019) recall as higher-order thinking. It is with these learning benefits in mind, that scholars such as Bidarra and Rusman (2017) and Ofosu-

Ampong (2020) call upon initial teacher education programmes to be intentional in developing primary school pre-service teachers' ability to integrate a board game-based teaching approach in their natural science teaching practice.

In the School of Education at a selected South African university, a group of 7 final-year natural science pre-service teachers were tasked to design and develop their own educational science board games that were underpinned by the pedagogical principles of board game-based education. Given this task, this study was interested in unravelling how the natural science pre-service teachers experienced the development of the educational science board games. The natural science pre-service teachers' personal reflections touched base on the different types of skills which they have developed, as well as the most enjoyable and least enjoyable experiences of engaging in the development of educational science board games. In the first instance, from the focus group discussion it was revealed how their engagement in developing the board games shaped practices that relate to "creativity", "improvisation", "innovation", "planning" and "organization".

Additionally, the participants also reported how their engagement in this project shaped professional teacher qualities such as being able to be "patient" and "committed" towards the design of a board game that is "presentable" and would allow for a "meaningful learning experience". Furthermore, they also reported how they could "select applicable topics" from the natural science school syllabus and "formulate written questions" to test learners' knowledge of natural science while playing the board game. Apart from these responses, three captured photographs (see **Figure 1**, **Figure 2**, and **Figure 3**) provided evidence of the level of skill and creativity that the participants displayed in developing the board games. This approach, aligns well with the expectation that pre-service teachers who are specialising in the teaching of natural science should be able to demonstrate the skill to teach the subject in a creative and interesting manner (Huizenga et al., 2017).

Apart from reporting on the skills that they had developed, their reflections also touched base on some of the more enjoyable experiences in developing educational science board games. These positive experiences were linked to themes that dealt with "the physical hands-on design of the board game", their "development of pedagogical content knowledge" and their ability to "prototype the board game" with their peers. In terms of the physical hands-on design of the board game, the research participants expressed how they utilised low-cost and recycled goods to design their board games. This was confirmed by a participant who claimed that "It was nice being able to use all the papers, magazines and cartons even old plastic milk bottles that I have not gotten rid of and turn it into something useful–participant 5".

Another positive experience that derived from the focus group discussion dealt with their development of pedagogical content knowledge. To be specific, the research participants claimed that their engagement with the task to develop educational science board games challenged their ability to "create board game instructions for learners to follow", "formulate questions to evaluate learners' understanding of natural science knowledge within the board game" and "evaluate learners' development of practical process skills". This approach of linking natural science subject knowledge with teaching knowledge, is what Shulman (1987) decades ago referred to as pedagogical content knowledge.

The assumption can thus be made that the research participants were successful in infusing their natural science subject knowledge and pedagogical content knowledge through the medium of an educational board game (Ladur et al., 2018). This approach aligns well with the idea that educational science board games are considered a highly versatile and flexible medium that allows learners to be tested on the cognitive domain (learners' development of knowledge and intellectual skills and abilities), the affective domain (learners' shaping of feelings, attitudes, and emotions) and the psychomotor domain (learners' physical movement, coordination, and use of the motor-skills) (Liu et al., 2020). Using the concept of game-based learning in education. These domains form part of Bloom's taxonomy of instructional objectives (Noda et al., 2019).

CONCLUSIONS AND IMPLICATIONS

The purpose of the study was to report on the natural science pre-service teachers' experiences on the development of educational science board games. This was done to introduce and familiarise the natural science pre-service teachers to the notion of a board game-based teaching approach. A board game-based teaching approach, in the context of natural science education, allows for the teaching of science topics through the medium of interactive educational board games. The board games that the pre-service teachers developed allowed for the integration of natural science topics within board game mechanics, aesthetics and board game thinking. This approach allows learners to engage in a playful yet meaningful science learning experience. A board game-based teaching approach is in contrast with more conventional teaching approaches such as direct teaching (Majuri et al., 2018; Muell et. al., 2020).

Verbal responses from the focus group discussion and photographic evidence through the use of photo-voice methodology revealed how the pre-service teachers' engagement in the development of educational science board games impacted both their personal and professional skill development. The team of pre-service teachers also expressed their positive experiences regarding the physical "hands-on" design of the board game, their development of pedagogical content knowledge and their ability to prototype their products with their peers. However, one could also learn from the pre-service teachers' less favourable experiences which they encountered in this regard. The necessity of materials to build to board game and the testing of the board game in a real-life teaching context are areas that require attention. On the other hand, given these issues raised this project did indeed make the pre-service teachers acknowledge the value of following a board game-based teaching approach teaching approach. Their engagement in this project did indeed spark their pedagogical thought processes in terms of putting the educational science board games into practice (Chiarello and Castellano, 2017).

Going forward, this study holds a series of implications for future research in the field of pre-service teacher development. Given the learning benefits tied to a board game-based teaching approach, future studies could focus on how educational board games could be tailored for other areas of subject specialisations, such as Mathematics, Technology and Social Science education. Future research could also investigate how pre-service teachers implement educational board games within a teaching practicum experience.

REFERENCES

Bayeck, R. Y. (2018). A review of five African board games: Is there any educational potential? *Cambridge Journal of Education*, 48(5), 533-552. https://doi.org/10.1080/0305764X.2017.1371671

Berland, M. and Lee, V. R. (2011). Collaborative strategic board games as a site for distributed computational thinking. *International Journal of Game-Based Learning,* 1(2), 65-81. https://doi.org/10.4018/ijgbl.2011040105

Bidarra, J. and Rusman, E. (2017). Towards a pedagogical model for science education: Bridging educational contexts through a blended learning approach. *Open Learning: The Journal of Open, Distance and E-learning*, 32(1), 6-20. https://doi.org/10.1080/02680513.2016.1265442

Boffa, A., McFeetors, J. and Higgins, M. (2020). Are STEM games intended to be educative? *Journal of the Canadian Association for Curriculum Studies*, 18(1), 117-118. https://doi.org/10.1002/bmb.2006.494034042644

Boghian, I., Cojocariu, V. M., Popescu, C. V. and Mata, L. (2019). Game-based learning. Using board games in adult education. *Journal of Educational Sciences & Psychology*, 9(1), 23-37.

Chiarello, F. and Castellano, M. G. (2017). Board games creation as motivating and learning tool for STEM. *Educational Research and Development*, 2(3), 13-22. https://doi.org/10.1007/978-3-030-29736-7_22

Coil, D. A., Ettinger, C. L. and Eisen, J. A. (2017). Gut check: The evolution of an educational board game. *PLoS Biology*, 15(4), 5-19. https://doi.org/10.1371/journal.pbio.2001984

Epstein, J. L. (2019). Theory to practice: School and family partnerships lead to school improvement and student success, in C. L. Fagnano and B. Z. Werber (eds), *School, family and community interaction* (pp. 39-52). New York: Routledge. https://doi.org/10.4324/9780429305375-4

Eriksson, M., Kenward, B., Poom, L. and Stenberg, G. (2021). The behavioural effects of cooperative and competitive board games in pre-schoolers. *Scandinavian Journal of Psychology*, 2(3), 78-94. https://doi.org/10.1111/sjop.12708

Gagné, R. M. (1985). *Conditions of learning and theory of instruction*. New York: Holt, Rinehart and Winston. Available at: https://agris.fao.org/agris-search/search.do?recordID=US201300622339

Gawlik, K. (2018). Focus group interviews, in M. Ciesielska and D. Jemielniak (eds), *Qualitative methodologies in organization studies* (97-126). New York: Palgrave Macmillan. https://doi.org/10.1007/978-3-319-65442-3_5

Goacher, R. E., Kline, C. M., Targus, A. and Vermette, P. J. (2017). Using a practical instructional development process to show that integrating lab and active learning benefits undergraduate analytical chemistry. *Journal of College Science Teaching*, 46(3), 65-73. https://doi.org/10.2505/4/jcst17_046_03_65

Greenhalgh, S. P., Koehler, M. J. and Boltz, L. O. (2019). The fun of its parts: Design and player reception of educational board games. *Contemporary Issues in Technology and Teacher Education*, 19(3), 469-497. Available at: https://www.learntechlib.org/primary/p/184644/

Hallifax, S., Serna, A., Marty, J. C. and Lavoué, E. (2019). Adaptive gamification in education: A literature review of current trends and developments. *Journal of Technology Enhanced Learning*, 3(12), 34-45. https://doi.org/10.1007/978-3-030-29736-7_22

Higgins, M. and McFeetors, J. (2019). Board games as play-full pedagogical pivots for STEM teaching and learning. *Journal of the Canadian Association for Curriculum Studies*, 17(1), 90-110.

Hoy, B. (2018). Teaching history with custom-built board games. *Simulation & Gaming*, 49(2), 115-133. https://doi.org/10.1177/1046878118763624

Huizenga, J. C., Ten Dam, G. T. M., Voogt, J. M. and Admiraal, W. F. (2017). Teacher perceptions of the value of game-based learning in secondary education. *Computers & Education*, 110(3), 105-115. https://doi.org/10.1016/j.compedu.2017.03.008

Hussein, M. H., Ow, S. H., Cheong, L. S., Thong, M. K. and Ebrahim, N. A. (2019). Effects of digital game-based learning on elementary science learning: A systematic review. *IEEE Access*, 7(1), 62465-62478. https://doi.org/10.1109/ACCESS.2019.2916324

Kaimara, P., Fokides, E., Oikonomou, A. and Deliyannis, I. (2021). Potential barriers to the implementation of digital game-based learning in the classroom: Pre-service teachers' views. *Technology, Knowledge and Learning*, 3(1), 1-20. https://doi.org/10.1007/s10758-021-09512-7

Ladur, A. N., van Teijlingen, E. and Hundley, V. (2018). Whose shoes? Can an educational board game engage Ugandan men in pregnancy and childbirth? *BMC Pregnancy and Childbirth*, 18(1), 1-8. https://doi.org/10.1186/s12884-018-1704-6

Li, M. C. and Tsai, C. C. (2013). Game-based learning in science education: A review of relevant research. *Journal of Science Education and Technology*, 22(6), 877-898. https://doi.org/10.1007/s10956-013-9436-x

Liu, Z. Y., Shaikh, Z. and Gazizova, F. (2020). Using the concept of game-based learning in education. *International Journal of Emerging Technologies in Learning*, 15(14), 53-64. https://doi.org/10.3991/ijet.v15i14.14675

Majuri, J., Koivisto, J., and Hamari, J. (2018). Gamification of education and learning: A review of empirical literature. *Journal of Technology Enhanced Learning*, 2(4), 123-144. Available at: http://ceur-ws.org/Vol-2186/paper2.pdf

Muell, M. R., Guillory, W. X., Kellerman, A., Rubio, A. O., Scott-Elliston, A., Morales, O. and Brown, J. L. (2020). Gaming natural selection: Using board games as simulations to teach evolution. *Evolution*, 74(3), 681-685. https://doi:10.1111/evo.13924

Noda, S., Shirotsuki, K. and Nakao, M. (2019). The effectiveness of intervention with board games: A systematic review. *Biopsychosocial Medicine*, 13(1), 1-21. https://doi.org/10.1186/s13030-019-0164-1

Ofosu-Ampong, K. (2020). The shift to gamification in education: A review on dominant issues. *Journal of Educational Technology Systems*, 49(1), 113-137. https://doi.org/10.1177/0047239520917629

Rowe, J. P., Lobene, E. V., Mott, B. W. and Lester, J. C. (2017). Play in the museum: Design and development of a game-based learning exhibit for informal science education. *International Journal of Gaming and Computer-Mediated Simulations*, 9(3), 96-113. https://doi.org/10.4018/IJGCMS.2017070104

Savin-Baden, M. and Major, C. (2013). *Qualitative research: The essential guide to theory and practice.* London: Routledge.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Sousa, M. J. and Rocha, A. (2019). Leadership styles and skills developed through game-based learning. *Journal of Business Research*, 94, 360-366. https://doi.org/10.1016/j.jbusres.2018.01.057

Taspinar, B., Schmidt, W. and Schuhbauer, H. (2016). Gamification in education: A board game approach to knowledge acquisition. *Procedia Computer Science*, 99(3), 101-116. https://doi.org/10.1016/j.procs.2016.09.104

Tsai, J. C., Cheng, P. H., Liu, S. Y. and Chang, C. Y. (2019). Using board games to teach socioscientific issues on biological conservation and economic development in Taiwan. *Journal of Baltic Science Education*, 18(4), 634-648. https://doi.org/10.33225/jbse/19.18.634

van Roy, R. and Zaman, B. (2018). Need-supporting gamification in education: An assessment of motivational effects over time. *Computers & Education*, 127(3), 283-297. https://doi.org/10.1016/j.compedu.2018.08.018

Wang, C. and Burris, M. (1997). Photo voice: Concept, methodology and use for participatory needs assessment. *Health Education & Behaviour*, 24(3), 369-387. https://doi.org/10.1177/109019819702400309

Yien, J. M., Hung, C. M., Hwang, G. J. and Lin, Y. C. (2011). A game-based learning approach to improving students' learning achievements in a nutrition course. *Turkish Online Journal of Educational Technology,* 10(2), 1-10. Available at: https://www.learntechlib.org/p/217589/

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M. and Yukhymenko, M. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research*, 82(1), 61-89. https://doi.org/10.3102/0034654312436980

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'Science is My True Villain': Exploring STEM Classroom Dynamics Through Student Drawings

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ABSTRACT

Classroom dynamics including interactions among peers and with teachers is a key component of students' STEM experiences, strongly influencing students' motivation to engage in the learning activities. Classroom dynamics and dialogue have been predominantly studied through longitudinal ethnographic observations of the classroom while the perspective of the students who are undergoing these experiences is largely unaccounted for. This research article showcases an empirical study that used student drawings to explore STEM classroom dynamics. In contrast with interviews, drawing allows the participant to illuminate their tacit knowledge and communicate ideas without interference from the researcher. The participants (n=32), 9th grade students from 16 public schools in Northern India, were asked to create a poster with drawings and words to show their experiences and feelings in mathematics and science classrooms. A thematic analysis of students' work was performed to draw inferences about the classroom dynamics. The posters provided an opportunity for students to authentically express themselves and represent the social and emotional consequences of teacher behaviour in STEM classrooms. Concurring with previous classroom dynamics research, findings identified a strong need to reassess teaching practices in rural Indian context.

Keywords: STEM, classroom dynamics, dialogue, student drawings, developing country perspective

INTRODUCTION

In a world moving rapidly towards digitization and automation, there is an increasing demand for a STEM (Science, Technology, Engineering and Mathematics) literate workforce (World Economic Forum, 2020). STEM literacy is becoming synonymous with high performance on international assessments such as TIMSS and PISA, even though the scores are not representative of quality STEM education (Ozer, 2020; Sjøberg, 2015). The over emphasis on performance rather than learning is consequentially reflected in everyday teaching practices and classroom dynamics leading to negative attitudes towards STEM subjects (Barroso et al., 2021; Kaya and Yildirim, 2014).

STEM classroom dynamics has been predominantly studied through longitudinal ethnographic observations of the classroom (Jocuns, 2013; Kayi-Aydar and Miller, 2018). While this approach provides an external view of student interactions, the perspective of the students who are undergoing these experiences is largely unaccounted for. In order to improve student experiences in STEM classrooms, there is a need to understand their perception of the classroom and sources of anxiety. Towards addressing this gap, an empirical study was conducted to explore the role of student drawings in understanding STEM classroom dynamics.

LITERATURE REVIEW

STEM classrooms, like any social space shared by diverse individuals, tend to have certain norms, socially constructed identities, and power structures (Tsukada and Perreault, 2016). Classroom dynamics is a broad term that encompasses all of these components in the classroom beyond academic content. It includes components such as (i) norms and expectations in the classroom, (ii) perceptions and behaviours of peers and teachers, and (iii) the physical configuration of the classroom (Omatsu, 2011). The complex interplay between the classroom elements creates unique dynamics within the classroom and shapes the educational experience of the students. Classroom dynamics have the potential to impact student behavioural, socioemotional, and academic outcomes (Wang et al., 2020).

Teacher expectation and behaviour is a critical element of classroom dynamics (Howe and Abedin, 2013). Teachers are known to form expectations for students based on indicators such as prior academic performance, socioeconomic status, and gender (Nathan et al., 2010). These flawed expectations from teachers translated into differential treatment of students (Flores, 2007). A 5-step path outlined by Wang et al. (2018) summarizes the effects teacher expectations and behaviour on student outcomes:

1. teacher forms expectation for students,
2. teacher behaves differently based on expectations,
3. student perceives teacher expectation,
4. student socio-psychological factors are influenced, and
5. student achievement outcomes are influenced.

Irrespective of actual teacher behaviour, students' perception of teacher differential treatment critically impacted student outcomes (Brey and Pauker, 2019). Often referred to as a 'the Pygmalion effect' or a 'self-fulfilling prophecy', teacher expectations can significantly predict student self-efficacy, attitudes and achievement outcomes in STEM subjects (Gentrup et al., 2020; Rosenthal and Jacobson, 1968).

Teachers not only influence student outcomes through direct interactions, but also moderate peer dynamics within the classroom. Through their behaviour in class, teachers model ways for students to interact and evaluate each other (Hendrickx et al., 2016). Consequently, teacher behaviour and differential treatment influences peers' perception of the student (Brey and Pauker, 2019; Montague and Rinaldi, 2001). Teacher expectations and academic achievement influence the formation of peer groups with high-achieving students selecting each other as friends (Véronneau et al., 2010). Peer perceptions and interactions are highly influential on student experiences, especially in middle school, as students strive to socially fit in. As social integration and academic outcomes are closely related, some students experiencing rejection or discrimination in the classroom may have difficulty in academic achievement (Schneider et al., 2012). In turn, poor academic performance reinforces biased treatment from peers and teachers.

Students develop their self-efficacy beliefs and identities as STEM learners based on the academic performance and perceptions of their peers and teachers (Hendrickx et al., 2016). While high expectations from teachers can improve student performance, low expectations create a significant challenge for them (Rosenthal and Jacobson, 1968; Zhan and Sherraden, 2011). In addition, teacher expectations and peer behaviour have an impact on student attitudes towards the subject and intent to pursue STEM careers (Benner and Mistry, 2007; Heaverlo, 2011; Lee et al., 2015). For example, teachers have a lower expectation for female students in subjects like mathematics, which contributes to an underrepresentation of women in related fields (Banerjee et al., 2018; Watson et al., 2015). However, female students were more likely to choose and stay in STEM majors when their female peers or friends had similar intentions (Raabe et al., 2019). Thus, classroom dynamics have the potential to shape students' self-perception and STEM career choices.

Impacted by their early STEM experiences, many students decide that STEM fields are too challenging or boring before they reach high school (PCAST, 2010). Poor attitudes towards STEM are also observed in students from rural schools in India (Menon et al., 2021). This trend consistently results in a shortage of qualified professionals in developed and developing countries (UNESCO, 2021). Given that student perception of classroom dynamics impacts student self-efficacy, attitudes, and achievement, there is a strong need to account for student voice and perception in classroom dynamics research. By integrating diverse perspectives and contexts, we could collectively work towards creating a conducive environment for developing positive STEM attitudes among students.

Drawings have been considered to provide a valuable insight into children's views, feelings and opinions (Puglionesi, 2016). In educational settings, drawings are noted as effective tools for learning (Prain and Tytler, 2012), assessment (Koester, 2015), and research (Bracher, 2003). In this study, drawing is positioned as a 'non-verbal language' that elicits images and reflections from lived experiences (Alerby and Bergmark, 2012). In contrast with interviews, drawing allows the participant to communicate their ideas without interference from the researcher (Mannay, 2010). Further, drawings have the potential to illuminate the tacit knowledge that might be common to the researcher and the participants (Alerby and Brown, 2008). Thus, student drawings were used as a tool to explore students' experiences within STEM classrooms.

METHODS AND ANALYSIS

The current study was a part of a larger project conducted in collaboration with a network of rural residential schools across India. The aim of the project was to support and improve mathematics and science teaching within the school system. The first step in the project was to assess the existing teaching practices and learning experiences within the science and mathematics classrooms. Towards this end, two-day workshops were conducted in several regions across India to engage with the science and mathematics teachers and underperforming students. Observations from one such student workshop session conducted in Northern India is presented here.

Participants (n=32) were 9th grade (ages 14-16) students from 16 rural residential schools in Northern India. Specifically, two students from each school who were identified as academically underperforming by their mathematics and science teachers were invited to participate. To ensure confidentiality, all students were seated in a classroom where only researchers were present and instructed not to write their names on the artwork. Students were asked to create a stand-alone poster with drawings and words to show their experiences and feelings in mathematics and science classrooms. Due to some design limitations of the workshop, group discussions about their classroom experiences were conducted in lieu of individual follow-up interviews with students.

Following the workshops with students and teachers, the project team conducted class observations in each of the participating schools. During this time, the team gained a deeper understanding of the school system, classroom dynamics, and student experiences through engagement with the whole class, teachers, and other administrative personnel. Thus, during the process of analysing the student posters, researchers were also informed by these experiences. Specifically, to analyse the student posters, and identify recurring patterns and themes, a critical visual methodology framework was used (Rose, 2001). Based on the questions identified by Rose (2001) and Guillemin (2004), the following questions about the poster were employed to guide the analysis:

a. What is being shown? What are the components of the poster? How are they arranged?
b. What do the different components signify?
c. What relationships are established between the components of the poster?
d. What knowledge and experiences are being deployed?
e. Who or what components are excluded from this representation?
f. Is this a contradictory image? (To other data or observation)

The students were bilingual, thus using English and Hindi in their art works. The analysis was conducted by researchers who were also fluent in Hindi and English. A translation for Hindi is provided wherever relevant.

RESULTS

Out of the 32 students, 3 of the student posters were excluded from the analysis as they depicted experiences from Civics and English classrooms. All of the remaining posters indicated a dislike for experiences associated with either mathematics or science or both classrooms. Through the posters, students provided explanations and examples of their classroom and subject experiences. About 79% of them indicated an academic difficulty as a part of the reason for their dislike. About 41% of the posters included an affective representation of their relationship with the subject. About 31% illustrated a classroom scene indicative of their experiences.

Academic Difficulties

A majority of the posters provided descriptions of particular topics and concepts that students found difficult. Students explained that they enjoyed topics in which they understood the content and could confidently answer test questions. On the other hand, they associated topics that were hard to understand with boredom and hatred. Students described their difficulty in science and maths by repeatedly referring to their 'marks' on the test and the test taking experiences. A few students explained that they tried very hard to study and learn the maths and science concepts, but somehow forgot or 'messed up' (गड़बड़) answers on the test leading to low scores. The low scores and inability to understand the topics triggered feelings of anxiety (परेशान) and confusion (दिमाग खराब *literally translates to brain-damage*) because of which they didn't feel like studying the subject anymore. They highlighted an expectation to remember diagrams, formulae, equations, descriptive answers, and mathematical solutions to be able to have a positive experience in maths and science classrooms. This expectation was a source of anxiety and fear for a majority of the participants (**Figure 1**).

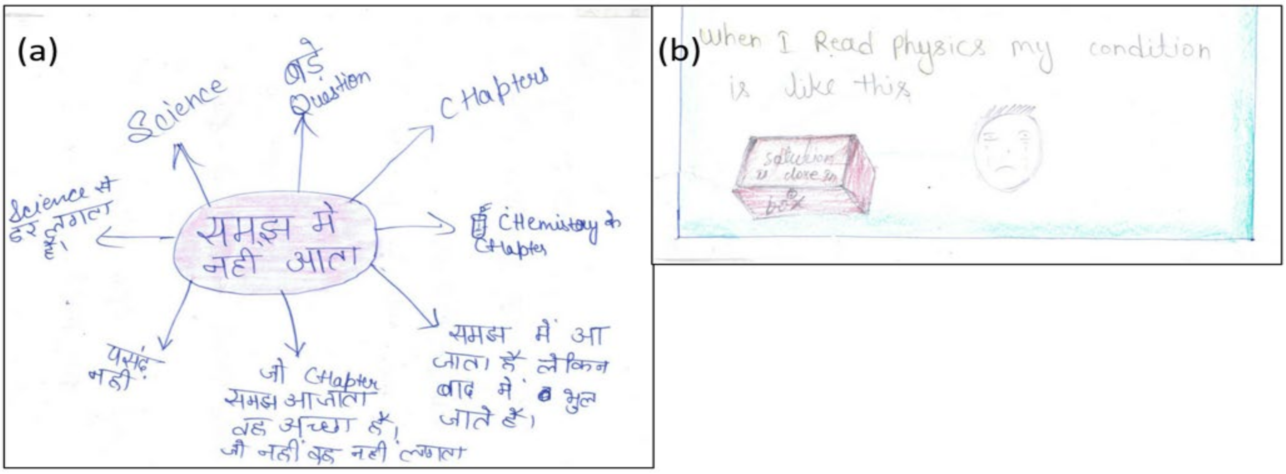

Figure 1. Student explanations of academic difficulty. (a) A central circle has the words “Cannot understand” with arrows leading to Science, long answer questions, chapters, chemistry chapter, ‘could understand, but forget later’, ‘the chapters that I can understand, I feel good about them, but do not feel good about the other chapters’, ‘don’t like’, ‘scared of Science’ (listed clockwise starting from top left). (b) An illustration of ‘when I read Physics, my condition is like this’ showing a student in tears next to locked box where the ‘solution is close[d] in’.

Affective Representations

Being in a residential setting, students spent almost all of their time with teachers and peers, leaving no separation between academic and social life. Thus the ability to perform well academically was a significant aspect of their life. Themes of dislike for maths and science were common among all student posters, but 12 of the students created an extremely emotional depiction of their feelings towards the subjects. In these posters, students depicted themselves as victims with unpleasant expressions. Two students personified mathematics as a ghost that’s haunting them (see **Figure 2**), while three others cautioned that maths and science denote ‘danger’.

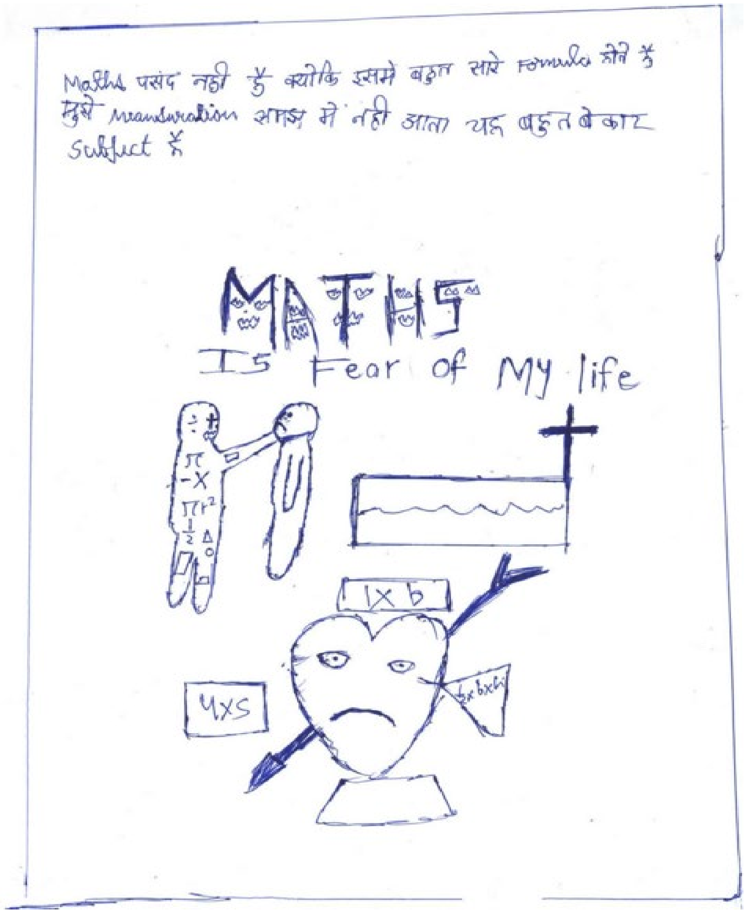

Figure 2. Example of personification of the subject

Students explains that they do not want to study mathematics because there are too many formulae. They cannot understand the chapter 'mensuration' and feel mathematics is a waste subject. The illustration is titled 'Maths is the fear of my life' with maths having several angry faces as seen from **Figure 2**. A human form of mathematics symbols is holding the student by their neck and threatening to end their life. Next to them is a grave and a sad heart remembering mathematical formulae for area measurements from the chapter 'mensuration'. Several students represented an unpleasant physical sensation associated with science and maths such as their heart on fire, brain explosion, and head spinning. Students used the phrases 'science is my true villain' and 'maths is the fear of my life' to represent the antagonistic role of the STEM subjects in their life.

Sometimes, their teachers and textbooks appear disproportionately large (for example, **Figure 3(d)** and **Figure 6**), potentially indicative of the looming power over them. Two students particularly created disturbing artworks indicating that mathematics 'will be with them until the end of life' (हमारे जीवन के आखरी लम्हो तक जुड़ा है). Due to the intense emotions associated with science and maths, few students created representations of 'getting back at' science and maths. They wanted to show their anger and frustration by throwing their textbooks into the 'dustbin' or fire (see **Figure 3**). One student was particularly waiting for 'their time to scare mathematics away'.

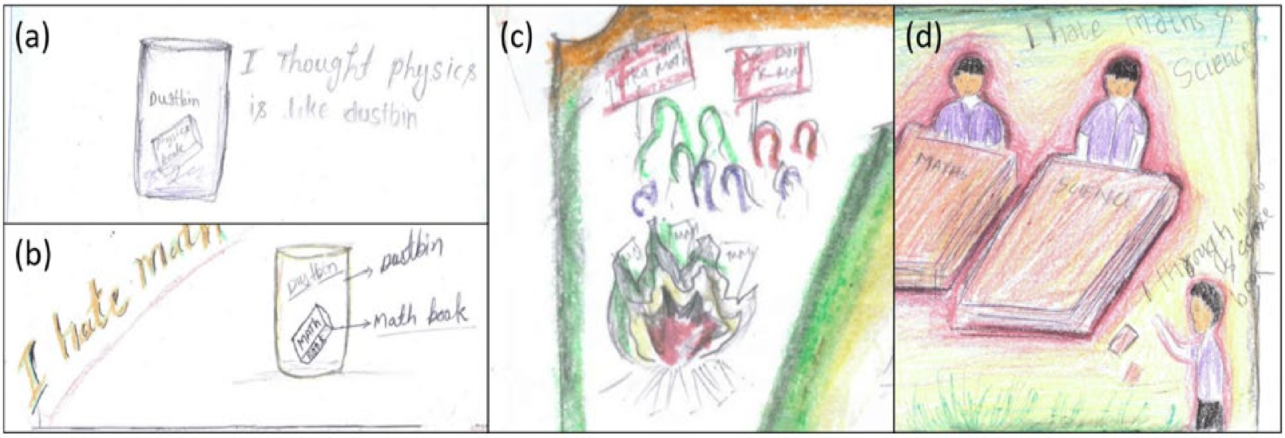

Figure 3. Examples of 'getting back at' maths and science. (a) A dustbin with a physics book inside it. Student describes 'I thought physics is like dustbin'. (b) Titled 'I hate math' a drawing of a math book in the dustbin. (c) A group of students holding placards 'I don't like math' are standing in front of a fire and throwing their mathematics textbooks into the fire. (d) Student sitting in front of extremely large mathematics and science textbooks saying 'I hate maths and science'. Another illustration of the same student on the corner throwing away books.

Classroom Scene

Eight students created drawings of a particular representative incident from their mathematics or science classroom. Most of the pictures represented a typical regimented classroom with the students seated in rows and columns facing the teacher and a black board. In all of the drawings, there was a one-way conversation from teacher to student with occasional response from the students. Based on the drawings, the dialogue with the teacher could be classified into two types, namely, (a) teacher explaining a concept and (b) teacher asking a question.

Explaining a concept

Four students created images of the teacher explaining a concept in class. The drawings showed students as bored, confused or unable to understand the topic. However, they were hesitant to voice their concerns and depicted themselves going through different emotions. Two of these drawings only represented themselves and the teacher while ignoring the existence of other students in the classroom (see **Figure 4** and **Figure 5**).

Informed by our classroom observations, these depictions may represent the lack of collaborative learning opportunities and isolated learning experiences for the students. The classroom was completely teacher centred with a lack of communication between the teacher and student. As students were unable to follow the teachers who remained unaware of students' issues, students developed negative attitudes towards the topics. While the student in **Figure 4** associated algebra with confusion, the student in **Figure 5** associated physics class and textbook with danger.

Two students depicted some of their peers having a similar experience while the teachers were explaining a concept (see **Figure 6** and **Figure 7**). Particularly, **Figure 6** depicted a classroom where a small number of students who were able to understand the teacher were usually more vocal. This left the majority of the students at a disadvantage. However, both **Figure 6** and **Figure 7** represented students who took comfort in the sentiment that they were not alone in their struggles.

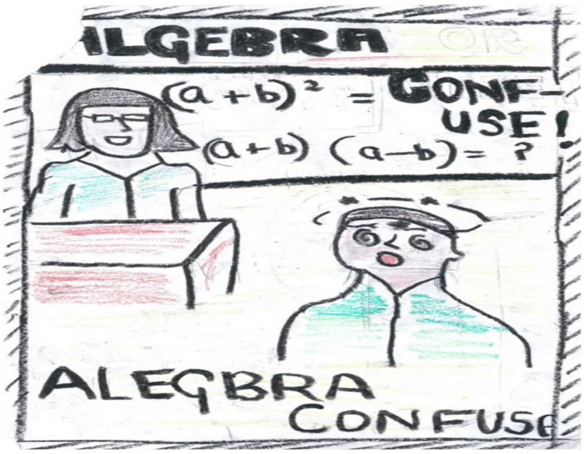

Figure 4. The artwork is titled 'Algebra'. A teacher is at the board writing down algebraic equations. But the student is experiencing confusion, unable to understand the equations. The student is shown with a feeling of head spinning with stars around his head. The artwork is retitled at the end of the page as 'Algebra Confuse'.

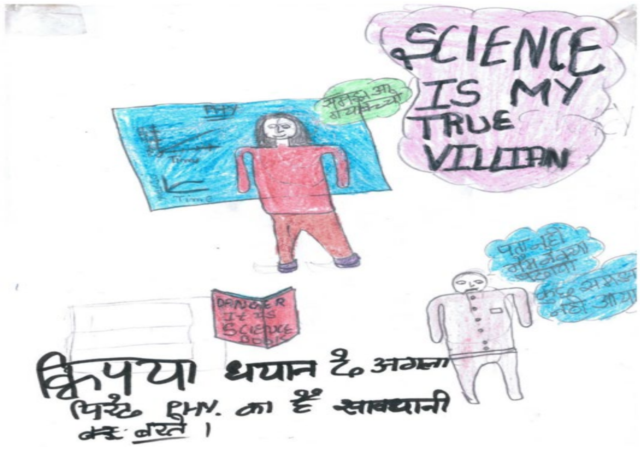

Figure 5. The drawing is titled 'Science is my true villain' depicting student feelings during physics class. The Physics teacher standing before the board is asking, 'Did you understand, students?'. The student is thinking to themself, 'I don't know what the teacher taught, I could not understand anything'. A science book is shown with a Danger warning and a note of caution 'please note that the next period is Physics, be careful'.

Figure 6. A scene from mathematics classroom shows a teacher at the front of the class teaching algebraic equations. The work is titled 'This is how our class is'. The teacher askes 'did you understand?'. Two of the students' reply 'yes', while the others think 'I didn't understand', 'I don't know what this is', '75% of the class cannot understand'. However, the teacher remains oblivious that 75% of the class does not understand.

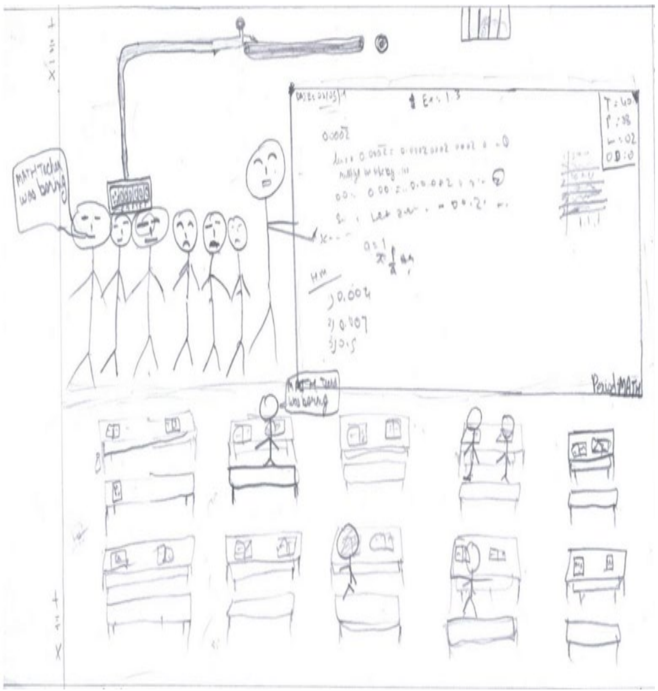

Figure 7. The artwork shows a mathematics classroom with the teacher at the front of the class writing on the board. Several students are leaving the classroom because they feel that the 'math teacher is boring'. Even the students still seated in their places are finding the math teacher boring.

Three out of four students (**Figure 4**, **Figure 5**, and **Figure 6**) depicted teaching approaches that instigated negative emotions towards the subject itself. Forced to assume the role of a passive learner, students felt distanced from the content and teaching process, thus labelling the subject as 'boring', incomprehensible, and a 'danger' to them. This represents a relationship between STEM classroom dynamics during instruction and students' attitude towards the subjects. One student, but, only depicted a 'boring teacher' and not their attitude towards the subject.

Figure 8. The artwork is titled 'what I don't understand' followed by a danger symbol. Student is thinking to themselves, 'I cannot understand the maths questions and I cannot remember the formulae'. Their heart is shown on fire with an elevated heartbeat, 'this is why I'm scared of maths'. There are several mathematical symbols and textbook in the background. In the test description, student explains, 'I cannot remember mathematics formulae and cannot understand some questions. I absolutely cannot understand the big answer questions in mathematics. The teacher comes to class and askes the students any question. If they cannot answer, they get beaten. This is why we get scared of mathematics and are unable to study.'

Asking a question

Three student drawings of classroom dynamics indicated unpleasant incidents of questioning by the teacher. One particular student described a scenario in which the maths teacher asked questions in the class and students were then punished if they gave incorrect answers (**Figure 8**). As a result of this experience, the student reported developing severe emotional and physical reactions towards mathematics while other students in the class also experienced fear and anxiety.

Two other students depicted teachers using a threatening tone while asking questions in the classroom. In both cases, the teachers' behaviour towards the student incites a derogatory reaction of laughing from their peers (**Figure 9** and **Figure 10**). The student from **Figure 9** demonstrates a feeling of isolation from their peers due to the dynamic of being put down by the teacher and peers. The student shows an emotional reaction of wanting to burn the mathematics books as a result. However, **Figure 10** depicts a comparison of mathematics and science classes. This student drawing indicates that the behaviour of their peers and attitude towards the subject depends on the behaviour of the teacher. Further, classroom experiences lead them either to 'love' or 'hate' the subject.

Teacher Intent

Based on the student narrative and posters, teachers are sometimes represented in an antagonistic role. However, as researchers who worked closely with these teachers for over a year, we observed that the teachers genuinely had the best interest of the students in mind. Given the residential setting, teachers were also caretakers of the students outside the classroom and shared a close personal bond with many students. Some of the instructional and classroom management practices noted from the student drawings were a norm in India, but do not demonstrate any malicious intent on the part of the teachers. These norms widely accepted as time tested classroom practices were still prevalent because the teachers were unaware of the associated social and emotional experiences of the students.

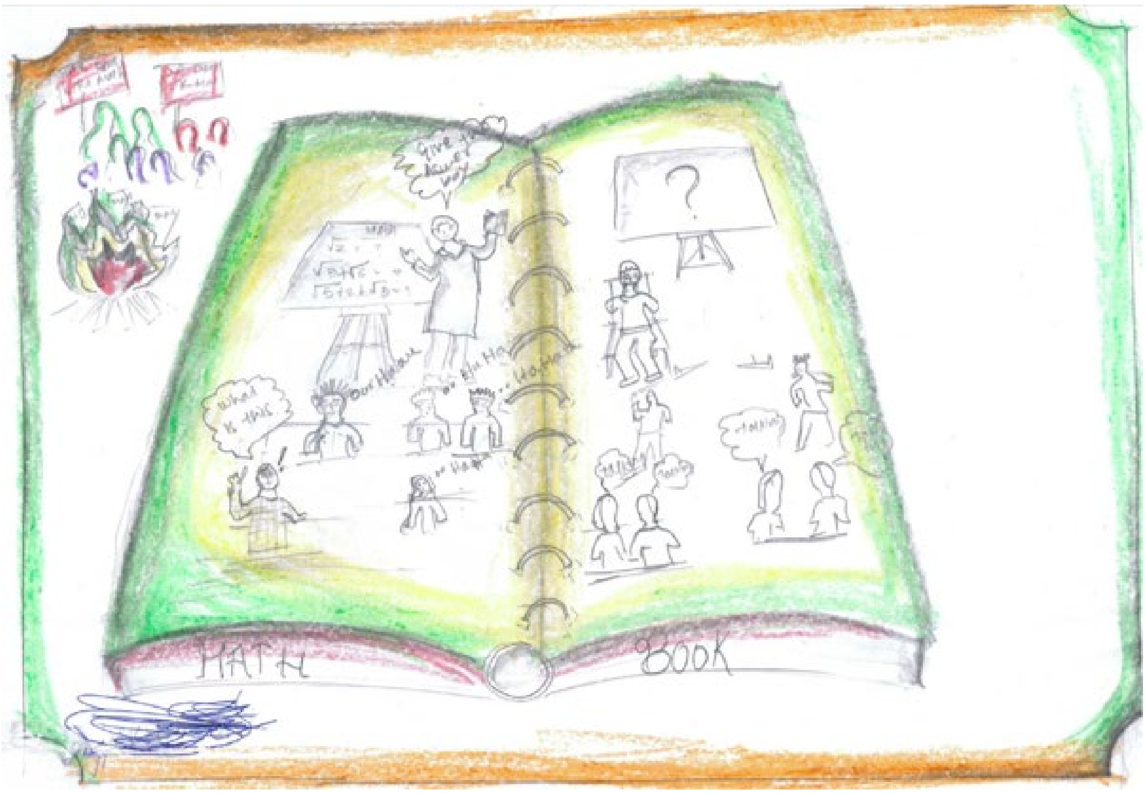

Figure 9. The drawing shows events within a mathematics classroom. In the first scene, the teacher is directing a question towards one student who is unable to answer. She says 'Give me the answer boy', while the other students laugh. In the second scene, the student who was unable to answer is sitting next to a blank board, while the rest of the students are socializing. Outside the classroom, a group of students are expressing their displeasure with mathematics by burning the textbooks.

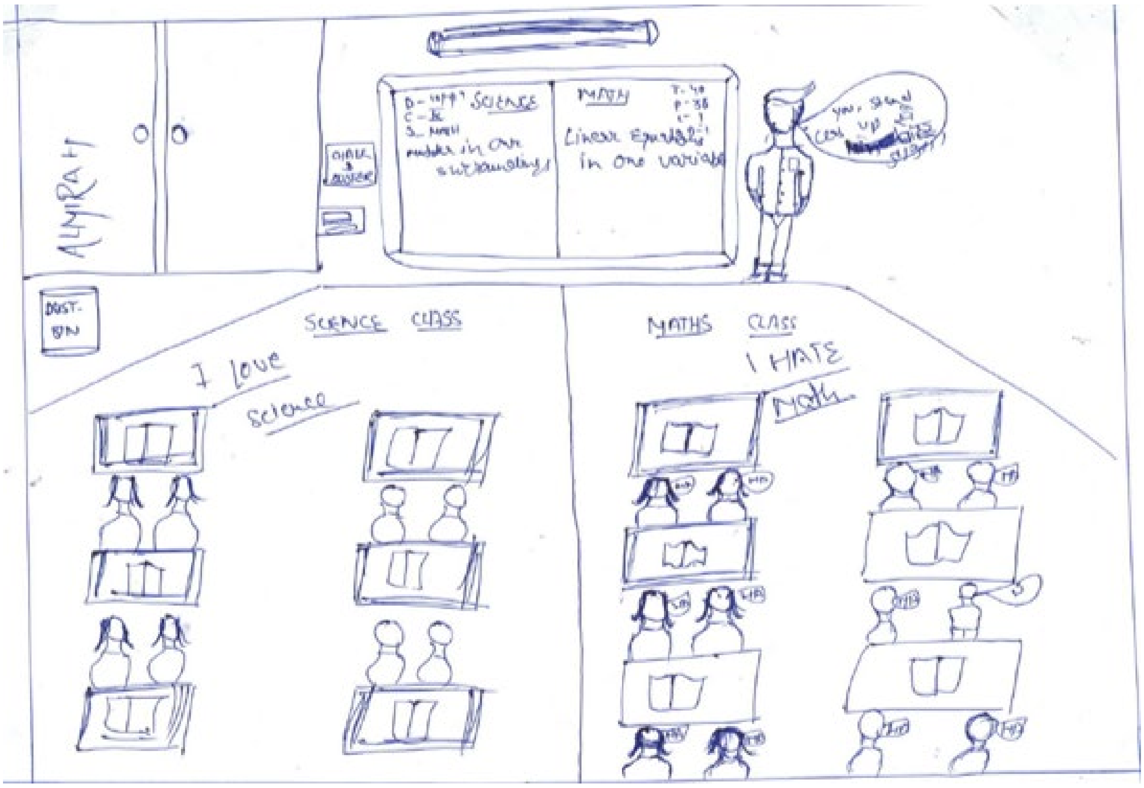

Figure 10. The drawing shows a comparison of maths and science classrooms. While the science classroom appears quiet without a teacher, the mathematics classroom shows the teacher asking a student to 'stand up and get out' while the other students laugh. The picture indicated that the student loves science but hates math.

DISCUSSION

In an assessment driven education system, there is a reluctance to move away from established systems which seem to be working well. Specifically, in the Indian context, as many students are still able to perform well academically in rigid educational settings, the students who struggle academically are often looked down upon. However, this study provides insights about the weaknesses in the existing systems that impacts all students. Posters created by students underperforming in mathematics and science demonstrates student experiences in STEM classrooms. The posters provided an opportunity for students to authentically express themselves (Mitchell et al., 2011) and represent the social and emotional consequences of teacher behaviour in STEM classrooms.

Classroom dynamics including student-teacher and student-student interactions in STEM classrooms play an important role in shaping student self-efficacy, attitudes, achievement, and future career choices. Specifically, prior research indicated that students who are identified as 'academically underperforming' by teachers are at risk of biased treatment by teachers and peers (Brey and Pauker, 2019; Howe and Abedin, 2013). As a result, they develop poor self-efficacy and negative attitudes towards the subject (Lee et al., 2015). The results from the current study aligned with existing research as all the students who were identified as academically underperforming in science or mathematics indicated a dislike for one or both of the subjects through their posters. Further, some of the students indicated the existing power dynamic within the classroom through words and illustrations.

Student posters that discussed classroom dynamics clearly indicated a teacher led classroom. Students were able to make connections between teacher behaviours, peer behaviours and their attitudes towards the subject. Specifically, as the classrooms lacked collaborative activities, students were unable to have an active role in their learning. They heavily depended on the teacher feedback and academic performance to evaluate themselves and their peers. As a result, they associated poor academic performance with lower STEM self-efficacy. Some students demonstrated biased treatment due to their academic performance and a causal relationship between rejection in the classroom and dislike towards the subject.

Several images clearly represented the emotional and physical manifestations of STEM related anxiety. Even though some students referred to 'boring' teaching practices, or threatening classroom climate, they did not view the teacher as a threat. Instead, a majority of the students viewed the subjects - mathematics or science or both, as the source of the problem, while representing themselves as victims. Some students were waiting for the day when they no longer needed to engage with mathematics or science. This implied that students had developed strong negative attitudes towards STEM subjects and were unlikely to pursue related careers.

The findings from this study suggest a strong need to reassess teaching practices in rural Indian context. Specifically, there is a need to reconsider teacher led classrooms and outdated teaching techniques involving shaming and harsh punishments. The artifacts generated by students are invaluable tools for facilitating discussions about best practices with pre-service and in-service STEM teachers. In future research and teacher training efforts, we aim to use the student artwork to demonstrate classroom dynamics from the perspective of underperforming students to provoke meaningful pedagogical changes.

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REFERENCES

Alerby, E. and Bergmark, U. (2012). What can an image tell? Challenges and benefits of using visual art as a research method to voice lived experiences of students and teachers. *Journal of Arts and Humanities*, 1(1), 95-104.

Alerby, E. and Brown, J. (eds). (2008). *Voices from the margins: School experiences of indigenous, refugee and migrant children*. Rotterdam, The Netherlands: Sense Publishers. https://doi.org/10.1163/9789087904623

Banerjee, M., Schenke, K., Lam, A. and Eccles, J. S. (2018). The roles of teachers, classroom experiences, and finding balance: A qualitative perspective on the experiences and expectations of females within STEM and non-STEM careers. *International Journal of Gender, Science and Technology*, 10(2), 287-307.

Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A. and Daucourt, M. C. (2021). A meta-analysis of the relation between math anxiety and math achievement. *Psychological Bulletin*, 147(2), 134-168. https://doi.org/10.1037/bul0000307

Benner, A. D. and Mistry, R. S. (2007). Congruence of mother and teacher educational expectations and low-income youth's academic competence. *Journal of Educational Psychology*, 99(1), 140-153. https://doi.org/10.1037/0022-0663.99.1.140

Bracher, E. R. (2003). *An investigation of the efficacy of analyzing student drawings as an adjunct to interviews aimed at researching the contexts of student life* [Unpublished doctoral dissertation]. Boston College, Boston, MA.

Brey, E. and Pauker, K. (2019). Teachers' nonverbal behaviors influence children's stereotypic beliefs. *Journal of Experimental Child Psychology*, 188, 104671. https://doi.org/10.1016/j.jecp.2019.104671

Flores, A. (2007). Examining disparities in mathematics education: Achievement gap or opportunity gap? *The High School Journal*, 91, 29-42. https://doi.org/10.1353/hsj.2007.0022

Gentrup, S., Lorenz, G., Kristen, C. and Kogan, I. (2020). Self-fulfilling prophecies in the classroom: Teacher expectations, teacher feedback and student achievement. *Learning and Instruction*, 66, 101296. https://doi.org/10.1016/j.learninstruc.2019.101296

Guillemin, M. (2004). Understanding illness: Using drawings as a research method. *Qualitative Health Research*, 14(2), 272-289. https://doi.org/10.1177/1049732303260445

Heaverlo, C. A. (2011). *STEM development: A student of 6th-12th grade girls' interest and confidence in mathematics and science* [Unpublished doctoral dissertation]. Drake University, Des Moines, IA.

Hendrickx, M. M., Mainhard, M. T., Boor-Klip, H. J., Cillessen, A. H. and Brekelmans, M. (2016). Social dynamics in the classroom: Teacher support and conflict and the peer ecology. *Teaching and Teacher Education*, 53, 30-40. https://doi.org/10.1016/j.tate.2015.10.004

Howe, C. and Abedin, M. (2013). Classroom dialogue: A systematic review across four decades of research. *Cambridge Journal of Education*, 43(3), 325-356. https://doi.org/10.1080/0305764X.2013.786024

Jocuns, A. (2013). Classroom discourse, in C. A. Chapelle (ed), *The encyclopaedia of applied linguistics*. Oxford: Blackwell Publishing Ltd. https://doi.org/10.1002/9781405198431.wbeal0134

Kaya, E. and Yildirim, A. (2014). Science anxiety among failing students. *Elementary Education Online*, 13, 518-525.

Kayi-Aydar, H. and Miller, E. R. (2018). Positioning in classroom discourse studies: A state-of-the-art review. *Classroom Discourse*, 9(2), 79-94. https://doi.org/10.1080/19463014.2018.1450275

Koester, M. (2015). *Science teachers who draw: The red is always there.* Deep University Press.

Lee, S. W., Min, S. and Mamerow, G. P. (2015). Pygmalion in the classroom and the home: Expectation's role in the pipeline to STEMM. *Teachers College Record*, 117(9), 1-36. https://doi.org/10.1177/016146811511700907

Mannay, D. (2010). Making the familiar strange: Can visual research methods render the familiar setting more perceptible? *Qualitative Research*, 10(1), 91-111. https://doi.org/10.1177/1468794109348684

Menon, R., Sridharan, A., Sankar, S., Gutjahr, G., Chithra, V. V. and Nedungadi, P. (2021, March). Transforming attitudes to science in rural India through activity based learning. *AIP Conference Proceedings*, 2336, 040003. https://doi.org/10.1063/5.0046269

Mitchell, C., Theron, L., Smith, A., Stuart, J. and Campbell, Z. (2011). Drawings as research method, in L. Theron, C. Mitchell, A. Smith and J. Stuart (eds), *Picturing research* (pp.17-36). Sense Publishers. https://doi.org/10.1007/978-94-6091-596-3_2

Montague, M. and Rinaldi, C. (2001). Classroom dynamics and children at risk: A followup. *Learning Disability Quarterly*, 24(2), 75-83. https://doi.org/10.2307/1511063

Nathan, M. J., Tran, N. A., Atwood, A. K., Prevost, A. M. Y. and Phelps, L. A. (2010). Beliefs and expectations about engineering preparation exhibited by high school STEM teachers. *Journal of Engineering Education*, 99(4), 409-426. https://doi.org/10.1002/j.2168-9830.2010.tb01071.x

Omatsu, G. (2011). Understanding classroom dynamics: A critical factor in teaching freshmen. *California State University*. Available at: https://www.csun.edu/sites/default/files/classdynamics.pdf

Ozer, M. (2020). What does PISA tell us about performance of education systems? *Bartın University Journal of Faculty of Education*, 9(2), 217-228.

Prain, V. and Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education*, 34(17), 2751-2773. https://doi.org/10.1080/09500693.2011.626462

President's Council of Advisors on Science and Technology (PCAST). (2010). Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future. *Report to the President.* Available at: https://nsf.gov/attachments/117803/public/2a--Prepare_and_Inspire--PCAST.pdf

Puglionesi, A. (2016). Drawing as instrument, drawings as evidence: Capturing mental processes with pencil and paper. *Medical History*, 60(3), 359-387. https://doi.org/10.1017/mdh.2016.28

Raabe, I. J., Boda, Z. and Stadtfeld, C. (2019). The social pipeline: How friend influence and peer exposure widen the STEM gender gap. *Sociology of Education*, 92(2), 105-123. https://doi.org/10.1177/0038040718824095

Rose, G. (2001). *Visual methodologies*. London: SAGE.

Rosenthal, R. and Jacobson, L. (1968). *Pygmalion in the classroom: Teacher expectations and pupils' intellectual development.* New York, NY: Holt, Rinehart & Winston.

Schneider, F. W., Coutts, L. M. and Gruman, J. A. (2012). *Applied social psychology: Understanding and addressing social and practical problems*. Thousand Oaks. CA: SAGE.

Sjøberg, S. (2015). OECD, PISA, and globalization: The influence of the international assessment regime, in C. H. Tienken and C. A. Mullen (eds), *Education policy perils: Tackling the tough issues* (pp. 114-145). London: Routledge.

Tsukada, H. and Perreault, A. (2016). Complicating how classroom climate works. *Transformative Dialogues: Teaching and Learning Journal*, 9(2), 1-17.

UNESCO. (2021). *Engineering for sustainable development: Delivering on the sustainable development goals*. Available at: https://unesdoc.unesco.org/in/documentViewer.xhtml?v=2.1.196&id=p::usmarcdef_0000375644&file=/in/rest/annotationSVC/DownloadWatermarkedAttachment/attach_import_bf945451-41f6-4e0b-a5db-50a8bb0c399b%3F_%3D375644eng.pdf&locale=en&multi=true&ark=/ark:/48223/pf0000375644/PDF/375644eng.pdf#p143

Véronneau, M.-H., Vitaro, F., Brendgen, M., Dishion, T. J. and Tremblay, R. E. (2010). Transactional analysis of the reciprocal links between peer experiences and academic achievement from middle childhood to early adolescence. *Developmental Psychology,* 46(4), 773-790. https://doi.org/10.1037/a0019816

Wang, M. T., Degol, J. L., Amemiya, J., Parr, A. and Guo, J. (2020). Classroom climate and children's academic and psychological wellbeing: A systematic review and meta-analysis. *Developmental Review*, 57, 100912. https://doi.org/10.1016/j.dr.2020.100912

Wang, S., Rubie-Davies, C. M. and Meissel, K. (2018). A systematic review of the teacher expectation literature over the past 30 years. *Educational Research and Evaluation*, 24(3-5), 124-179. https://doi.org/10.1080/13803611.2018.1548798

Watson, P. W. S., Rubie-Davies, C. M., Meissel, K., Flint, A., Peterson, E. R., Garrett, L. and McDonald, L. (2015). Gendered teacher expectations of mathematics achievement in New Zealand: Contributing to a kink at the base of the STEM pipeline? *International Journal of Gender, Science and Technology*, 8(1), 82-102.

World Economic Forum. (2020). The future of jobs report 2020. *World Economic Forum, Geneva, Switzerland.*

Zhan, M. and Sherraden, M. (2011). Assets and liabilities, educational expectations, and children's college degree attainment. *Children and Youth Services Review*, 33(6), 846-854. https://doi.org/10.1016/j.childyouth.2010.12.006

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Examining Kindergarten Children's Testing and Optimising in the Context of a Gear Engineering Task

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ABSTRACT

Introducing kindergarten children to the engineering design process (EDP) is an important objective of early STEM education. Studies indicate that children often miss the crucial steps of testing and optimising during the EDP and do not persist in making solutions better. The present study explores how children's goal awareness, self-evaluation ability, domain-specific content knowledge, spatial skills and intelligence relate to their persistence, testing and optimising behaviour and to solution quality. In a standardized procedure, 41 children (4 to 7 years) in Germany worked on an engineering task in the domain of gears. The engineering process was videotaped, children's testing and optimising, solution quality, goal awareness, self-evaluation, and task persistence were rated with a coding scheme and with interviewer questions. Domain-specific content knowledge, mental rotation ability and figural reasoning were measured with standardized tests. Correlational analyses indicated that goal awareness was positively related to solution quality. However, most children required support by the interviewer to retrieve the goal specifications. Moreover, children's self-evaluation was negatively related to task persistence. Most children were satisfied with their first solution, even when it did not meet the requirements. Our findings emphasize the important role of teachers in helping children to tackle challenges with the EDP.

Keywords: individual differences, problem-solving, kindergarten, gears, engineering

INTRODUCTION

Scientists and practitioners agree that STEM (science, technology, engineering, and mathematics) education should begin as early as kindergarten (e.g., NRC, 2013; OECD, 2018) as it can provide children with a fundamental knowledge base for learning STEM subjects in later school years (Kaderavek et al., 2020). Early STEM education aims at promoting children's understanding of domain-specific content knowledge, fostering domain-general process skills, and establishing an understanding of epistemic practices (NRC, 2013). In recent years, engineering has been increasingly emphasized as a central component of early STEM education (Bustamante et al., 2018; John et al., 2018). For instance, the *Next Generation Science Standards* framework in the US integrated engineering into science education by raising engineering design to the same level as scientific inquiry, and thus emphasises how closely the two are linked to each other (NRC, 2013; on the close link see also Schauble et al., 1991). For instance, an analysis and interpretation of data is required in order to (i) understand relations between causes and effects (scientific inquiry) and (ii) to determine if a designed product works as intended to solve a problem (engineering design). Moreover, there is a growing body of research exploring young children's engineering skills in both formal learning settings, such as preschool and elementary school (Bairaktarova et al., 2011; Gold et al., 2020; Kendall, 2015; Lottero-Perdue and Tomayko, 2020; Strimel et al., 2018a), and informal learning settings, such as museum exhibits (Eshan et al., 2021; Marcus et al., 2021; Tõugu et al., 2017).

In engineering education, particular emphasis is placed on introducing children to the engineering design process (EDP) as the disciplinary core idea of engineering (NRC, 2013). The EDP has evolved as the systematic and iterative problem-solving strategy engineers use to identify and solve problems (Cross, 2008; Lucas et al., 2014; Pleasants and Olson, 2019). The EDP is systematic in that it follows a characteristic sequence of steps comprising (i) identifying a problem, (ii) planning solutions, (iii) building models and prototypes, and (iv) evaluating solutions and prototypes (Cross, 2008). The EDP is iterative in that engineers build various prototypes, continuously test and optimise their solutions, analyse and interpret data, learn from failures, and make decisions based on evidence in order to improve solution quality (Cross, 2008; Lucas et al., 2014). Design failures, i.e. solutions that fail to meet one or more criteria, and the need to revise designs are regarded normal parts of the process (Petroski, 1992). Thus, persisting and learning from failure is considered as a crucial epistemic practice of engineering (Crismond and Adams, 2012; Lucas et al., 2014). Studies comparing the design processes of experts and novices reveal that expert designers go through significantly more iterations than novices, resulting in increased quality of the engineering solution (Atman et al., 2007; Strimel et al., 2018b). However, there are only a few empirical studies that have examined the EDP with focus on the crucial practices of persisting, testing and optimising in kindergarten and elementary school-aged children. Learning more about young children's persistence, testing and optimising, is highly relevant because of its theoretical implications and because it might also inform practitioners for developing targeted intervention programs based on these findings (Strimel et al., 2018a). In the present exploratory study, we therefore investigate kindergarten children's task persistence, testing and optimising when solving an engineering design task.

Empirical Studies Examining Children's Task Persistence, Testing and Optimising

Testing and optimising require the ability to analyse and interpret data (NRC, 2013), which develops between the ages of 3 and 7 (Zimmerman and Klahr, 2018). Children as young as 3 years are capable of spontaneously producing evidence that would enable causal learning (Schulz et al., 2007). However, studies observing children's engineering indicate that pre-schoolers and kindergartners do not sufficiently analyse and interpret data since they tend to neglect testing and optimising (for an overview, see Gold et al., 2020). For instance, Bairaktarova et al. (2011) stress that 3- to 5-year-olds' testing during free play activities with unstructured materials, such as sandboxes or water tables, semi-structured materials, such as paints and paper, and structured play materials, such as snap circuits focused mainly on the completion of a single construction, rather than on evaluating different prototypes to improve the solution quality. Similarly, in a study by Strimel et al. (2018a) 5- to 7-year-old kindergarten children spent only a very small part of their effort on evaluating solutions when solving engineering design tasks. Moreover, most children ended their design session once a single prototype was built (Strimel et al., 2018a). So far, little is known about young children's persistence, and neglection of testing and optimising. However, the few studies indicate that kindergarteners' persistence, testing and optimising might be related to the problem type (well- vs. ill-defined), children's goal awareness, ability to realistically self-evaluate solutions, and domain-specific content knowledge (Kendall, 2015; Lottero-Perdue and Tomayko, 2020; Strimel et al., 2018a). In the following, we will briefly address these points.

Children might need to be aware of the goal in order to test and optimise. Strimel et al. (2018a) suggest that the low incidence of persisting, testing and optimising in their study might have been due to the fact that they provided children with ill-defined engineering tasks. In ill-defined engineering tasks, the goal and constraints are not given in advance; thus, the criteria for evaluating a solution must be determined by the problem solver (Dörner and Funke, 2017). As kindergarten children often find it difficult to identify such criteria, well-defined engineering tasks seem more appropriate to investigate kindergarten children's testing and optimising (Haluschak et al., 2018; Strimel et al., 2018a). In well-defined engineering tasks, there is a clearly defined goal that allows for multiple solutions, and the criteria to evaluate a solution are given in advance (Crismond, 2001). In a museum's activity context, Pagano et al. (2019) investigated how the setting of a goal affected family's conversation about engineering practices. Families in a program with a set goal reflected more often on testing, things not working, optimising, and being successful or unsuccessful than families who completed an activity without a set goal.

Nevertheless, well-defined engineering tasks require the problem solver to build and maintain a mental representation of the goal state, which places high demands on the problem solvers' working memory (Kintsch, 2007). As the capacity of working memory in kindergarten children is still developing (Diamond, 2013), children might have problems in building and maintaining adequate mental representations of a goal state. Karmiloff-Smith (1979) demonstrated that 4- to 9-year-olds built accurate initial mental representations of a problem's goal state, but tended to simplify the problem by modifying their mental representation of the goal state during their problem-solving process (Karmiloff-Smith, 1979). In a qualitative study with a well-defined engineering task, Kendall (2015) investigated how six kindergarten children evaluated two design solutions of bridges. When asked to recall the requirements the bridge had to meet (length and sturdiness), most children did recall only one of the two requirements. Consequently, studies on kindergarten children's persisting, testing and optimising should control whether children are aware of a task's goal and the task's requirements.

Learning from failures by continuously testing and optimising prototypes requires the ability to assess one's own performance and solutions realistically. Findings from developmental psychology indicate that self-evaluations of 4- to 7-year-olds tend to be unrealistically positive (Harter and Bukowski, 2015; Marsh et al., 2012; Oppermann et al., 2018). Such a bias in perception might lead children not to optimise, as there is nothing to optimise from their point of view. When the children in the study by Kendall (2015) were asked to test and optimise the engineered bridges, children tended to focus on what worked, but neglected failures and their sources. Contrary, in a study by Lottero-Perdue and Tomayko (2020) 5- to 7-year-old kindergarten children were able to accurately self-evaluate their engineered solution with respect to the requirements it had to meet, and almost all of the children opted to optimise their design when asked by the researchers. As the authors acknowledge, the engineering task was quite straightforward with respect to success or failure: The children were asked to build a fence out of wooden and foam blocks to contain a small, fast-, and randomly-moving *HEXBUG nano*® robot and give the robot as much room as possible to move. The children could hardly ignore design failures as in that case the robot evidently broke through the fence. Most children were able to detect failures' causes (e.g., the foam blocks were too light), however, an accurate failure analysis did not automatically lead the children to apply this knowledge in a revised design solution (Lottero-Perdue and Tomayko, 2020). Thus, research on kindergarten children's engineering behaviour might investigate how children's self-evaluation of their solutions relate to their persistence, testing and optimising.

Professional engineers apply scientific and mathematical content knowledge to design, test and optimise solutions (Pleasants and Olson, 2019). For young children, however, the relationship between domain-specific content knowledge and testing, optimising and engineering outcome is less straightforward. On the one hand, studies with 3- to 5-year-olds suggest that children are able to carry out meaningful tests and manipulations on a novel toy, use this evidence to infer causal structures, and thus, learn how the toy works without prior domain-specific knowledge (Schulz et al., 2007). Thus, engaging children in engineering practices such as testing and optimising might provide learning opportunities for relevant domain-specific content knowledge (Lin et al., 2020; Penner et al., 1997).

On the other hand, museum studies with 4- to 9-year-old children and their parents in two conditions (brief instruction on relevant domain-specific content knowledge or not) showed that instructed families displayed more engineering-related talk, and their children made use of the domain-specific knowledge more often than in the other condition (Benjamin et al., 2010; Marcus et al., 2021). To the best of our knowledge, engineering studies with young children so far did not measure children's prior-knowledge in the relevant science domain. In the present study, we therefore measure prior-knowledge and examine how it relates to task persistence, testing, optimising and solution quality.

Moreover, spatial ability has been found to be strongly associated with the development of expertise in STEM over the course of education (Wai et al., 2009). With respect to engineering, spatial skills have been found to be closely linked to physical object manipulation (such as testing and making changes to constructions) for 9- to 13-year-old children (Ramey and Uttal, 2017). The correlation between spatial skills and engineering is likely to be greater the more the engineering task requires the problem-solver to mentally manipulate information about objects in the environment and the motion of objects (Tõugu et al., 2017). In the present study, the children were given a task in which the rotation of gears had to be considered. Consequently, mental rotation ability could possibly play a role and was therefore assessed.

Furthermore, fluid intelligence is one of the most important prerequisites for learning and closely interrelated with reasoning and problem-solving (Diamond, 2013). To the best of our knowledge, studies on engineering in kindergarten did not control for children's fluid intelligence and how it might relate to persistence, testing, optimising and solution quality.

Present Study

In the present exploratory study, we aim at learning more about how kindergarten children's persistence, testing and optimising in an engineering task is related to children's goal awareness, their self-evaluation of the solution, and their domain-specific content knowledge, spatial skills, and fluid intelligence. As previous studies mostly used more qualitative methods providing fine-granulated insights, we would like to complement these qualitative analyses with a more quantitative approach by measuring and statistically correlating children's persistence, testing and optimising, goal awareness, self-evaluation of the solution, and the objective solution quality to learn more about the interrelations. Additionally, we measure children's content knowledge in the relevant domain, and include mental rotation ability as an indicator of spatial skills as well as figural reasoning as an indicator of fluid intelligence in our analysis. We address the following research questions (RQs):

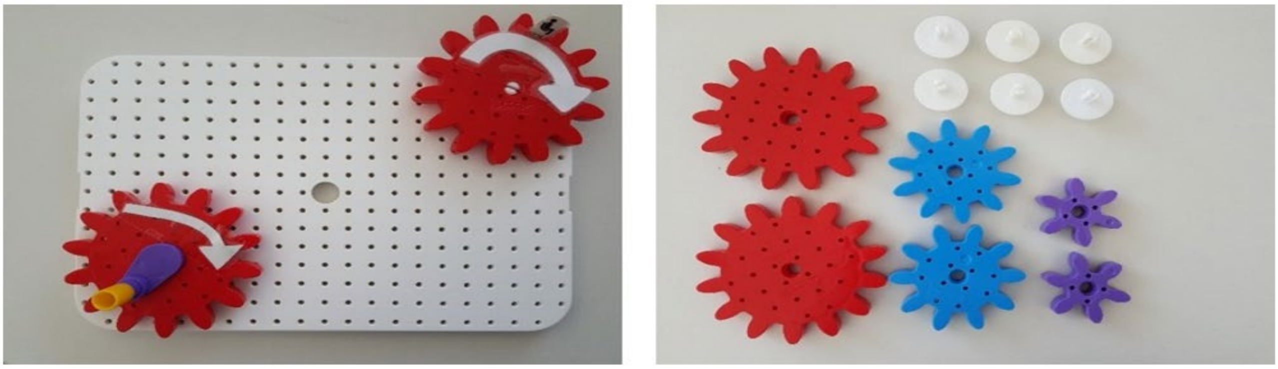

Figure 1. Peg board driving gear and "carousel" | construction materials

1. **RQ-1:** What solution quality do the children achieve? (solution quality)
2. **RQ-2:** Do the children test and optimise? (testing and optimising)
3. **RQ-3:** Are the children aware of the goal? (goal awareness)
4. **RQ-4:** Are the children satisfied with their solution? (self-evaluation)
5. **RQ-5:** Do the children make full use of the given time for engineering? (time-on-task as an indicator of task persistence)
6. **RQ-6:** Do the children want to make a change to their solution when explicitly asked? (willingness to make changes as an indicator of task persistence)
7. **RQ-7:** How are solution quality, testing, optimising, goal awareness, self-evaluation, task persistence, domain-specific content knowledge, spatial skills, and fluid intelligence related?

We expect that the better the children's goal awareness is, the more they will test and optimise, which will correspond with a higher time-on-task, and result in better solution quality. Moreover, we assume a negative correlation between children's self-evaluation and their willingness to make changes to their solution.

METHODS

Participants

Forty-one children (18 girls and 23 boys) participated in the study. We recruited the children by convenience sampling in seven kindergartens in a rural part of Germany. All participants were informed about the goals of the study. The children participated voluntarily and with the written consent of their parents. The convenience sampling yielded the following age distribution: Three children were 4 years old (one child was 51 months, two children were 58 months), 17 children were 5 years old, another 17 children were 6 years old, and two children were 7 years old (82 months and 91 months). The age information is missing for two children. Given the explorative nature of our study, we deliberately decided to allow the wide age range to get as much variance as possible in our data.

Engineering Task

We developed a well-defined engineering design task in the domain of gears. Gears seem to be a suitable domain to study 4- to 7-year-old children's testing and optimising for at least three reasons: (i) Children can easily construct, test and modify gears with age-appropriate (toy) gear-kits. (ii) Gears allow for formulating tasks with clear goals (well-defined problems), e.g., making a target gear spin in a given direction with specified turning direction of a driving gear. Moreover, the children can directly and constantly test the achievement of such a goal by turning the gears and receive immediate feedback by observing the resulting turning direction. (iii) Gears are an elementary component of mechanics and incorporate domain-specific content knowledge. Developmental studies suggest that children differ with respect to their content knowledge about gears' turning direction (Reuter and Leuchter, 2021; Lehrer and Schauble, 1998). Among 4- to 7-year-olds, there are children who know that meshed gears turn in opposite directions, children who have naïve concepts (meshed gears turning in the same direction), and children who have no apparent concepts (Reuter and Leuchter, 2021).

In a one-to-one setting, the children received a plastic peg board (31cm×22cm) with two red plastic gears (approximately 12 cm in diameter with 14 teeth) that were permanently fixed on the board. One gear was on the left-hand side at the front of the peg board and had a crank (driving gear). An arrow pointing to the right was glued on the driving gear. The other gear was on the right-hand side further back on the peg board. This gear also had an arrow on it pointing to the right. Additionally, a sitting stick figure made of paper looking in the direction of the arrow was placed at the gear (see **Figure 1**).

The interviewer told the children that this gear was a 'carousel' with a person on it. Then, the interviewer instructed the children that the 'carousel' should turn forward, i.e., in the direction of the arrow (specification 1) when the driving gear is turned in the direction of the arrow (specification 2). As constructional materials, the children received two red gears that were the same size as the driving gear and carousel (large gear), two medium-sized blue gears (approximately 9cm in diameter with ten teeth), two small purple gears (approximately 6 cm in diameter with six teeth) and six plugs (see **Figure 1**). The peg board had prefabricated holes that allowed one to easily mount the gears with a plug. The interviewer pointed out to the children that she or he could use all of the materials, but they did not have to do so. It was possible to connect the driving gear with the carousel using two gears (e.g., the two large red ones). The intended difficulty for the children was to realize that this straightforward (and maybe the most obvious) solution would result in the wrong turning direction of the carousel; thus, it would not meet specification 1. The task can be characterized as a well-defined engineering task since it had a clear goal state, i.e., clearly defined specifications (turning direction of the carousel with a given turning direction of the driving gear); it demanded goal-oriented thinking under constraints (the driving gear and carousel were fixed, and the construction materials and space were restricted); and it allowed for more than one possible solution (e.g., connecting driving gear and carousel with three or with five gears, and there were different possible arrangements of the gears).

Test Procedure

The engineering design task was conducted in one-to-one situations in a quiet room in the children's kindergartens. The interviewer and the child were sitting side by side at a table or on the floor. It was carried out using a standardized procedure, consisting of three or four steps: (i) introduction, (ii) engineering trial 1, (iii) assessment of task persistence, goal awareness and probing for children's self-evaluation of their solution and, if applicable (iv) engineering trial 2. **Table 1** describes the procedure of the engineering task in detail. The complete procedure was videotaped.

Table 1. Procedure of the engineering task

	Step	Interviewer does …	Interviewer says …
Introduction	1	Places an empty peg board, two yellow large size gears, two blue medium-sized gears, two purple small size gears, and plugs on the table.	Today, you can play with gears. Here, you have various gears. Now you get to test how to put the gears on the peg board.
	2	Removes the mounted gears from the peg board.	Okay, now you know how it works!
	3	Places the peg board with the fixed driving gear and fixed "carousel" on the table.	
	4	Points to the driving gear.	Look, here is a gear with a crank. You can turn it.
	5	Points at the "carousel" gear.	The gear here is a carousel. You see, there is a person sitting on it.
	6	(i) turns the carousel in the direction of the arrow with his finger, and (ii) turns the driving gear in the direction of the arrow with his finger	*Introducing the well-defined problem:* Now, your task is this: (i) The carousel should rotate in the direction of the arrow so that the person on the carousel moves forward (ii) when you turn the crank in the direction of the arrow. Turn the crank in the direction of the arrow! That's right, you can turn this way. Then, the person should move forward on the carousel. Turn the carousel forward! Okay, that's how the carousel should go. You can use all the gears and plugs for building - but you do not have to. Do you understand the task? Do you have any questions? Since more children are supposed to get their turn with this game today, I have to look at the clock. When the time is up, I will tell you and we will look at what you have built. If you have a product before then, you let me know. Okay, start now!
Trial 1	7	Stops the time (max. 3 minutes)	

Table 1 (Continued).

	Step	Interviewer does …	Interviewer says …
Assessment	8		*Exploring task persistence:* [If child finishes before the three minutes are up]: Okay, you have a product you want to show me yet? I'll look in a minute. [If the three minutes are up]: Okay, I'm afraid the time is up. I can't wait to see what you've built!
	9		*Probing goal awareness:* Before we look at your construction, tell me again: What was the task? [If the child did not provide a complete description of the task, the interviewer probed for the missing specifications]: E.g., What direction should the carousel turn?
	10		*Probing self-evaluation:* Are you satisfied with your solution?
	11		*Probing task persistence:* Do you want to change something? [If yes]: Okay, then you can build again!
Trial 1	12	Stops the time (max. 2 minutes)	
	13		Okay, you did a good job! Now we're done for today.

Table 2. Scoring solution quality

Score		Description
3 points	Complete, adequate prototype	Driving gear and carousel are connected with an *odd* number of gears
2 points	Complete, inadequate prototype	Driving gear and carousel are connected with an *even* number of gears
1 point	Incomplete prototype	Gears have been built on the driving gear and/or the carousel, but driving gear and carousel are not connected
0 points	No prototype	Neither driving gear nor carousel are meshed with another gear

Note. When a child builds a complete prototype but then makes an alteration making it incomplete again at the 3 minutes mark of trial 1 (or 2 minutes mark of trial 2), it would be coded as an incomplete prototype.

Coding Scheme for the Engineering Design Task

To analyse the children's testing and optimising, we developed a coding scheme in a two-step process. First, all categories of the coding scheme were derived in a top-down approach. We therefore adapted parts of the *Metacognitive Skills in Constructional Play Engagement (MetaSCoPE)* coding scheme (Spektor-Levy et al., 2017). Second, two raters independently tested the coding scheme with 20 videos. To obtain interrater agreement, we calculated Cohen's kappa (Cohen, 1960). In an iterative process, the coding scheme was revised in a bottom-up procedure, uncertainties were discussed by the raters and decision criteria were clarified. The final coding scheme comprised a code to rate the solution quality, four dichotomous codes indicating children's testing and optimising, and two codes to record the children's goal awareness.

Solution quality

We rated the quality of the prototype the children had built with a score ranging from 0 to 3 points (see **Table 2**) after trial 1 and, if applicable, after trail 2. Rater agreement was substantial with Cohen's kappa=.767. However, given the clear coding scheme, this appears to be a rather low agreement. In some cases, it was not clear from the videos whether two (or more) gears were meshing or not. We decided for these cases to always code as if the gears were meshing (i.e., to give the higher score).

Testing and optimising

We coded indications of testing and optimising for trial 1 and, if applicable, for trial 2. To account for the findings of Bairaktarova et al. (2011) and Strimel et al. (2018a), we distinguished between children's testing of incomplete prototypes (e.g., turning two meshed gears) and of complete prototypes (turning the driving gear to move the carousel) during the trial. Following the same logic, we distinguished between changes children made to incomplete and to complete prototypes during the trial. Cohen's kappa was .614; thus, according to Landis and Koch (1977), rater agreement can be regarded as substantial.

Table 3. Correlations

		1	2	3	4	5	6	7	8	9
1	solution quality[a]									
2	testing[b]	**.713**								
3	optimising[b]	**.459**	**.681**							
4	goal awareness[c]	**.316**	.140	**.444**						
5	self-evaluation[b]	.180	-.167	-.356	-.007					
6	task persistence (time-on-task)[b]	-.009	**.453**	**.479**	-.078	**-.573**				
7	task persistence (willingness to make changes)[b]	-.218	.032	.229	-.037	**-.677**	.004			
8	content knowledge gears' turning direction[a]	.034	-.056	.039	.290	-.362	-.099	.168		
9	mental rotation ability[a]	**.336**	.238	.233	.103	-.227	-.221	.186	-.069	
10	figural reasoning ability[c]	.131	-.056	.210	.015	.033	-.168	.267	-.005	**.374**

Note. [a]Interval, normally distributed; [b]Cntinuous dichotomy; [c]Interval, non-normally distributed; Significant correlations ($p<.05$) are highlighted in bold.

Goal awareness

We recorded and coded whether the children were able to name specification 1 (the carousel should turn in the direction of the arrow) without the help of the interviewer, with help or not at all. We did the same for specification 2 (the driving gear has to be turned in the direction of the arrow). The final rater agreement was substantial with Cohen's kappa=.754. We calculated a score to quantify children's goal awareness. For each of the two specifications, the children received 2 points if they provided the correct answer on their own, 1 point if they provided the correct answer after the probing of the interviewer, and 0 points if they did not give a correct answer even after probing. Thus, the score ranged from 0 to 4 points.

Testing Domain-Specific Knowledge, Spatial Skills and Figural Reasoning

We tested children's domain-specific conceptual knowledge of gears' turning direction in a standardized one-to-one interview (gear-interview). The children were shown eight different gear configurations (items) built with physical gears. Each item consisted of a driving gear with an arrow indicating the turning direction that was meshed with one or more other gears (target gears). The children had to predict the turning direction of the target gears. All gears were fixed, that is, they could not rotate. This meant that the children could not learn during the test. Moreover, there was no teaching on gear functioning before. For a detailed description of the procedure see Authors. The internal consistency was high with α_{KD20}=.912. The children could achieve a maximum score of 26 points.

We assessed mental rotation ability with the *Picture Rotation Test (PRT)* (Quaiser-Pohl, 2003) as an indicator for spatial skills. Children were presented with coloured three-dimensional target images of people (e.g., an ice-skater) and animals (e.g., a tiger) as well as three comparison images. Two of them were mirrored and rotated and one was only rotated. The children had to identify the rotated image of the target image. The maximum score was 16 points.

As an indicator of fluid intelligence, we measured figural reasoning with the matrices subtest from the *Culture Fair Test (CFT)* (Weiß and Osterland, 2013). The children could reach a maximum score of 15 points. All tests were conducted about one week before the engineering task to ensure adequate testing time and cognitive loads for the age group.

Correlational Analysis

For the correlational analysis, we considered the different measurement levels of the variables and whether the data were distributed normally or not (c.f. Field, 2011; see **Table 3**). We calculated Pearson's correlation coefficient r for pairs of variables that were normally distributed at the interval level. We calculated Spearman's correlation coefficient ϱ for pairs of variables with one or both variables non-normally distributed at the interval level. We calculated the biserial correlation coefficient r_b for pairs of variables where one of the variables was measured dichotomously but had an underlying continuum, and the other variable was normally distributed at the interval level. In cases of non-normally distributed data of the interval level variable, we calculated the biserial correlation coefficient based on Spearman's correlation coefficient ϱ. We calculated the tetrachoric correlation coefficient r_{tet} for pairs of dichotomously measured continuous variables.

RESULTS

Mean Values and Proportions

RQ 1: Solution quality

The mean quality of children's solutions in trial 1 was 1.61 (SD=1.02, range=0-3). Nine children built a complete and adequate prototype, 14 children a complete but inadequate prototype. Eleven children had an incomplete prototype at the end of trial 1 (max. 3 minutes), and seven children had no prototype. For the subsample of the children who did trial 2 (n=23), the mean score slightly increased from 1.48 (SD=0.95) after trial 1 to 1.70 (SD=0.88) after trial 2. However, the mean scores of trial 1 and trial 2 did not differ significantly, t(22)=-1.417, p=.171, as a paired sample t-test revealed. Thus, only trial 1 will be considered in the further analyses.

RQ 2: Testing and optimising

We first analysed children's testing and optimising regardless of the completeness of the prototype. Thirty children tested at least once. Twenty-six children made at least one change. To examine whether children's testing behaviour differed for incomplete and complete prototypes, we restricted our analysis to children who finished trial 1 with a complete prototype (n=23). Sixteen of them tested the functioning of both incomplete and complete prototypes. Four of them tested the functioning of complete prototypes only, and one child the functioning of incomplete prototypes only. Two of them did not test at all. To examine whether children's optimising behaviour differed for incomplete and complete prototypes, we restricted our analysis to children who finished trial 1 with a complete, but inadequate prototype (n=14). Six of them made changes to both incomplete and complete prototypes, another six children made at least one change to an incomplete, but not to a complete prototype, and two of them did not make any changes.

RQ 3: Goal awareness

The mean score for goal awareness was 2.24 (SD=1.07, range=0-4). Five children (12%) provided a complete and correct description of both specifications on their own. 27 children (66%) provided an incomplete description of the task and did not mention the turning direction. However, with probing of the interviewer, they were able to give the complete description. Thus, there were a total of 32 children (78%) who could correctly name both specifications. The remaining nine children (22%) provided incomplete or no description of one or of both specifications, despite the interviewer's probing.

RQ 4: Self-evaluation

When asked by the interviewer, 31 children (75%) said that they were satisfied with their solution in trial 1.

RQ 5 and RQ 6: Task persistence

Sixteen children (39%) made full use of the time allowed at trial 1 and thus were interrupted by the interviewer after 3 minutes of engineering. Correspondingly, the other 25 children (61%) presented a solution to the interviewer before the 3 minutes were over. Their mean time-on-task was 114 seconds (SD=41.8). When asked by the interviewer, 23 children (56%) opted to make changes to their solution. Hence, these 23 children did trial 2. Nine of these children made full use of the two minutes that were allowed in trial 2. The other 14 children finished before the two minutes were over with a mean time-on-task of 76 seconds (SD=32.8). The mean time-on-task for the children who did trial 1 only was 134 seconds (SD=51.2), and it was 237 seconds (SD=58.4) for the children who did both trial 1 and trial 2.

Correlational Analyses

RQ 7: correlations

The solution quality was positively related to testing, to optimising, to goal awareness and to children's mental rotation ability. Testing was positively related to optimising, and to time-on-task. Optimising was positively related to goal awareness and to time-on-task. The children's self-evaluation of their solution was negatively related to time-on-task. Moreover, self-evaluation was negatively related to the children's willingness to make a change to their solution. Mental rotation ability (M=9.78, SD=4.11) was positively correlated with figural reasoning ability (M=4.29, SD=2.72). Domain-specific content knowledge on gears' turning direction (M=11.49, SD=5.64) did not significantly correlate with any of the other variables. **Table 3** gives an overview of the correlation matrix.

Table 4. Association between solution quality and testing and optimizing, goal awareness, self-evaluation, task persistence, and content knowledge

Solution quality after trial 1	Trial 1: Number of children who …										
				… were aware of the goal					Content knowledge gears' turning direction		
		… tested at least once	… optimised at least once	Total[1]	without probing	… were satisfied with the solution (self-evaluation)	… made full use of the 3 minutes (task persistence)	… wanted to make changes when asked after trial 1 (task persistence)	… had a correct concept of gears' turning direction	… had an incorrect concept of gears' turning direction	… had no apparent concept of gears' turning direction
	n	(n=30)	(n=26)	(n=32)	(n=5)	(n=31)	(n=16)	(n=23)	(n=9)	(n=14)	(n=18)
3 pts.	9	9	6	8	(3)	9	2	4	3	3	3
2 pts.	14	12	12	12	(2)	9	7	6	4	6	4
1 pt.	11	7	7	7	(0)	7	6	10	2	3	6
0 pt.	7	2	1	5	(0)	6	1	3	0	2	5

Note. 3 pts.: Complete, adequate prototype; 2 pts.: Complete, inadequate prototype; 1 pt.: Incomplete prototype; 0 pt.: No prototype; 1 number of children who named both specifications with or without probing of interviewer.

Our next analysis is concerned with the association between solution quality and all other variables (**Table 4**). However, with respect to content knowledge, the mean value does not adequately represent the concepts. Thus, we categorize the children as either having the correct concept (meshed gears turn in opposite directions), an incorrect concept (meshed gears turn in the same direction), or no apparent concept by using the binomial distribution (P26;1/2 [X=17]=8.43%, meaning that 17 out of 26 consistent responses have 8.43% probability of occurring by chance, i.e., by guessing). Children with at least 17 out of 26 correct predictions in the gear interview were considered as having the correct concept (n=9). Children with at least 17 out of 26 incorrect predictions were considered as having the incorrect concept (n=14). Children without a consistent answer pattern were considered as guessing, thus having no apparent concept (n=18).

Due to the small sample size, Fisher-Freeman-Halton's exact test was used to determine if there was a significant association between solution quality and the respective variable (Bortz and Lienert, 2008). In the case of a significant association, we performed post-hoc pairwise comparisons with Bonferroni corrected significance level of $p<.008$. There was a statistically significant association between solution quality and testing, $\chi^2=10.942$, $p=.006$. The higher the solution quality, the higher the proportion of children who tested at least once. Pairwise comparisons revealed that children with a complete and adequate prototype (3 points) differed significantly (Fisher's exact test, $p=.005$) from children with no prototype (0 points) in their testing behaviour (9/9 vs. 2/7). Furthermore, there was a statistically significant association between solution quality and optimising, $\chi^2=9.776$, $p=.016$. Pairwise comparisons revealed that children with a complete, but inadequate prototype (2 points) differed significantly (Fisher's exact test, $p=.003$) from children with no prototype (0 points) in their optimising behaviour (12/14 vs. 1/7). There was no statistically significant association between solution quality and any of the other variables (all $p>.05$).

However, on a descriptive level, there was a U-shaped association between solution quality and self-evaluation: For both 3 points and 0 points, the proportion of children who were satisfied with their constructions was high (9/9 and 6/7), whereas for both 2 points and 1 point the proportion was comparably low (9/14 and 7/11). Likewise, on a descriptive level, an inverted U-shaped association could be observed between solution quality and task persistence: For both 3 points and 0 points, the proportion of children making full use of the three minutes was rather low (2/9 and 1/7), whereas for both 2 points and 1 point the proportion was comparably high (7/14 and 6/11). Furthermore, 10 out of 11 children with 1 point in solution quality wanted to make a change to their construction when asked by the interviewer after trial 1. For all other children, this proportion was lower with 43 %.

With respect to children's content knowledge of gears' turning direction, descriptive data show on the one hand: The better the solution quality, the greater the proportion of children with the correct concept. On the other hand, the data also show: Among the children with an adequate prototype (3 points), 3 out of 9 had the correct concept of gears' turning direction. Another 3 achieved the 3 points with an incorrect concept, and the remaining 3 children without an apparent concept.

DISCUSSION

In our exploratory study, we attempted to learn more about kindergarten children's persistence, testing and optimising in an engineering task and how these behaviours are related to children's goal awareness, their self-evaluation of the solution, their domain-specific content knowledge, spatial skills, and fluid intelligence. Therefore, we had 4- to 7-year-old children work on a well-defined engineering task with more than one possible correct solution in the domain of gears. We rated the solution quality (RQ-1); observed the children's engineering behaviour for incidences of testing and optimising (RQ-2); and measured goal awareness (RQ-3), self-evaluation of the solution (RQ-4), and task persistence (RQ-5 and RQ-6). Moreover, we included the children's domain-specific content knowledge, mental rotation ability and figural reasoning ability and explored how all aspects were related to each other (RQ-7). The discussion section aims at integrating the results of the research questions and attempts to draw a coherent picture of the findings.

Testing, Optimising and Task Persistence

The majority of the children showed at least one indication of testing and optimising in the course of the engineering trial. As expected, both testing and optimising did correspond with a higher time-on-task and with increased solution quality. These findings are in line with studies showing that experts achieve better solutions than novices by going through more design iterations (Atman et al., 2007; Strimel et al., 2018b). Thirty-nine percent of the children made full use of the 3 minutes. Other than expected, there was no significant linear correlation between time-on-task and solution quality. Descriptive data showed that children who succeeded to build an adequate prototype did not necessarily make full use of the time. This indicates that the task was easy enough for these children. Moreover, children who did not succeed in the task at all did not make full use of the time as well. This might be an indicator that the task was not sufficiently interesting for these children (Crismond, 2001) or that they did not succeed in inhibiting other stimuli (Miyake et al., 2000). Approximately 50% of the children opted to make changes to their solution when explicitly asked by the interviewer. There was no significant correlation between willingness to make changes and solution quality. Moreover, as descriptive data showed, the proportion of children who wanted to make a change to their construction was highest among those with an incomplete prototype, whereas the proportion was low for children with a complete, but inadequate prototype. These findings suggest that children's testing and optimising mainly aims at the completion of one single construction rather than at constructing and evaluating different prototypes, which is in line with other studies (Bairaktarova et al., 2011; Strimel et al., 2018a). Interestingly, a substantial proportion of the children (43%) who built a correct prototype wanted to continue building and making changes. We cannot say from our data whether this reflects what Lucas et al. (2014) calls the engineering habit of mind of relentlessly trying to make things work better, or if the children just enjoyed building with the gears without pursuing such a goal.

We examined various aspects that might be related to children's persistence and their testing and optimising behaviour. We will discuss them in the following sections.

Goal awareness

As shown in a study by Kendall (2015), children had difficulties in recalling the two specifications on their own. Indeed, the majority of the children stated independently from the interviewer that the carousel should rotate when they turn the crank, but they specified the turning direction only when explicitly asked for. This suggests that when children were introduced to the task, they built an accurate mental representation of the goal state (Kintsch, 2007), but they might have 'simplified' this goal representation during the course of the 3-minute engineering phase (Karmiloff-Smith, 1979). Even after the probing of the interviewer, one out of five children did not provide a complete description of how the construction was supposed to work. These children may have built an incomplete initial mental model of the goal state, or may have difficulties in maintaining an adequate representation of the goal even with well-defined problems. This difficulty may be related to the limited capacity of working memory in 4- to 7-year-old children (Diamond, 2013). Future studies should therefore examine the role of working memory and other executive functions for engineering in early childhood, e.g., using the *EF touch battery* (Willoughby et al., 2013). As expected, goal awareness was positively related to solution quality and optimising. Other than expected, we found no significant correlation between goal awareness and testing. This lack of correlation can be interpreted as children having tested regardless of a correct and complete goal representation.

Self-evaluation

Overall, the majority of the children were satisfied with their solution. Moreover, as expected, the children who were satisfied with their solution were less willing to make changes to their prototype when asked by the interviewer. However, there was no significant linear correlation between self-evaluation and solution quality.

Descriptive data rather showed indications of a u-shaped relation: both the children who built an adequate prototype and the children who finished trial 1 with constructions showing no evidence of a prototype were satisfied. In contrast, the proportion of satisfied children was lower among those who built an incomplete prototype or a complete but inadequate prototype. These findings are partly in line with research showing that self-evaluations of 4- to 7-year-olds might be unrealistically positive (Harter and Bukowski, 2015; Marsh et al., 2012; Oppermann et al., 2018). This bias in self-evaluation could be one reason why kindergarten children use little or no iterative approach when working on an engineering design task (Gold et al., 2020; Strimel et al., 2018a). However, as indicated by findings of Kendall (2015) and Lottero-Perdue and Tomayko (2020), children are willing to improve their solutions if the requirements are made clear to them and if they are instructed to test their solutions. In this respect, a methodological shortcoming of our study is the interviewer's question *"Are you satisfied with your solution?",* which might be too general. If the question was put in relation to the demanded task specifications (e.g., *"Does your carousel turn in the demanded direction?"* or *"Compare your solution to the demanded requirements."*), the children might be able to evaluate their solution in depth. However, since we stated the requirements a few seconds before, when probing for children's goal awareness, we assume that it was possible for the children to relate our question to the task specifications. Nevertheless, a future study could examine whether children come to a more realistic assessment if they are given an explicit criterion for evaluation (Crismond, 2001; Lottero-Perdue and Tomayko, 2020).

Domain-specific content knowledge

We found no significant correlations of domain-specific content knowledge with the other variables in our data. This result indicates that it was possible for the children to test and optimise and to succeed in building an adequate prototype, even without specific knowledge of meshed gears' turning directions. As can be seen in the descriptive data, among the children with the correct solution, one third of them had a correct, an incorrect or no apparent concept of gears' turning direction respectively. However, as Lottero-Perdue and Tomayko (2020) also note in their study, task characteristics might have elicited this result. In our study, it obviously was possible to solve the task in a short time. Exploring the gears and observing their behaviour thoroughly might have been sufficient to succeed. An indication of the relevance of this interpretation can be found in Schulz et al.'s (2007) findings that children are able to produce evidence to infer causal structures of a mechanism by thorough testing. However, the descriptive data also show that the better the solution, the greater the proportion of children with the correct concept on gears' turning direction. This is in line with studies indicating that prior-knowledge in the relevant science domain can contribute to better engineering processes and outcomes (Benjamin et al., 2010; Marcus et al., 2021). Future studies should therefore try to differentiate whether successful solutions are achieved through trial and error procedures or through the application of content knowledge. Moreover, upcoming research might investigate and compare kindergarten children's engineering behaviour in different science domains, e.g., the stability of block buildings (Weber et al., 2020), one-sided levers as simple machines (Leuchter and Naber, 2018), floating of objects (Hong and Diamond, 2012), and pursue two directions: (1) Studies should examine for different science domains whether kindergarten children can learn domain-specific content knowledge by being exposed to engineering design tasks (Lin et al., 2020; Penner et al., 1997). (2) Studies might compare children who received a training in the relevant domain-specific knowledge beforehand with children who did not receive a training (Benjamin et al., 2010; Marcus et al., 2021). This will provide insights into children's failure analysis and the role of domain-specific content knowledge for optimising.

Spatial skills and fluid intelligence

Mental rotation ability did positively correlate to figural reasoning ability. Moreover, mental rotation ability was positively related to solution quality, indicating that children with better spatial skills achieved better solutions. This is in line with research suggesting spatial skills to be positively related with success in STEM (Wai et al., 2009). However, our study showed no significant correlation between spatial skills and testing and optimising. This is in contrast to findings from observations with older children (Ramey and Uttal, 2017). Furthermore, figural reasoning was not significantly related to any of the other variables. These findings indicate that children can engage with the engineering design process from an early age regardless of their spatial skills and their fluid intelligence, which is in line with observational studies of young children's engineering behaviour (for an overview, see Gold et al., 2020).

Our results highlight some practical implications. With respect to engineering intervention programs for kindergarten children, our findings emphasize the important role of teachers. They should learn techniques that help children to tackle challenges they might face with respect to persisting, testing and optimising, such as asking the children whether they remember the goal, helping them to retrieve the goal specifications, stating that nobody succeeds in the first attempt, and motivating them to remain on track (Lottero-Perdue and Tomayko, 2020).

Limitations

First, in the present study, the test power was limited; thus, we might not have discovered relations in our sample that exist in the population. A larger sample size would also allow us to apply path models to describe the directed dependencies among the variables. Moreover, with a larger sample size it might be worthwhile to examine whether there are (latent) "engineering profiles" among young children, e.g., children that stand out by their talent for thinking up creative solutions, whereas others are better at a critical evaluation, testing and optimisation of a solution. Second, we used only one engineering task in one domain (gears) with one aspect (turning direction). Future studies could use problems on the relative turning speed of gears. Third, we interpreted children's goal awareness, self-evaluation, and task persistence from our observations of the problem-solving process and from the children's answers to the interviewer's questions. This procedure seems to be appropriate as a first step in order to obtain an impression of which aspects might be relevant for children's testing and optimising behaviour. However, future studies should use standardized and validated test instruments to assess children's executive functioning, self-evaluation, and general task persistence. Fourth, the procedure we used in the present study did not allow us to measure competencies developed or demonstrated in group settings, which are important both in school settings and engineering practice, where communication and teamwork are essential (Lucas et al., 2014). Future studies might therefore use group settings as well.

However, to date, not many studies have been conducted in this area and with this age group. Therefore, we assume that the knowledge gained from our exploratory study is worthwhile. We have given the children a well-defined problem, conducted and videotaped the problem-solving process in a standardized way, developed a coding scheme to analyse children's testing and optimising and examined control variables. Thus, we were able to relate persistence and testing and optimising to solution quality and to the control variables. With our study, we have contributed to the development of further studies to investigate young children's EDP competencies as a relevant part of early STEM learning.

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REFERENCES

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S. and Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education*, 96(4), 359-379. https://doi.org/10.1002/j.2168-9830.2007.tb00945.x

Bairaktarova, D., Evangelou, D., Bagiati, A. and Brophy, S. P. (2011). Early engineering in young children's exploratory play with tangible materials. *Children, Youth and Environments*, 21(2), 212-235.

Benjamin, N., Haden, C. A. and Wilkerson, E. (2010). Enhancing building, conversation, and learning through caregiver-child interactions in a children's museum. *Developmental Psychology,* 46(2), 502-515. https://doi.org/10.1037/a0017822

Bortz, J. and Lienert, G. A. (2008). *Kurzgefasste Statistik für die klinische Forschung: Leitfaden für die verteilungsfreie Analyse kleiner Stichproben* [Condensed statistics for clinical research: Guide to nonparametric analysis of small samples]. Berlin, Heidelberg: Springer Berlin Heidelberg.

Bustamante, A., Greenfield, D. and Nayfeld, I. (2018). Early childhood science and engineering: Engaging platforms for fostering domain-general learning skills. *Education Sciences*, 8(3), 144. https://doi.org/10.3390/educsci8030144

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, 20, 37-46. https://doi.org/10.1177/001316446002000104

Crismond, D. P. (2001). Learning and using science ideas when doing investigate-and-redesign tasks: A study of naive, novice, and expert designers doing constrained and scaffolded design work. *Journal of Research in Science Teaching*, 38(7), 791-820. https://doi.org/10.1002/tea.1032

Crismond, D. P. and Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, 101(4), 738-797. https://doi.org/10.1002/j.2168-9830.2012.tb01127.x

Cross, N. (2008). *Engineering design methods: Strategies for product design*. New York, NY: Wiley. http://www.loc.gov/catdir/enhancements/fy0810/2008002727-d.html

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135-168. https://doi.org/10.1146/annurev-psych-113011-143750

Dörner, D. and Funke, J. (2017). Complex problem solving: What it is and what it is not. *Frontiers in Psychology*, 8, 1153. https://doi.org/10.3389/fpsyg.2017.01153

Ehsan, H., Rehmat, A. P. and Cardella, M. E. (2021). Computational thinking embedded in engineering design: Capturing computational thinking of children in an informal engineering design activity. *International Journal of Technology and Design Education,* 31(3), 441-464. https://doi.org/10.1007/s10798-020-09562-5

Field, A. (2011). *Discovering statistics using SPSS: (and sex and drugs and rock 'n' roll)*. SAGE.

Gold, Z. S., Elicker, J., Kellerman, A. M., Christ, S., Mishra, A. A. and Howe, N. (2020). Engineering play, mathematics, and spatial skills in children with and without disabilities. *Early Education and Development*, 38(2), 1-17. https://doi.org/10.1080/10409289.2019.1709382

Haluschak, E., Stevens, M., Moore, T., Tank, K., Cardella, M., Hynes, M., Gajdzik, E. and Lopez-Parra, R. (2018). Initial problem scoping in K-2 classrooms (fundamental) [Paper presentation]. *2018 ASEE Annual Conference & Exposition*. Salt Lake City, UT. https://doi.org/10.18260/1-2--30663

Harter, S. and Bukowski, W. M. (2015). *The construction of the self: Developmental and sociocultural foundations*. Guilford Press.

Hong, S. - Y. and Diamond, K. E. (2012). Two approaches to teaching young children science concepts, vocabulary, and scientific problem-solving skills. *Early Childhood Research Quarterly*, 27(2), 295-305. https://doi.org/10.1016/j.ecresq.2011.09.006

John, M. - S., Sibuma, B., Wunnava, S., Anggoro, F. and Dubosarsky, M. (2018). An iterative participatory approach to developing an early childhood problem-based STEM curriculum. *European Journal of STEM Education*, 3(3). https://doi.org/10.20897/ejsteme/3867

Kaderavek, J. N., Paprzycki, P., Czerniak, C. M., Hapgood, S., Mentzer, G., Molitor, S. and Mendenhall, R. (2020). Longitudinal impact of early childhood science instruction on 5th grade science achievement. *International Journal of Science Education*, 42(7), 1124-1143. https://doi.org/10.1080/09500693.2020.1749908

Karmiloff-Smith, A. (1979). Problem-solving procedures and children's construction and representations of closed railway circuits. *Archives of Psychology,* XLVII, 37-59.

Kendall, A. (2015). Evaluate-and-redesign tasks: Using interviews to investigate how elementary students iterate (fundamentals), in *122nd ASEE Annual Conference & Exposition*, Seattle, Washington. https://doi.org/10.18260/p.24025

Kintsch, W. (2007). *Comprehension: A paradigm for cognition*. Cambridge University Press.

Landis, J. R. and Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33, 159-174. https://doi.org/10.2307/2529310

Lehrer, R. and Schauble, L. (1998). Reasoning about structure and function: Children's conceptions of gears. *Journal of Research in Science Teaching*, 35(1), 3-25. https://doi.org/10.1002/(SICI)1098-2736(199801)35:1<3::AID-TEA2>3.0.CO;2-X

Leuchter, M. and Naber, B. (2018). Studying children's knowledge base of one-sided levers as force amplifiers. *Journal of Research in Science Teaching*, 33(10), 1099. https://doi.org/10.1002/tea.21470

Lin, X., Yang, W., Wu, L., Zhu, L., Wu, D. and Li, H. (2020). Using an inquiry-based science and engineering program to promote science knowledge, problem-solving skills and approaches to learning in preschool children. *Early Education and Development*, 32(5), 1-19. https://doi.org/10.1080/10409289.2020.1795333

Lottero-Perdue, P. S. and Tomayko, M. (2020). Kindergartners' engagement in an epistemic practice of engineering: Persisting and learning from failure [Paper presentation]. *The ASEE's Virtual Conference 2020.* https://doi.org/10.18260/1-2--34892

Lucas, B., Hanson, J. and Claxton, G. (2014). *Thinking like an engineer: Implications for the education system*. Royal Academy of Engineering.

Marcus, M., Tõugu, P., Haden, C. A. and Uttal, D. H. (2021). Advancing opportunities for children's informal STEM learning transfer through parent-child narrative reflection. *Child Development,* 92(5), e1075-e1084. https://doi.org/10.1111/cdev.13641

Marsh, H. W., Xu, M. and Martin, A. J. (2012). Self-concept: A synergy of theory, method, and application. In K. R. Harris, S. Graham and T. C. Urdan (eds.), *APA educational psychology handbook* (pp. 427-458). American Psychological Association. https://doi.org/10.1037/13273-015

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A. and Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, 41(1), 49-100. https://doi.org/10.1006/cogp.1999.0734

NRC. (2013). *Next generation science standards*. National Academies Press. https://doi.org/10.17226/18290

OECD. (2018). *Early learning matters: The international early learning and child well-being study.* https://www.oecd.org/education/school/Early-Learning-Matters-Project-Brochure.pdf

Oppermann, E., Brunner, M., Eccles, J. S. and Anders, Y. (2018). Uncovering young children's motivational beliefs about learning science. *Journal of Research in Science Teaching*, 55(3), 399-421. https://doi.org/10.1002/tea.21424

Pagano, L. C., Haden, C. A., Uttal, D. H. and Cohen, T. (2019). Conversational reflections about tinkering experiences in a children's museum. *Science Education,* 103(6), 1493-1512. https://doi.org/10.1002/sce.21536

Penner, D. E., Giles, N. D., Lehrer, R. and Schauble, L. (1997). Building functional models: Designing an elbow. *Journal of Research in Science Teaching*, 34(2), 125-143. https://doi.org/10.1002/(SICI)1098-2736(199702)34:2<125::AID-TEA3>3.0.CO;2-V

Petroski, H. (1992). *To engineer is human: the role of failure in successful design*. Vintage.

Pleasants, J. and Olson, J. K. (2019). What is engineering? Elaborating the nature of engineering for K-12 education. *Science Education*, 103(1), 145-166. https://doi.org/10.1002/sce.21483

Quaiser-Pohl, C. (2003). The mental cutting test "Schnitte" and the picture rotation test-two new measures to assess spatial ability. *International Journal of Testing*, 3(3), 219-231. https://doi.org/10.1207/S15327574IJT0303_2

Ramey, K. E. and Uttal, D. H. (2017). Making sense of space: Distributed spatial sensemaking in a middle school summer engineering camp. *Journal of the Learning Sciences,* 26(2), 277-319. https://doi.org/10.1080/10508406.2016.1277226

Reuter, T. and Leuchter, M. (2021). Children's concepts of gears and their promotion through play. *Journal of Research in Science Teaching*, 58(1), 69–94. https://doi.org/10.1002/tea.21647

Schauble, L., Klopfer, L. E. and Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching,* 28(9), 859-882. https://doi.org/10.1002/tea.3660280910

Schulz, L. E., Gopnik, A. and Glymour, C. (2007). Preschool children learn about causal structure from conditional interventions. *Developmental Science,* 10(3), 322-332. https://doi.org/10.1111/j.1467-7687.2007.00587.x

Spektor-Levy, O., Basilio, M., Zachariou, A. and Whitebread, D. (2017). Young children's spontaneous manifestation of self-regulation and metacognition. *Teachers College Record*, 119(13). https://doi.org/10.1177/016146811711901314

Strimel, G. J., Bartholomew, S. R., Kim, E. and Zhang, L. (2018). An investigation of engineering design cognition and achievement in primary school. *Journal for STEM Education Research*, 87(2), 121. https://doi.org/10.1007/s41979-018-0008-0

Strimel, G. J., Kim, E., Bartholomew, S. R. and Cantu, D. V. (2018). Examining engineering design cognition with respect to student experience and performance. *International Journal of Engineering Education*, 34(6), 1910-1929.

Tõugu, P., Marcus, M., Haden, C. A. and Uttal, D. H. (2017). Connecting play experiences and engineering learning in a children's museum. *Journal of Applied Developmental Psychology,* 53, 10-19. https://doi.org/10.1016/j.appdev.2017.09.001

Wai, J., Lubinski, D. and Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, 101(4), 817-835. https://doi.org/10.1037/a0016127

Weber, A. M., Reuter, T. and Leuchter, M. (2020). The impact of a construction play on 5- to 6-year-old children's reasoning about stability. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2020.01737

Weiß, R. H. and Osterland, J. (2013). *CFT 1-R*. Hogrefe.

Willoughby, M. T., Pek, J. and Blair, C. B. (2013). Measuring executive function in early childhood: A focus on maximal reliability and the derivation of short forms. *Psychological Assessment*, 25(2), 664-670. https://doi.org/10.1037/a0031747

Zimmerman, C. and Klahr, D. (2018). *Development of scientific thinking*. In J. T. Wixted and S. Ghetti (eds), *Stevens' handbook of experimental psychology and cognitive neuroscience, developmental and social psychology* (pp. 223-247). Newark: John Wiley & Sons, Inc. https://doi.org/10.1002/9781119170174.epcn407

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The Influence of Error Learning Orientation on Intrinsic Motivation for Visual Programming in STEM Education

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ABSTRACT

Secondary school students often lack the necessary motivation to program visually. The present study aims to analyse the effects of error learning orientation on students' intrinsic motivation for visual programming. According to the control-value theory of Pekrun (2006), we posit that the influence of error learning orientation on intrinsic motivation is mediated by self-efficacy for visual programming as well as by error-related achievement emotions. A sample of 269 Swiss secondary school students (grades 7 to 9), who were beginners in visual programming, filled out a questionnaire as part of a course on visual programming. A structural equation model was established to illustrate the expected relationships between students' attitudes and their impacts. As expected, the results point to the need of paying more attention to errors in STEM education and indicate that students' error learning orientation had a low but significant effect on their intrinsic motivation for visual programming. The findings confirmed the effects of error learning orientation on intrinsic motivation for visual programming, which are mediated by self-efficacy but not by error related achievement emotions in the context of coding activities.

Keywords: errors, coding lessons, intrinsic motivation, mediation, secondary education

INTRODUCTION

Because programming is included in the curricula of multiple countries, it has been examined in many different ways. Several studies shed light on learning at the student level (e.g., Fanchamps et al., 2021; Cederqvist, 2020), but also on how teachers deal with this rather new subject (e.g., Vinnervik, 2020). Some investigations focus on programming with a specific microcontroller such as the micro:bit (e.g., Cederqvist, 2020), or on specific programming languages (e.g., Portelance et al., 2016). This paper looks at errors as another important aspect of learning a new visual programming language at the student level. With visual programming, errors can often occur, and the students quickly receive feedback as to whether they have programmed correctly or incorrectly. Moreover, visual programming with a microcontroller, such as the micro:bit, allows them to directly see the effects of their errors. Visual programming of a microcontroller therefore offers productive learning opportunities for students to learn from errors. In this context, our paper aims to analyse the possible influence of students' error learning orientation, as a cognitive feature of dealing with errors, on their intrinsic motivation for visual programming. Intrinsic motivation could be considered a central driver of learning, in contrast to extrinsic motivation, which is caused by external incentives or factors. According to self-determination theory, intrinsic motivation is particularly important for persistent and effective learning. Nevertheless, in school, more extrinsic forms, e.g., integrated or identified regulation, can also be regarded as beneficial forms of motivation on the way to more autonomous student learning. An intrinsically motivated student achieves a task due to the inherent satisfaction in completing it, i.e., for fun or to overcome the challenge (Ryan and Deci, 2000). However, in finishing a programming activity, students could make errors, which may possibly affect their intrinsic motivation. When students engage productively with errors, they are supposed to learn (Kreutzmann et al., 2014; Pekrun, 2006). Dealing with them productively creates a sense of competence, as well as being enjoyable and motivating. In contrast, unfavourable feelings of self-esteem caused by the experience of problems with a programming task are associated with more negative emotions, which are a hindrance to intrinsic motivation (Kreutzmann et al., 2014; Pekrun, 2006). Furthermore, if students do not see errors as learning opportunities, either because they are afraid of them or because the teacher puts pressure on the students, they are not likely to deal with them in a learning-enhancing way (Pekrun, 2006; Spychiger et al., 2006).

With respect to these first considerations of the experience of errors as part of secondary school students' learning and their influence on students' intrinsic motivation, the question arises as to how STEM educators could specifically address student's dealing with errors and the influence of errors on learning in STEM (science, technology, engineering and mathematics) education. The question will be discussed here specifically in regard to visual programming languages, as this content is an ideal learning environment for developing a positive error learning orientation.

THEORETICAL BACKGROUND

Dealing with Errors

One outcome of the international comparative study PISA (Programme for International Student Assessment) is the increasing importance of a positive error culture as a criterion for good teaching (Meyer et al., 2006; OECD, 2021). In STEM subjects, varying tasks can be offered in which the students can work with errors in different ways, e.g., by using the trial-and-error method (Bei et al., 2013; Edwards, 2004), the debugging process (Michaeli and Romeike, 2019; Perscheid et al., 2016) or the productive-failure approach (Kapur, 2015). In this context, attention should be focused not only on the tasks themselves, but also on the effects on learning when students encounter errors during the activity. If the experience is positive, dealing with them can increase students' motivation and self-efficacy and generate pleasant emotions (Schumacher, 2008; Schunk and Usher, 2012; Tulis and Ainley, 2011). However, the frustration caused by errors can also lead to an abandonment of the learning activity. Therefore, more importance should be attributed by teachers to how students handle errors as part of the learning process.

Errors in lessons are often defined as "facts or processes that deviate from a norm" (Kobi, 1994, p. 6). Norms can be related to a subject or be social or moral, and must be known by the students (Oser et al., 1999). Errors in class in relation to a subject can be, for example, incorrectly solved tasks or wrongly assessed verbal reports. Social errors include, for instance, disrupting a lesson, and moral ones involve, for example, lying (Kreutzmann et al., 2014). In this study, which has a focus on subject-related errors, they can set important learning processes in motion if students view errors as something they can learn from. Depending on how they are handled, errors can be conducive to learning, but they can also be an obstacle. A distinction must be made between the way teachers and students deal with errors (Spychiger et al., 2006). In order for students to learn from them, both instructors and pupils need to adopt a positive attitude towards the handling of errors (Spychiger et al., 2006). On the part of the teachers, this means that they must be error-friendly. In other words, they should create situations in which errors are allowed to happen, and should react positively to the errors of the students (by being patient and not scolding or shouting). Teachers must also admit their own errors and model how to deal with them in a positive way. In addition, they should always make it clear to the students which norms apply, so that the students are aware when they have deviated from these and consequently have made an error (Spychiger et al., 2006). Although the teacher's approach is also important, the decisive factor as to whether or not students learn from errors is the way in which they deal with them themselves (Kreutzmann et al., 2014; Spychiger et al., 2006). With respect to the topic of this research, this shows that programming is associated with specific opportunities and traps in terms of learning and dealing with errors.

Programming is a part of the curriculum in multiple countries. This rather new subject offers many facets of learning, such as fostering problem-solving skills (e.g., Gülbahar and Kalelioglu, 2014), learning through trial and error (Bei et al., 2013; Edwards, 2004) and grasping a new language (e.g., Portelance et al., 2016). In contrast to other subjects, such as, e.g., languages, in programming, the counterpart is not a human being with emotions, social competences and the ability to interpret, but a technical device, which only understands what has been communicated through visual or text-based programming. This means that communication must be accurate. If there is the slightest error, such as an incorrect block in visual programming or a comma instead of a dot in text-based programming, the technical device does not understand what it has to do. These circumstances inevitably lead to students making errors. However, this also opens up great potential for learning from them. Coding lessons in STEM education offer ideal conditions for establishing a positive error culture in the classroom, which will be described below. In this study, we focus on the errors secondary school students make using the technical device micro:bit.

First, working with the micro:bit has the advantage that errors are recognized immediately and the students do not have to compare their solution with a sample one or wait for the teacher's feedback. Second, if there is an error while working with the micro:bit, either nothing happens or the micro:bit does not carry out the desired action. This means that the students must look for the cause of the problem. In doing so, they can exchange ideas with their classmates and discover other solutions. At times, the students are not able help themselves. In this case, they can apply the "trial-and-error" method, as has been described by, amongst others, Edwards (2004). This is a learning method that, for security reasons, cannot really be applied in other school contexts, such as, for example, in physics when working with electricity or in chemistry when working with chemicals. As part of this method, students work, as the name suggests, by trial and error. Hence, they try something out, change an element in the code and observe what happens. Through this process, students identify steps that lead to the end goal, but also include actions that are not successful (Bei et al., 2013; Edwards, 2004).

Furthermore, in digital-based learning settings, whether classical programming lessons or those in which scientific problems are solved with the help of programming, debugging tasks can be provided for students who perceive errors as learning opportunities. Incorrect solutions are provided, which are then improved or debugged by the students (Michaeli and Romeike, 2019; Perscheid et al., 2016). To correct the errors, students can use their knowledge, as well as the "trial-and-error" method, to solve the problems. In such cases, pedagogical methods including cooperative thinking and learning support a positive experience of handling errors.

Programming offers possibilities for teachers to create tasks and environments that allow students to understand errors as opportunities to learn and in which they could experience emotions that should increase their motivation for learning programming. In the following section we will outline, based on the "Control-Value Theory of Achievement Emotions" (CVTAE) of Pekrun (2006), how errors as part of learning are connected to students' attitudes, affects and motivation.

Intrinsic Motivation, Self-Efficacy, and Emotions in Dealing with Errors

The "Control-Value Theory of Achievement Emotions" (CVTAE) of Pekrun (2006) (see **Figure 1**) describes the emotional processes that might occur during learning. This is focused on the influences on and effects of emotions (Pekrun, 2006). According to the CVTAE, achievement goals and beliefs predict the control and value appraisals, which, in turn, predict emotional reactions. Furthermore, emotions, e.g., error-related achievement ones, are deemed to be antecedents of the motivation to learn.

Not all aspects of the model can be investigated in this study. The focus will be on the impact of the error learning orientation as a part of achievement goals and beliefs on the intrinsic motivation for visual programming and the mediating effects of self-efficacy for visual programming and error-related achievement emotions.

As described above, dealing with errors, specifically error learning orientation as the cognitive feature, can be located as an element of achievement goals and beliefs. According to the CVTAE, error learning orientation is assumed to have an influence on intrinsic motivation for visual programming. This statement can be supported by Schumacher (2008), who states that the successful overcoming of errors leads to a greater intrinsic motivation to learn. He further states that intrinsically motivated students are less likely to be dissuaded from learning if they fail. In this study, we focus on the experienced level of intrinsic motivation for visual programming.

Furthermore, and according to CVTAE, error learning orientation affects self-efficacy as a part of control expectancy. This statement is also supported by Kreutzmann et al. (2014) and Schunk and Usher (2012), who proved that error learning orientation was predictive of self-efficacy. According to Schunk and Usher (2012), successes like correctly solved tasks can increase students' self-efficacy, while errors can decrease it. Students with a high level of self-efficacy are more likely to set higher goals, persevere even in the face of failure and regain their sense of efficacy after making an error, as well as to report more positive emotions. Students with low self-efficacy set themselves low objectives and are more likely to give up when they make errors and subsequently undergo negative emotions. However, errors do not always have to be associated with low self-efficacy (Schunk and Usher, 2012). As self-efficacy is topic-specific, we focus on a particular type, the self-efficacy for visual programming with Microsoft MakeCode for micro:bit.

Error-related achievement emotions can be associated with achievement emotions. According to Pekrun et al. (2006), positive attitudes towards errors can facilitate positive emotions and reduce negative ones. Hence, a constructive error learning orientation should facilitate positive emotions and reduce negative ones. Tulis and Ainley (2011) were able to show that not all students always experience negative emotions after making an error. In their study of 182 fifth grade students, 46% of the students surveyed reported experiencing no emotions

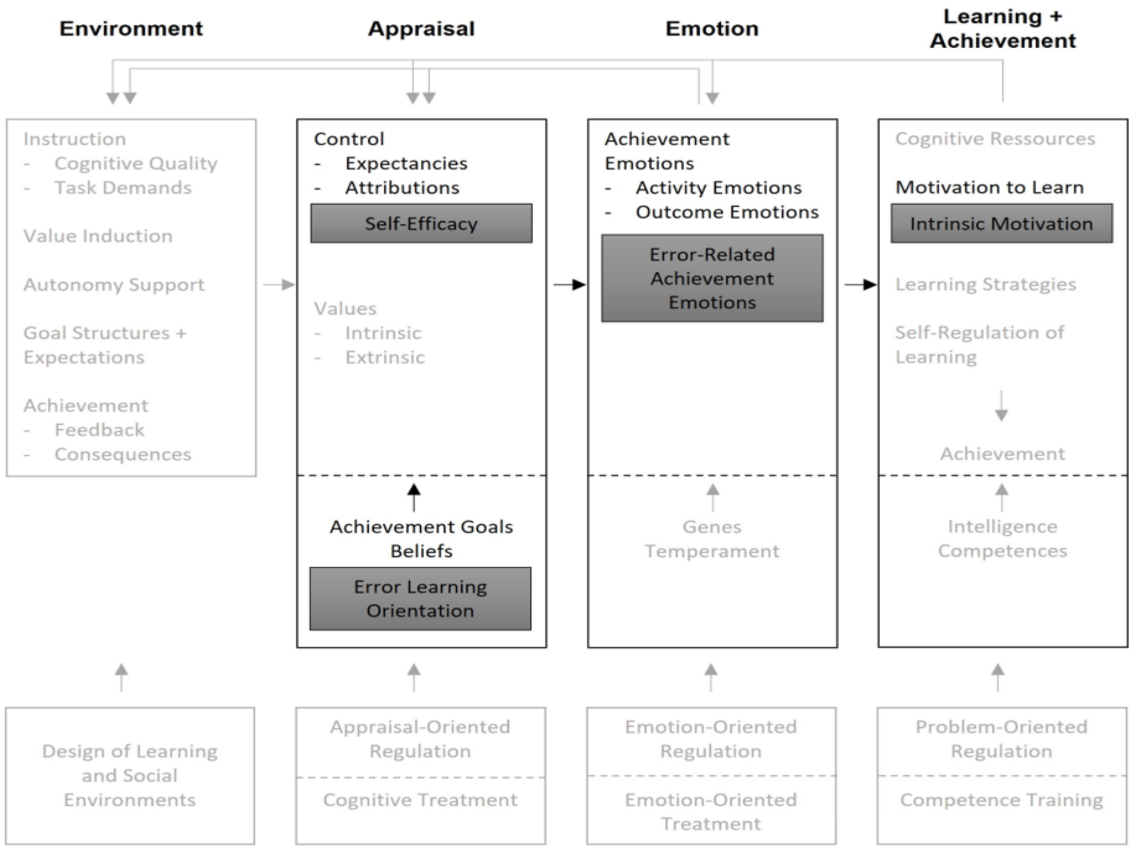

Figure 1. The "Control-Value Theory of Achievement Emotions" adapted from Pekrun (2006). Variables located: investigated variables in grey boxes and investigated paths in black

following making an error, 33% anger and boredom, 5% anxiety and despondency (sadness, shame, fear) and 16% positive emotions. These included interest, joy and pride. A comparison of students reporting negative emotions after making an error with those experiencing pleasant ones showed that more positive attitudes towards making errors and mastery orientation correlated. These results corroborate the findings of Diener and Dweck (1980) and Dweck and Leggett (1988), namely, that certain students reported positive emotions after making an error, others reported anger and boredom, and a third group reported inward-looking emotions, such as anxiety, shame and sadness. Furthermore, according to the CVTAE, emotions have an impact on one's motivation to learn.

In addition, research has shown that in STEM subjects, there are gender differences in learning motivation (e.g., Oppermann et al., 2020) and self-efficacy (e.g., Kessels, 2012). As expected, these results are also reflected specifically for programming (e.g., Funke et al., 2015). Boys seem to be more motivated to program compared to girls (Adleberg, 2013).

Furthermore, boys seem to have higher self-efficacy using a computer (Cassidy and Eachus, 2002) and also feel more able to program compared to girls (Gunbatar and Karalar, 2018). With regard to the emotions experienced after making an error, Dresel et al. (2013) were able to show that boys report a higher affective-motivational adaptivity of error reactions in mathematics than girls. It is therefore inferred that boys will also report more positive emotions after an error in programming than girls. In contrast, Arndt (2020) was able to show that girls have a higher error learning orientation than boys.

Intrinsic motivation seems to dwindle over the school years. However, this also depends on the type of subject, with maths showing the greatest decline over time (Gottfried et al., 2001). It is assumed that younger students have a higher intrinsic motivation for programming than older ones. A similar assertion can be made for self-efficacy. In terms of computer self-efficacy, Simsek (2011) showed that elementary students were more self-efficient than secondary ones. It is assumed that younger students also have a higher self-efficacy in programming than older ones. Furthermore, Hascher and Hagenauer (2010) were able to show that the older the students become, the less they experience errors as emotionally stressful. Wang et al. (2019) could not find a correlation between error learning orientation and age in their study, in which a positive error learning orientation led to learning from errors and negative emotions moderated this effect. It should be noted, however, that their investigation surveyed adults aged 20-56.

By grounding our analysis in the CVTAE, we gain a theoretical framework for embedding the aforementioned four scales, namely, error learning orientation, intrinsic motivation for visual programming, self-efficacy for visual programming and error-related achievement emotions, that we aim to explore and relate to each other in our study.

RESEARCH QUESTION AND DESIGN

We propose that students' error learning orientation is related to their intrinsic motivation, self-efficacy, and emotions through direct or moderated effects. These postulated relationships are relevant for understanding and supporting students' handling of errors in visual programming. The focus is on the following question:

To what extent does error learning orientation have an effect on students' intrinsic motivation for visual programming?

Specifically, we postulate that:

1a) error learning orientation has a positive effect on a student's intrinsic motivation for visual programming.

2a) error learning orientation with regard to intrinsic motivation is mediated by self-efficacy for visual programming.

2b) error learning orientation with respect to intrinsic motivation is mediated by error-related achievement emotions.

Research Design

To answer the research question, we applied a quantitative cross-sectional model. The students were questioned at the beginning of a programming activity at the out-of-school STEM lab Smartfeld (www.smartfeld.ch).

Sample

The sample consisted of 269 Swiss secondary school students (grades 7 to 9) from the eastern region of Switzerland. The age range was between 12 and 16 years. The mean age was 13.6 and the majority of the students were in grade eight. All students were classified by the teachers as beginners in visual programming, with little prior knowledge. Consent to participate in the study was obtained through the respective teacher. By participating in the course, the teacher confirmed that the students would take part in the survey. The questionnaires were completely anonymous.

Instruments

The students' questionnaire consisted of four scales, with reference to error learning orientation, error-related achievement emotions, specific self-efficacy and intrinsic motivation for visual programming (**Table 1**). In addition, the students' gender and age were obtained. All items used in the four scales were adapted from the literature.

Table 1. Investigated objects of the present study

Original name of the variable used	Name of the scale adapted to the model	Localization in CVTAE
Error learning orientation (Spychiger et al., 2006)	Error learning orientation	Achievement goals and beliefs
Affective-motivational adaptive responses to errors (Dresel et al., 2013)	Error-related achievement emotions	Achievement emotions
Specific self-efficacy (Güdel, 2014)	Self-efficacy for visual programming with Microsoft MakeCode for micro:bit	Control appraisal (expectancy)
Intrinsic Motivation Inventory (IMI) (Center for Self-Determination Theory, n.d.)	Intrinsic motivation for visual programming with Microsoft MakeCode for micro:bit	Motivation to learn

As we focus on the students' individual handling of errors, the "error learning orientation" scale by Spychiger et al. (2006) was selected and adjusted for this paper. This scale includes the cognitive feature of dealing with errors at an individual level. The items refer to attitudinal, achievement motivational and reflective aspects with regard to behaviour after making an error (Spychiger et al., 2006). The "error learning orientation" scale contained five items.

To measure the emotions students experience after making an error, the "affective-motivational adaptivity" scale developed by Dresel et al. (2013) was chosen and adapted for the questionnaire. This scale "refers to the maintenance of learning enjoyment and motivation as well as the regulation of negative emotions and associated motivation-relevant cognitions (e.g. task-irrelevant thoughts, self-doubt)" (Dresel et al., 2013). The final scale was renamed according to the CVTAE to refer to error-related achievement emotions and consisted of six items.

The "self-efficacy for visual programming" scale in our study, with Microsoft MakeCode for micro:bit, was adapted from Güdel (2014) and included six items.

The last scale, which concerned the intrinsic motivation for visual programming with Microsoft MakeCode for micro:bit, was modified from the interest/enjoyment subscale of the Intrinsic Motivation Inventory (IMI). As described in the article, this subscale elicits students' intrinsic motivation (Center for Self-Determination Theory, n.d.). The scale for "intrinsic motivation for visual programming" with Microsoft MakeCode for micro:bit was also composed of six items.

In addition to the four scales, the students' age and gender were included in the questionnaire.

As the questionnaire was used in German-speaking Switzerland, all items were formulated in German. The items were translated into English for this paper and can be found in **Appendix A**.

We utilized a six-point Likert scale for the questionnaire (1 = completely false, 2 = mostly false, 3 = somewhat false, 4 = somewhat true, 5 = mostly true, 6 = completely true). The scales were checked for reliability and all items had a Cronbach Alpha > .70 (Bühner, 2011).

Data Analyses

Statistical analyses of the data were conducted with SPSS for descriptive analysis and correlations. MPlus 7 was used for the computation of structural equation models (SEM) in order to investigate the relationships of the research model (see **Figure 1**).

The model fit was evaluated according to the following criteria: the chi-square test of model fit, root mean square error of approximation (RMSEA), comparative fit index (CFI) and the Tucker–Lewis index (TLI). The following values were considered a good fit between the hypothesized model and the observed data: RMSEA values $\leq .06$, CFI and TLI values $\geq .95$, whereas RMSEA values $\leq .08$, CFI and TLI values $\geq .90$ indicated an acceptable fit (Hu and Bentler, 1999; McDonald and Ho, 2002).

RESULTS

Generally, the students' error learning orientation and error-related achievement emotions, and the intrinsic motivation for visual programming, were somewhat positive, with rather high standard deviations for self-efficacy and intrinsic motivation. The students' self-efficacy for visual programming was exactly in the middle of the scale. Therefore, the mean value was neither positive nor negative. In addition, self-efficacy had a rather high standard deviation. The mean age of the students was 13.6, with a standard deviation of 1.04. The sample was almost equally distributed in terms of gender, with a slightly larger number of male students (**Table 2**).

Table 2. Mean and standard deviations of the four scales, age, and gender

Scale	*M*	*SD*
Error learning orientation	4.30	.70
Error-related achievement emotions	3.93	.83
Self-efficacy for visual programming with Microsoft MakeCode for micro:bit	3.55	1.05
Intrinsic motivation for visual programming with Microsoft MakeCode for micro:bit	3.96	1.31
Age	13.6	1.04
Gender	.55	.50

Note: Six-point Likert scale used in the questionnaire (1 = completely false, 2 = mostly false, 3 = somewhat false, 4 = somewhat true, 5 = mostly true, 6 = completely true); gender: female=0, male=1.

To show the impact of error learning orientation and the mediation effect of self-efficacy and error-related achievement emotions on intrinsic motivation, several structural equation models, in line with the research model, were tested and compared. The SEM was estimated with aggregated manifest variable indicators (the means calculated from parcels of items) to reduce the number of parameters calculated in the complex models, owing to the sample size. In a further step, age and gender were included as control variables for all four scales. The final model showed the following good fit values: $\chi^2 = 5.05$, df (degrees of freedom) = 2, $p = 0.08$, RMSEA = 0.075, CFI = 0.99 and TLI = 0.94 (see **Figure 2**).

As outlined in **Figure 2**, significant direct and indirect paths were observed to explain a student's intrinsic motivation for visual programming. The total effect of error learning orientation on intrinsic motivation is significant (*beta* = .370, $p = .000$). The main direct path is between error learning orientation and the intrinsic motivation for visual programming (thick path). This path showed a small but significant effect (*beta* = 0.156, $p = 0.002$) of error learning orientation on intrinsic motivation.

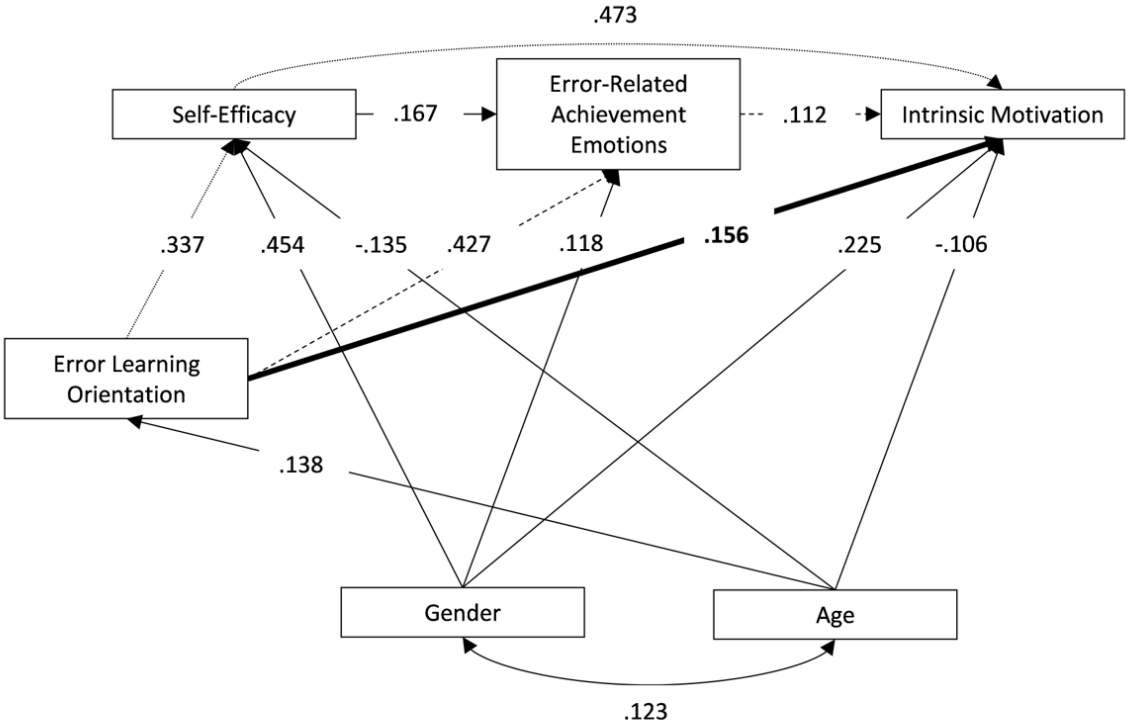

Figure 2. SEM of the observed variables (standardized estimates, all paths significant, p-values < .05)

Although the paths from error learning orientation to error-related achievement emotions and from emotions to intrinsic motivation both show substantial beta values, there was only a small indirect effect of error learning orientation on intrinsic motivation for visual programming via error-related achievement emotions (dashed path, *beta* = 0.048, *p* = 0.033). Hence, error-related achievement emotions do not act as a mediator between error learning orientation and intrinsic motivation.

Furthermore, there was an indirect effect of error learning orientation on the intrinsic motivation for visual programming via self-efficacy (dotted path, *beta* = 0.159, *p* = 0.000). Self-efficacy for visual programming acts as a mediator between error learning orientation and intrinsic motivation for visual programming. This higher self-efficacy led to a positive impact on intrinsic motivation. However, when error-related achievement emotions are included as well, then the indirect effect of error learning orientation on intrinsic motivation mediated by self-efficacy and error related-achievement emotions become insignificant, meaning there is no longer any indirect influence (*beta* = 0.006, *p* = 0.092) (see also **Figure 2**).

The model explained 53% of the students' variance in intrinsic motivation, 32% of the students' variance in self-efficacy, and 32% of students' variance in error-related achievement emotions.

Furthermore, we notice that gender has a high positive effect on self-efficacy and intrinsic motivation, and a low positive effect on error-related achievement emotions. Boys have higher self-efficacy and intrinsic motivation for visual programming, and they experienced more pleasant emotions after making an error than girls. Age has a negative effect on self-efficacy and intrinsic motivation, and a positive one on error learning orientation. Younger students have a higher self-efficacy and greater intrinsic motivation for visual programming, but older ones perceive errors more as learning opportunities than younger students. Finally, gender has no effect on error learning orientation and age has no impact on error-related achievement emotions. Male and female students have a similar error learning orientation and those at different ages have similar error-related achievement emotions.

DISCUSSION AND CONCLUSION

The research question was to what extent error learning orientation has an effect on students' intrinsic motivation for visual programming. According to the CVTAE a positive effect of secondary school students error learning orientation on their intrinsic motivation for visual programming was proposed (hypothesis 1a). Furthermore, it was assumed that error learning orientation with regard to intrinsic motivation is mediated by self-efficacy for visual programming (hypothesis 2a) and by error-related achievement emotions (hypothesis 2b). The students selected were all beginners in visual programming. Hence, these students had little background with the subject. In this context, they brought along the experience of numerous errors from their first attempts.

In our study we confirmed hypothesis 1a that error learning orientation has a small but significant effect on students' intrinsic motivation for visual programming. This means that when students perceive errors as learning opportunities, they also seem to possess a high intrinsic motivation for visual programming. The results clarified that in addition to students' behaviour regarding errors, namely, the successful overcoming of errors (Schumacher, 2008), students' positive attitudes towards errors, that is, error learning orientation, fosters the intrinsic motivation to learn. The results showed that error learning orientation is important to explain differences in students' intrinsic motivation for visual programming. The fact that motivation is influenced by other factors, such as teacher performance, could explain the remaining variance (Tambunan et al., 2021), in addition to teaching strategies (Bomia et al., 1997) and classroom climate (Starr et al., 2020), as well as parental advice (Fan and Williams, 2009).

The results also confirmed hypothesis 2a that error learning orientation with regard to intrinsic motivation is mediated by self-efficacy for visual programming. The outcome indicates that the relationship between error learning orientation and intrinsic motivation is complex. It showed that positive error learning orientation increases self-efficacy, which, in turn, has a positive effect on intrinsic motivation. Kreutzmann et al. (2014) and Schunk and Usher (2012) support the findings that error learning orientation has a positive impact on self-efficacy. Research by Ryan and Deci (2000) and Krapp and Ryan (2002) further underlined that self-efficacy has an important influence on intrinsic motivation.

The findings could not confirm hypothesis 2b that error learning orientation with regard to intrinsic motivation is mediated by error-related achievement emotions. The effects of error-related achievement emotions, as the beta effect (0.048) was very low. This shows that error-related achievement emotions do not seem to play an important role in students' intrinsic motivation to work on coding problems. According to Pekrun's (2006) CVTAE, however, error-related achievement emotions were expected to have an impact on intrinsic motivation.

In our study, boys had higher self-efficacy and intrinsic motivation for visual programming and they experienced more pleasant emotions after making an error than girls. These results are in accordance with the findings of previous research (Adleberg, 2013; Dresel et al., 2013; Gunbatar and Karalar, 2018).

Age has a negative effect on self-efficacy and intrinsic motivation, and a positive effect on error learning orientation. This means that younger students have a higher self-efficacy and a higher intrinsic motivation for visual programming, but older learners perceive errors as learning opportunities more than younger ones. The findings that younger students have higher self-efficacy and greater intrinsic motivation are consistent with previous research (Gottfried et al., 2001; Simsek, 2011). However, no correlation between error learning orientation and age has been found in previous investigations (Wang et al., 2019). Our discovery that older students have a higher error learning orientation is desirable, as they should become more autonomous learners as they progress through school. Finally, gender has no effect in our study on error learning orientation and age has no impact on error-related achievement emotions. This means that male and female students have a similar error learning orientation and those at different ages have similar error-related achievement emotions. These results are also not in accordance with the literature. Arndt (2020) has shown that girls have a higher error learning orientation than boys and Hascher and Hagenauer (2010) were able to show that the older the students become, the less they experience errors as emotionally stressful.

However, there are some limitations to our research. Firstly, due to Covid-19 and the cancelling of in-service teacher courses at the above-mentioned science centre Smartfeld, only a small sample of 269 Swiss secondary school students participated in our survey. Therefore, it is necessary to clarify whether other studies dealing with errors in the classroom reported similar or different results. In addition, in the present investigation, we had a sample of beginners in visual programming. It would be worthwhile repeating this analysis with more experienced students, who would have already programmed several times. Would this produce similar or different results?

Whereas from a socio-historical perspective the focus of a teacher would have been primarily on avoiding errors in the students' learning process, a contemporary, authentic science lesson should acknowledge the producing of errors while working on tasks and a teacher should use errors for learning purposes. As long ago as 1986, Fisher and Lipson, in their contribution "Twenty questions about student errors", highlighted the importance of taking into account the question of errors as part of the learning process of science. They, therefore, focused on the cognitive aspect of knowledge processing. However, they also posed a question in regard to "how motivation and other mental/emotional states (might) influence learning" (Fisher and Lipson, 1986, p. 798). Since the publication of this work, the handling of errors has received attention in various other theoretical and empirical works. Consequently, it is not a new idea that errors should be used as learning opportunities. However, not enough attention has yet been paid to errors in STEM educational research. To enhance students' ability to view errors as learning opportunities, teachers and students need to create a classroom atmosphere in which errors are handled in a way that promotes learning (Spychiger et al., 2006). This means, among other things, that the norms must be known and the teachers must be error-friendly (Spychiger et al., 2006). In addition, tasks should regularly be set in which the students recognize the learning potential of the error. This includes, for example, activities that give students direct feedback on whether they have done something correctly or not, or tasks or assignments that they can solve using the productive-failure approach (Kapur, 2015) or the "trial-and-error" method (Bei et al., 2013;

Edwards, 2004). Furthermore, students should not be afraid of making errors and should see errors as learning opportunities (Spychiger et al., 2006).

Visual coding lessons offer optimal conditions for furthering a positive error culture in the classroom and for letting students perceive errors as learning opportunities and not as failures. Compared to school subjects like mathematics or physics, coding lessons enable students to see or experience errors instantly, without having to wait for the teacher's feedback. Furthermore, students can work with the "trial-and-error" method without the risk of being blamed for making errors or not knowing the answer immediately. As a final point, teachers can provide students with prepared tasks aimed to promote learning from errors, namely debugging tasks, whereby students have to find and correct the problem. All these aforementioned aspects clarify why visual coding lessons are very useful in creating a supportive classroom environment in terms of handling errors.

The findings of this study showed that more attention should be paid to error learning orientation as a cognitive component in dealing with errors to foster students' intrinsic motivation. In addition, students' self-efficacy needs to be considered when dealing with errors in the (STEM) classroom. Self-efficacy mediates error learning orientation and intrinsic motivation. Unexpectedly, no mediation effect of emotions could be proven. Our results complement the existing research with respect to the handling of errors in the classroom as it has been analysed in relation to the specific area of visual programming with Microsoft MakeCode for micro:bit.

In this context, further research could investigate other aspects of dealing with errors and their effect on intrinsic motivation. So instead of error-related achievement emotions, only the fear of error could be considered. The scale assessing the fear of errors developed by Spychiger et al. (2006) could be used for this purpose. It would also be worthwhile to consider other aspects of the CVTAE, such as, for example, the environment, in order to better understand this complex process of learning from errors and consequently to design and support it in a more optimal way. Finally, additional studies could focus on a longitudinal design to examine changes in the way students deal with errors.

REFERENCES

Adleberg, B. M. (2013). Scratch programming and remix culture: Gender differences in interaction and motivation for pre-Adolescents [Master thesis, Georgetown University]. https://repository.library.georgetown.edu/bitstream/handle/10822/558248/adleberg_georgetown_0076m_12272.pdf?sequence=1

Arndt, S. A. (2020). F(r)u(r)chtbare Fehler? Prädiktoren für die Fehlerlernorientierung und die Fehlerangst im Mathematikunterricht – eine regressionsanalytische Betrachtung [Master thesis, Freie Universität Berlin]. https://www.ewi-psy.fu-berlin.de/einrichtungen/arbeitsbereiche/schulentwicklungsforschung/downloads/Empirische-Masterarbeit_Regression_Beispiel.pdf

Bei, X., Chen, N. and Zang, S. (2013). *On the complexity of trial and error*. Paper presented at the Proceedings of the 45th annual ACM symposium on Theory of Computing. https://doi.org/10.1145/2488608.2488613

Bomia, L., Beluzo, L., Demeester, D., Elander, K., Johnson, M. and Sheldon, B. (1997). The impact of teaching strategies on intrinsic motivation. *Educational Resources Information Center (ERIC)*. https://files.eric.ed.gov/fulltext/ED418925.pdf

Bühner, M. (2011). *Einführung in die Test- und Fragebogenkonstruktion*. Pearson Studium.

Cassidy, S. and Eachus, P. (2002). Developing the computer user self-efficacy (CUSE) scale: Investigating the relationship between computer self-efficacy, gender and experience with computers. *Journal of Educational Computing Research*, 26(2), 133-153. https://doi.org/10.2190/JGJR-0KVL-HRF7-GCNV

Cederqvist, A.-M. (2020). An exploratory study of technological knowledge when pupils are designing a programmed technological solution using BBC Micro:bit. *International Journal of Technology and Design Education*, 32, 355-381. https://doi.org/10.1007/s10798-020-09618-6

Center for Self-Determination Theory. (n.d.). *Intrinsic Motivation Inventory (IMI)*. http://selfdeterminationtheory.org/intrinsic-motivation-inventory/

Diener, C. I. and Dweck, C. S. (1980). An analysis of learned helplessness: II. The processing of success. *Journal of Personality and Social Psychology*, 39(5), 940-952. https://doi.org/10.1037/0022-3514.39.5.940

Dresel, M., Schober, B., Ziegler, A., Grassinger, R. and Steuer, G. (2013). Affektiv-motivational adaptive und handlungsadaptive Reaktionen auf Fehler im Lernprozess. *Zeitschrift für Pädagogische Psychologie*, 27(4), 255-271. https://doi.org/10.1024/1010-0652/a000111

Dweck, C. S. and Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review*, 95(2), 256-273. https://doi.org/10.1037/0033-295X.95.2.256

Edwards, S. H. (2004). *Using software testing to move students from trial-and-error to reflection-in-action*. Paper presented at the Proceedings of the 35th SIGCSE Technical Symposium on Computer Science Education. https://doi.org/10.1145/971300.971312

Fan, W. and Williams, C. M. (2009). The effects of parental involvement on students' academic self-efficacy, engagement and intrinsic motivation. *Educational Psychology. An International Journal of Experimental Educational Psychology*, 30(1), 53-74. https://doi.org/10.1080/01443410903353302

Fanchamps, N. L. J. A., Slangen, L., Hennissen, P. and Specht, M. (2021). The influence of SRA programming on algorithmic thinking and self-efficacy using Lego robotics in two types of instruction. *International Journal of Technology and Design Education*, 31, 203-222. https://doi.org/10.1007/s10798-019-09559-9

Fisher, K. M. and Lipson, J. I. (1986). Twenty questions about student errors. *Journal of Research in Science Teaching*, 23(9), 783-803. https://doi.org/10.1002/tea.3660230904

Funke, A., Berges, M., Mühling, A. and Hubwieser, P. (2015). *Gender differences in programming: research results and teachers' perception*. Paper presented at the 15th Koli Calling Conference on Computing Education Research. https://doi.org/10.1145/2828959.2828982

Gottfried, A. E., Fleming, J. S. and Gottfried, A. W. (2001). Continuity of academic intrinsic motivation from childhood through late adolescence: A longitudinal study. *Journal of Educational Psychology*, 93(1), 3-13. https://doi.org/10.1037/0022-0663.93.1.3

Güdel, K. (2014). *Technikaffinität von Mädchen und Jungen der Sekundarstufe I. Untersuchung von Technikinteresse, Selbstwirksamkeitserwartung, Geschlechterrollen und Berufswünschen* [PhD dissertation, University of Geneva]. https://archive-ouverte.unige.ch/unige:41471

Gülbahar, Y. and Kalelioglu, F. (2014). The effects of teaching programming via Scratch on problem solving skills: A discussion from learners' perspective. *Informatics in Education–An International Journal*, 13(1), 33-50.

Gunbatar, M. and Karalar, H. (2018). Gender differences in middle school students' attitudes and self-efficacy perceptions towards mBlock programming. *European Journal of Educational Research*, 7(4), 925-933. https://doi.org/10.12973/eu-jer.7.4.925

Hascher, T. and Hagenauer, G. (2010). Lernen aus Fehlern, in C. Spiel, R. Reimann, B. Schober and P. Wagner (eds), *Bildungspsychologie* (pp. 377-381). Göttingen, Germany: Hogrefe.

Hu, L.-t. and Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, 6(1), 1-55. https://doi.org/10.1080/10705519909540118

Kapur, M. (2015). Learning from productive failure. *Larning: Research and Practice*, 1(1), 51-65. https://doi.org/10.1080/23735082.2015.1002195

Kessels, U. (2012). Selbstkonzept: Geschlechtsunterschiede und Interventionsmöglichkeiten, in H. Stöger, A. Ziegler and M. Heilemann (eds), *Mädchen und Frauen in MINT. Bedingungen von Geschlechterunterschieden und Interventionsmöglichkeiten* (pp. 163-191). Münster, Germany: LIT Verlag.

Kobi, E. (1994). Fehler. *Die neue Schulpraxis*, 2, 5-10.

Krapp, A. and Ryan, R. M. (2002). Selbstwirksamkeit und Lernmotivation. Eine kritische Betrachtung der Theorie von Bandura aus der Sicht der Selbstbestimmungstheorie und der pädagogisch-psychologischen Interessentheorie, in M. Jerusalem and D. Hopf (eds), *Zeitschrift für Pädagogik. Selbstwirksamkeit und Motivationsprozesse in Bildungsinstitutionen. 44. Beiheft* (pp. 54-82). Beltz Verlag.

Kreutzmann, M., Zander, L. and Hannover, B. (2014). Versuch macht kluch g?! Der Umgang mit Fehlern auf Klassen- und Individualebene. Zusammenhänge mit Selbstwirksamkeit, Anstrengungsbereitschaft und Lernfreude von Schülerinnen und Schüler. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie*, 46(2), 101-113. https://doi.org/10.1026/0049-8637/a000103

McDonald, R. P. and Ho, M.-H. R. (2002). Principles and practice in reporting structural equation analyses. *Psychological Methods*, 7(1), 64-82. https://doi.org/10.1037/1082-989X.7.1.64

Meyer, L., Seidel, T. and Prenzel, M. (2006). Wenn Lernsituationen zu Leistungssituationen werden: Untersuchung zur Fehlerkultur in einer Videostudie. *Schweizerische Zeitschrift für Bildungswissenschaften*, 28(1), 21-41. https://doi.org/10.24452/sjer.28.1.4717

Michaeli, T. and Romeike, R. (2019). Debuggen im Unterricht - Ein systematisches Vorgehen macht den Unterschied, in A. Pasternak (ed), *Informatik für alle* (pp. 129-138). Gesellschaft für Informatik.

OECD. (2021). *PISA. Programme for International Student Assessment*. https://www.oecd.org/pisa/#

Oppermann, E., Keller, L. and Anders, Y. (2020). Geschlechtsunterschiede in der kindlichen MINT Lernmotivation: Forschungsbefunde zu bestehenden Unterschieden und Einflussfaktoren. *Journal of Childhood and Adolescence Research*, 1, 38-52. https://doi.org/10.3224/diskurs.v15i1.04

Oser, F., Hascher, T. and Spychiger, M. (1999). Lernen aus Fehlern. Zur Psychologie des "negativen" Wissens, in W. Althof (ed), *Fehlerwelten. Vom Fehlermachen und Lernen aus Fehlern* (pp. 11-41). Wiesbaden: Springer Fachmedien. https://doi.org/10.1007/978-3-663-07878-4_1

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review*, 18(4), 315-341. https://doi.org/10.1007/s10648-006-9029-9

Pekrun, R., Elliot, A. J. and Maier, M. A. (2006). Achievement goals and discrete achievement emotions: A theoretical model and prospective test. *Journal of Educational Psychology*, 98(3), 583-597. https://doi.org/10.1037/0022-0663.98.3.583

Perscheid, M., Siegmund, B., Taeumel, M. and Hirschfeld, R. (2016). Studying the advancement in debugging practice of professional software developers. *Software Quality Journal*, 25, 83-110. https://doi.org/10.1007/s11219-015-9294-2

Portelance, D. J., Strawhacker, A. L. and Umaschi Bers, M. (2016). Constructing the ScratchJr programming language in the early childhood classroom. *International Journal of Technology and Design Education*, 26, 489-504. https://doi.org/10.1007/s10798-015-9325-0

Ryan, R. M. and Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, 25, 54-67. https://doi.org/10.1006/ceps.1999.1020

Schumacher, R. (2008). Der produktive Umgang mit Fehlern. Fehler als Lerngelegenheit und Orientierungshilfe, in R. Caspary (ed), *Nur wer Fehler macht, kommt weiter. Wege zu einer neuen Fehlerkultur* (pp. 49-72). Herder.

Schunk, D. H. and Usher, E. L. (2012). Social cognitive theory and motivation, in R. M. Ryan (ed), *The Oxford handbook of human motivation* (pp. 13-27). University Press. https://doi.org/10.1093/oxfordhb/9780195399820.013.0002

Simsek, A. (2011). The relationship between computer anxiety and computer self-efficacy. *Contemporary Educational Technology*, 2(3), 177-187. https://doi.org/10.30935/cedtech/6052

Spychiger, M., Kuster, R. and Oser, F. (2006). Dimensionen von Fehlerkultur in der Schule und deren Messung. Der Schülerfragebogen zur Fehlerkultur im Unterricht für Mittel-und Oberstufe. *Schweizerische Zeitschrift für Bildungswissenschaft*, 28, 87-110. https://doi.org/10.24452/sjer.28.1.4720

Starr, C. R., Hunter, L., Dunkin, R., Honig, S., Palomino, R. and Campbell, L. (2020). Engaging in science practices in classrooms predicts increases in undergraduates' STEM motivation, identity, an achievement: A short-term longitudinal study. *JRST Wiley*, 57, 1093-1118. https://doi.org/10.1002/tea.21623

Tambunan, H., Sinaga, B. and Widada, W. (2021). Analysis of teacher performance to build student interest and motivation towards mathematics achievement. *International Journal of Evaluation and Research in Education*, 10(1), 42-47. https://doi.org/10.11591/ijere.v10i1.20711

Tulis, M. and Ainley, M. (2011). Interest, enjoyment and pride after failure experiences? Predictors of students' stateemotions after success and failure during learning in mathematics. *Educational Psychology*, 31(7), 779-807. https://doi.org/10.1080/01443410.2011.608524

Vinnervik, P. (2020). Implementing programming in school mathematics and technology: teachers' intrinsic and extrinsic challenges. *International Journal of Technology and Design Education*, 32, 213-242. https://doi.org/10.1007/s10798-020-09602-0

Wang, W., Yang, C., Wang, B., Chen, X., Wang. B. and Yuan, W. (2019). When error learning orientation leads to learning from project failure: The moderating role of fear of face loss. *Frontiers in Psychology*, 10, 1-9. https://doi.org/10.3389/fpsyg.2019.01317

APPENDIX A

Variables/Items	Cronbach Alpha
Specific self-efficacy for visual programming with Microsoft MakeCode for micro:bit, adapted from Güdel (2014)	.90
I am confident that I can program visually.	
I am confident that I can program text-based information.	
I am confident that I can program the micro:bit.	
I am confident that I can write my own programs for the micro:bit.	
I am confident that I can find errors in a code.	
I am confident that I can improve a buggy code.	
Intrinsic motivation for visual programming with Microsoft MakeCode for micro:bit, adapted from the Center for Self-Determination Theory (n.d.)	.96
I like programming very much.	
I enjoy programming.	
I find programming boring. (-)	
I am not at all interested in programming. (-)	
I find programming very interesting.	
I find programming very exciting.	
Error learning orientation, adapted from Spychiger et al. (2006)	.74
Sometimes in class it is helpful to remember an error, so I do not make it again.	
If I do something wrong in class, I use it as an opportunity from which to learn.	
Errors made in class help me improve afterwards.	
I reconsider incorrect solutions in assignments several times.	
I enjoy acquiring new knowledge through errors.	
Error-related achievement emotions, adapted from Dresel et al. (2013)	.83
If I do something wrong, it ruins the whole task for me. (-)	
If I do something wrong, I still enjoy the task just as much.	
If I cannot do something, I will still enjoy the task in the future.	
If I cannot complete a task, I will have less fun next time. (-)	
If I make an error, I will enjoy the task less afterwards. (-)	
If I cannot do something, I am still motivated to work.	

Note: Negative items are marked with (-).

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Fostering Critical Thinking Skills Using Integrated STEM Approach among Secondary School Biology Students

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ABSTRACT

Globally, critical thinking skills have been acknowledged as an important goal of education and integrated STEM-based approaches have been reported to have the potential to enhance critical thinking. Therefore, this study examined integrated STEM instructional material for genetic learning to increase secondary school biology students' critical thinking skills. The study adopted a quasi-experimental design, specifically a pre-test-post-test control group design. The sample size was made up of 112 students, two schools were randomly selected and assigned to the experimental and control group. The experimental group was made up of 58 students and the control group was 54. An integrated STEM approach module was developed for the experimental group, critical thinking skill test was used for pre-test and post-test data. The instrument yielded a reliability of between 0.71 - 0.76 for all the subskills of critical thinking skills. The pre-test results in all critical thinking subskills of inference, recognizing assumption, deduction, interpretation, and evaluation Wilks' $\wedge = .93$, $F\,(5, 94) = 1.370$, $p = (.24) > 0.05$, indicating that the two groups were equivalent in their critical thinking skills before treatment. The findings of the within-group comparison show that the experimental group shows a significant difference between pre-test and post-test with a large effect size ($d^2=1.56$) compared to the control group with a small effect size ($d^2=0.01$). The between-group comparison using MANOVA shows a significant difference in students' critical thinking skills of inference, recognizing assumption, deduction, interpretation, and evaluating arguments (Wilks' $\wedge = .31$, $F\,(5,106) = .68$, $p = (0.00) < 0.05$). Therefore, it can be concluded that an integrated STEM approach was more effective in enhancing students' critical thinking skills.

Keywords: critical thinking skills, genetics, integrated STEM approach, secondary school biology students

INTRODUCTION

The nations of the world are continually confronted with global competition and the need for mankind to solve problems such as climate change, environmental degradation, resource utilization, and control. On the other hand, companies, industries, and employees are constantly challenged by the demand for innovative products and solutions to emerging problems by their clients. Dealing with these problems and many more requires present and future employees to be able to think critically. Therefore, critical thinking skill is one of the most sought skills by employers of labour, to improve and increase their outputs (P21, 2015; Retnowati, Riyadi and Subanti, 2020). This underscores the importance of education that is relevant to the needs of the 21st century and produces critical thinkers. Therefore, the role of these skills in economic development is seen as a crucial issue in assisting nations to attain higher employment opportunities, economic empowerment, self-reliance as well as coping with increasing competition in the global market and an uncertain future (Kalelioğlu and Gülbahar, 2014; P21, 2015). The emphasis in 21st century learning is not on memorization and rote learning but on the acquisition of competencies and the ability to infer, analyse, deduce, interpret, and draw a conclusion as well as apply these skills to solve problems in real-life. There is an accord in the literature highlighting the significant role of critical thinking skills for meaningful living in the 21st century. However, employers of labour observed that graduates are deficient in critical thinking and problem-solving skills (Kivunja, 2015; Retnowati et al., 2020). This implies that the instructional strategies employed by teachers do not seem to enhance learners' critical thinking skills.

The educational policy in Nigeria stipulated that "the country's educational goals shall be set out in terms of their relevance to the needs of the individual and those of the society" in consonance with the world, the 21st century skills such as critical and creative thinking skills and the integration of technology are what is relevant to the present labour market (Papadakis, Vaiopoulou, Sifaki, Stamovlasis, Kalogiannakis and Vassilakis, 2021) among others.

Nevertheless, science teaching and learning do not seem to enhance students' critical thinking skills in most countries of the world, especially in Nigeria (Pitan and Adedeji, 2012; Retnowati et al., 2020). There seems to be a mismatch between the skills students acquire in the classroom and the skills required in the labour market. They reported a lack of skills such as critical thinking, decision-making, and analytical skills. This, however, calls for a paradigm shift from classroom instructions that are traditionally based and focus on lower skills to a new paradigm that will foster critical thinking skills (Dorouka, Papadakis and Kalogiannakis, 2020). The new paradigm should emphasize students' active exploration in the instructional process, where instruction is characterized by open-ended problem solving, question prompts, hands-on, minds-on, and authentic learning, among others (Thibaut et al., 2018). These elements may bring about meaningful learning and acquisition of twenty-first-century skills such as critical thinking skills.

However, despite the importance of critical thinking to problem-solving and meaningful living in the 21st century, researchers have reported a deficiency of critical thinking skills among learners across the world, Nigeria inclusive (Grosser and Nel, 2013; Salami, 2013; Wartono, Hudha and Batlolona, 2018). To enhance students' ability to think and achievement in science, there is a need to adopt appropriate instructional approaches and models among others. Wartono et al. (2018) reported that appropriate instructional models can enhance meaningful learning and the ability to think critically. Therefore, learning models with the potential of enhancing critical thinking skills could be integrated STEM approach because it is characterised by hands-on and mind-on activities as reported by researchers (Duran and Sendag, 2012; Thibaut et al., 2018). Integrated STEM education is an instructional approach in that science and mathematics concepts are learned in the context of technology and engineering. Students engage in scientific inquiry, and technological and engineering design iterative processes. In support of this (Sumarni and Kadarwati, 2020) opined that STEM-based instruction enables students to develop and formulate ideas to solve problems thus engaging their Higher Order Thinking Skills (HOTS). The approach is a learner-centred while the teachers act as a facilitator in the learning process. Thus, it provides the liberty for students to engage in higher cognitive processes such as ideas generation, evaluation, inference, explanation, and drawing conclusions which could enhance learners' critical thinking skills. In the next subsections, the statement of the problem, research questions, methodology, results, and discussions will be discussed.

Statement of Problem

The impact of globalisation and the evolving economy has influenced the school system to reconsider ways of effective teaching and learning because the current conventional instructional practices in the classroom were designed in the 20th century, which was a period of the industrial-based economy and was not envisioned for the knowledge-based economy of the 21st century (Jacobs, 2010; Wagner, 2008). While the practices in the classroom in Nigeria are keeping the status-quo (conventional instructional practices) the present workplace demand is evolving very fast. There is an agreement in previous literature that the development of 21st century skills is very vital to the economy and technological development (Pickering, 2010; Wagner, 2008). Nevertheless, Nigerian students do not demonstrate the ability to think critically, that is they lack the ability to infer, conclude deduce, and recognise assumptions (Pitan and Adedeji, 2012; Salami, 2013; Stapleton, 2011).

The reason can be attributed to the fact that classroom interaction is dominated by the teacher and knowledge acquisition during instruction is focused on lower thinking skills of Bloom's taxonomy which is characterised by memorization, recall, and rote learning. Innovative instructional strategies that are student-centred and characterised by active learning which could stimulate thinking skills are not adopted. The evaluation also focuses on facts and lower cognitive skills. Therefore, students exhibit a low level of critical thinking skills and students' performance in science continues to dwindle in Nigeria (Ezeudu, Ofoegbu and Anyaegbunnam, 2013; Pitan and Adedeji, 2012; Salami, 2013). Hence, the need to explore alternative teaching approaches that may enhance students' acquisition of critical thinking skills is required. One of such instructional strategies may be integrated STEM education.

Statistics have shown that STEM-based occupations will increase by 17% ability to employ more workers compare to the non-STEM occupation which will be less than 10% (Butcher, 2013). Therefore, STEM education is critical to an individual's ability to live a meaningful life in the 21st century because it empowers society in several ways. STEM-based knowledge and skills have the potential to enhance innovations and the quality of life. In view of the critical role of STEM education, Nugroho et al. (2021) opined that emphasis should be placed on developing and designing STEM-based instructional activities to enhance meaningful learning and acquisition of learning skills such as critical thinking skills.

The lack of critical thinking skills in the nation's future workforce will negatively affect the quest to compete effectively in the global market and also impede the nation's quest for sustainable development. Therefore, this study examined fostering critical thinking skills employing an integrated STEM approach among secondary school students in Minna, Niger State.

Research Question

The research question that is formulated to guide the study:

1. Does the integrated STEM approach enhance secondary school students' critical thinking skills in the experimental and control group?

Research Hypotheses

The following null hypotheses were formulated and tested at a 0.05 level of significance:

$H0_1$. There is no significant mean difference in the within-group comparison of secondary school students' critical thinking skills in the experimental and control group.

$H0_2$. There is no significant mean difference in secondary school students' critical thinking skills between the experimental and control group.

LITERATURE REVIEW

Relevant literature to this study was reviewed under the following sub-headings; integrated STEM approach, critical thinking skills, and in each sub-sections, empirical studies were highlighted.

Integrated STEM Approach

STEM education seems to have the potential to foster students' ability to think critically because it is characterised by question prompts, questioning, real-world open-ended problem, collaboration, and self-directed learning among others. Sumarni and Kadarwati (2020) investigated the effects of Ethno-STEM project-based instruction on critical and creative skills among secondary school students, the findings indicated that students' critical thinking skills were enhanced. Han, Capraro, and Capraro (2016) reported that STEM-based instruction enhanced students learning outcomes. Similarly, Mater et al. (2020) conducted on the effects of STEM on critical thinking skills, and the results showed that the experimental group who learned with the STEM approach had improved critical thinking skills compared to the traditional group.

Phonchaiya (2014) examined the effect of STEM education on learners' development of critical and creative skills, the findings showed that STEM education enhanced students' critical thinking. Similarly, Oonsim and Chanprasert (2017) conducted a study on promoting the critical thinking skills of secondary school students using STEM-based instruction in physics. The findings indicated that STEM education enhanced students' ability to think critically. Kim, Sharma, Land, and Furlong (2013) reported that instructional approaches characterised by questioning serve as scaffolds that provided students with the opportunity for deeper thought and enhanced the development of critical thinking skills.

Critical Thinking Skills

Critical thinking is a complex phenomenon and has been defined severally and categorised into several dimensions or subskills in the literature (Facione, 1998; Halpern, 2014; Watson and Glaser, 2010). It is defined as a cognitive skill that involves the ability to interpret, infer, analyse, evaluate, and conclude to make decisions (Facione, 2011). Therefore, in this study critical thinking is the process of learning that requires students to generate ideas, analyse, interpret, evaluate, and draw a conclusion to make a decision. The following dimensions have been adopted; inference, interpretation, recognizing assumptions, deduction, and evaluation (Smith, Rama and Helms, 2018; Watson and Glaser, 2010). Critical thinking skills are cognitive processes that results in interpretation, evaluation of arguments, deduction and making inference and recognition of assumption among secondary school students in this study.

As highlighted earlier, critical thinking is an important goal of science education. Therefore, students can be taught critical thinking skills in the science classroom. However, this requires effective teaching and learning strategy as well as a learning environment that will enhance thinking skills development. Kek and Huijser (2011) opined that the learning environment and instructional strategies should help the learner develop the ability to define a problem and generate and analyse information to solve a problem. In view of this, to help students improve their ability to think critically among others. The learning environment should be modified to provide students with the opportunity to take charge of their learning and collaborate to solve a problem (Johns, 2012). Integrated STEM classroom activities that foster experiences that are interdisciplinary and characterized by small group interaction, inquiry, and the open-ended problem can significantly impact students' ability to think critically (Duran and Sendag, 2012).

The theory that supports critical thinking is rooted in Benjamin Bloom's work (Bloom, 1956) who classified the cognitive domain into six levels, each of the levels corresponds to the cognitive ability of an individual (Duron, Limback and Waugh, 2006). Critical thinking and scientific thinking are enhanced by activities with higher order thinking abilities (Schulz and FitzPatrick, 2016). Kuhn (2002) conceptualized scientific thinking to mean everyday thinking of an individual and as an example of higher-order thinking. Consequently, the STEM activities are authentic and real-life in nature which could enhance critical thinking which is synonymous with scientific thinking.

Scientific thinking is the process of rational thought that must be adapted to promote the increase of science content knowledge, it is a knowledge-seeking process (Kuhn, 2010). This form of thinking provides the opportunity for exploration and follows the scientific method or procedures of problem-solving where learners find answers to open-ended problems. Scientific procedures such as engage, explore, expand, elaborate, and evaluate (5E), as well as drawing a conclusion (Bybee, 2010). The engineering design process was adopted for this study and seems to align with the 5Es.

The subject-specific learning of critical thinking skills was also adopted; therefore, the instructional content was a genetic concept in biology. The study was supported by the social constructivist theory which emphasis that learning should be student-centred through active engagement in the learning process and learning should take place in a social context.

Integrated STEM Approach and Critical Thinking Skills

The integrated STEM approach is characterized by a driving question that will provide the students to think critically for example what do you understand about the problem? This question will stimulate the ability to think. This approach provides the opportunity for students to generate their ideas, find solutions to an open-ended problem, and engage in hands-on and mind-on activities (English, 2016). The approach is also characterized by collaboration among students where students share and justify their ideas. Han et al. (2016) opined that employing an integrated approach in the instructional process that encourages student engagement and exploration in classroom instruction could promote critical thinking skills and the transfer of these skills from the classroom to a real-life situation.

Literature has advocated that scientific thinking can be seen as part of critical thinking skills (Suciati, Ali, Imaningtyas and Anggraini, 2018). Hence the stages of scientific thinking are investigation, analyse, inference, and argument (Kuhn, 2002; Suciati et al., 2018), which are similar to activities than could foster the individual ability to think critically. It is important to highlight that an integrated STEM education approach could provide the latitudes for students to engage in scientific thinking and in the process enhance their critical thinking skills. Watson and Glaser (2008) critical thinking definition and test were adopted for this study.

RESEARCH METHODOLOGY

The quasi-experimental research design was adopted because of the researcher's inability to employ true randomization as well as control all external variables. In this case, intact classes were used for both the experimental and control group (Creswell, 2015). The population of the study is all unity schools in Niger State, Nigeria. First, a convenient sampling technique was adopted to select two schools from the population, these schools were selected based on similar characteristics such as they are special science schools created by the Nigerian government with well-equipped science laboratories, the method of teachers' recruitment is the same and each of the schools has well-equipped computer laboratories. Secondly, the selected schools are randomly assigned to an experimental and control group, two intact classes from two schools will form the experimental and control group. A total of 112 students were involved, where 58 (52%) and 54 (48%) students were assigned to the experimental and control group, respectively.

A newly married couple with normal skin colour gave birth to their first child with abnormal skin colour and there is no trace of such colour in both families of the husband and wife in your town. The wife is accused of infidelity and the husband is threatening divorce. (Soltis, 2010)

Figure 1. An example of an open-ended problem

Science Critical Thinking Instrument

Data was collected using the Science Critical Thinking Test (SCTT), the test was made up of five subsections: inference, recognizing assumption, interpretation, deduction, and evaluation. These subskills were adopted from the Watson and Glaser Critical Thinking Appraisal Test (WGCTA), which test is a multiple-choice test (Watson and Glaser, 1980). The SCTT measures an individual's ability to define a problem, choose important information for a solution to a problem, recognise whether an assumption is made or not, formulate hypotheses, perform evaluation, and draw conclusions. These skills are related to solving a problem in science (genetics); students are presented with a genetic problem, and the students define the problem, formulate hypotheses, generate ideas, evaluate the ideas, and select the best idea to apply. The learners evaluate the entire process and communicate findings. All the questions in the subskills are based on scientific content. The SCTT items were adopted from previous critical thinking tests.

The SCTT was made up of fifty questions (each section has 10 questions). The instrument was validated by psychometry and science education experts and their observations and comments were used to improve the SCTT. The reliability of the subsections of the instrument was between 0.71, and 0.78 which was considered adequate (Sekaran and Bougie, 2010). The pre-test was administered, followed by the intervention, and after the intervention post-test was administered.

Treatment

An instructional material was developed for the implementation of an integrated STEM approach. The instructional process was based on a 5-phased iterative engineering design process: Identify a problem, gather ideas, design a solution, evaluate the solution, and disseminate the findings. This approach is learner-centred while the teacher acts as a facilitator. The facilitator employed question prompts or questioning and clues. The students learn in a small group of five students through collaboration with each other and with the facilitator. At the beginning of the instruction, the students were presented by an open-ended scenario or problem; A problem or scenario that engages students' ability to think, the problem must have several ways to resolve the problem. The problem should be relevant to learners' real-life, for example, the genetic problem or scenario in this study. This problem relates to the social and real-life of the learner.

The first phase is understanding or defining the problem which involves understanding the problem through analysing it and identifying the goal of the problem. The second phase, generation of ideas involves researching for scientific knowledge and ideas in the process students learn the instructional content of biology that can be used to solve the problem. The learners brainstorm to establish the right idea or ideas that will be applied in solving the problem. During this phase, students engage in justifying their ideas. The third phase is the design solution, which includes the application of the ideas generated to solve the open-ended problem. The students evaluated the solution developed to determine whether the goal of solving the problem have been achieved and finally disseminate the findings. These activities involve higher cognitive activities which will lead to the enhancement of critical thinking skills. The learning process is characterized by an open-ended problem, driving question and question prompts among others. An example of an open-ended problem is shown in **Figure 1**.

The approach provided the latitudes for students to define the problem, generate and analyse ideas (the students search for materials online and in textbooks to gather information to understand the problem and to provide the solution. The students work in small groups of five (5) students each while teachers serve as the facilitator of the learning process through question prompts, learning clues and reflective questions, among others. The control group were taught using the conventional (traditional method) where the teacher explains the problem, explain the concepts of genetics that will be required to solve the problem. This method is teacher centred and students are not actively engaging in the classroom instruction, compare to the experimental group that is student-centred and

Table 1. Pre-test results of the experimental and control groups critical thinking skills

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's trace	.982	1176.208[b]	5.000	106.000	.000
	Wilks' lambda	.018	1176.208[b]	5.000	106.000	.000
	Hotelling's trace	55.482	1176.208[b]	5.000	106.000	.000
	Roy's largest root	55.482	1176.208[b]	5.000	106.000	.000
Group	Pillai's trace	.088	2.038[b]	5.000	106.000	.079
	Wilks' lambda	.912	2.038[b]	5.000	106.000	.079
	Hotelling's trace	.096	2.038[b]	5.000	106.000	.079
	Roy's largest root	.096	2.038[b]	5.000	106.000	.079

Table 2. Within-group comparison of critical thinking skills

Dependent variable	Group	Pre-test ($\bar{x}$±SD)	Post-test ($\bar{x}$±SD)	df	*t-value*	*p-value*	d^2
Inference	Experimental	5.93±2.51	10.46±3.21	57	-7.88	.00	1.56
	Control	8.00±3.00	8.03±3.08	53	-.07	.94	0.01
Recognising assumption	Experimental	7.29±2.35	10.58±3.61	57	-5.87	.00	1.08
	Control	8.89±1.99	9.33±3.12	53	.97	.34	0.19
Deduction	Experimental	9.31±3.20	11.45±3.29	57	-3.26	.00	0.65
	Control	8.43±2.61	9.07±3.32	53	-1.15	.25	0.21
Interpretation	Experimental	6.60±2.47	10.36±3.18	57	-7.31	.00	1.32
	Control	7.33±3.02	8.11±3.45	53	-1.31	.20	0.24
Evaluation	Experimental	9.590±2.47	11.62±2.66	57	-4.62	.00	0.79
	Control	9.20±1.55	9.67±2.25	53	-1.31	.19	0.25
Overall	Experimental	38.72±5.74	54.48±8.55	57	-11.26	.00	2.16
	Control	42.31±5.49	43.80±7.24	53	-1.49	.14	0.23

learners are actively engage in the learning process. The pre-test was administered before the intervention began and the post-test was administered after the intervention which lasted for eight (8) weeks.

The data collected was analysed using a dependent t-test and a multivariate analysis of variance (MANOVA). The dependent t-test was used to determine the significant difference between the pre- and post-test groups (within-group comparison). While the MANOVA is to determine the effects of independent variables (integrated STEM approach and lecture method) on multiple continuous variables (critical thinking sub-skills).

RESULTS

To determine the equality of the experimental and control critical thinking skills before treatment, critical thinking pre-test was administered, and the data collected was analysed using MANOVA. The pre-test result is presented in **Table 1**.

Table 1 reveals the Multivariate Analysis of Variance (MANOVA) result of the experimental and control group critical thinking skills pre-test. The results show that there was no significant difference between the experimental and control group in all critical thinking subskills of inference, recognizing assumption, deduction, interpretation, and evaluation Wilks' $\Lambda = .93$, $F(5, 94) = 1.370$, $p = (.24) > 0.05$. Therefore, the two groups were equivalent in their critical thinking skills before treatment. Hence the post-test data will be analysed using MANOVA.

Within-group Comparison of Critical Thinking Skills

To test the formulated hypothesis one, an independent t-test was used to determine if there was any significant difference between the pre-test and post-test of the experimental and control group. The effect size of treatment for each group was also determined and the analysis is presented in **Table 2**.

Table 2 reveals a significant mean difference can be observed between the pre-test and the post-test mean scores of the experimental in inference subskills of critical thinking skills $t(57) = -7.88$, $p(.00) < .05$; $d^2 = 1.56$. The effect size was large. On the other hand, there was no significant mean difference in the inference subskill mean score of the traditional group $t(53) = -.07$, $p(.94) > .05$, $d^2 = 0.01$, the effect size was small. The result also shows a significant mean difference between the mean of pre-test and post-test of the experimental group in recognising assumption $t(57) = -5.87$, $p(.00) < .05$, $d^2 = 1.08$; deduction $t(57) = -3.26$, $p(.00) < .05$, $d^2 = 0.65$; interpretation $t(57) = -7.31$, $p(.00) < .05$, $d^2 = 1.32$; and evaluation $t(57) = -4.46$, $p(.00) < .05$, $d^2 = 0.8$. on the other hand there is no significant mean difference in all the critical thinking subskill of the traditional group: recognising assumption $t(53) = .97$, $p(.34) > .05$, $d^2 = 0.19$; deduction $t(53) = -1.15$, $p(.25) > .05$,

Table 3. MANOVA result of critical thinking sub-skills for experimental and control

Effect		Value	*F*	Hypothesis *df*	Error *df*	Sig.	Partial eta squared
Intercept	Pillai's trace	.977	884.470[b]	5.00	106.00	.00	.977
	Wilks' lambda	.023	884.470[b]	5.00	106.00	.00	.977
	Hotelling's trace	41.720	884.470[b]	5.00	106.00	.00	.977
	Roy's largest root	41.720	884.470[b]	5.00	106.00	.00	.977
Group	Pillai's trace	.324	10.149[b]	5.00	106.00	.00	.324
	Wilks' lambda	.676	10.149[b]	5.00	106.00	.00*	.324
	Hotelling's trace	.479	10.149[b]	5.00	106.00	.00	.324
	Roy's largest root	.479	10.149[b]	5.00	106.00	.00	.324

Table 4. Univariate tests for each dependent variable

Source	Dependent variable	Type III sum of squares	*df*	Mean square	*F*	Sig.	Partial eta squared
Intercept	Inference	9573.42	1	9573.42	962.27	.000	.897
	Recognizing assumption	10606.27	1	10606.27	1223.71	.000	.918
	Deduction	11777.63	1	11777.63	1074.20	.000	.907
	Interpretation	9543.04	1	9543.04	868.46	.000	.888
	Evaluation	12694.11	1	12694.11	2067.74	.000	.949
	Total	270100.67	1	270100.6	4269.29	.000	.975
Group	Inference	164.92	1	164.92	16.57	.000	.131
	Recognizing assumption	80.56	1	80.56	9.29	.003	.078
	Deduction	157.63	1	157.63	14.37	.000	.116
	Interpretation	141.69	1	141.69	12.89	.000	.105
	Evaluation	104.75	1	104.75	17.06	.000	.134
	Total	3193.53	1	3193.53	50.47	.000	.315
Error	Inference	1094.35	110	9.94			
	Recognizing assumption	953.40	110	8.66			
	Deduction	1206.04	110	10.96			
	Interpretation	1208.73	110	10.98			
	Evaluation	675.30	110	6.13			
	Total	6959.24	110	63.26			

$d^2 = 0.21$; interpretation $t(53) = -1.13, p(.20) > .05, d^2 = 0.24$; and evaluation $t(53) = -1.31, p(.19) > .05, d^2 = 0.25$.

Given the proceeding, there was a significant mean difference between the pre-test and post-test in the overall critical thinking skills of the experimental group $t(57) = -11.26, p = .00 < .05$, the overall effect size of the experimental group ($d^2 = 1.56$), indicating large effect size. On the contrary, there was no significant mean difference between the pre-test and post-test in the overall critical thinking skills of the traditional group $t(53) = -1.49, p = .14 > .05$, the overall effect size of the traditional group ($d^2 = 0.23$), indicating small effect size. Therefore, in comparison, the experimental had a large effect on enhancing students' critical thinking skills while the traditional method had a small effect size in helping students to think critically.

Fostering Critical Thinking Skills Using Integrated STEM Approach

To determine the effects of treatment between the experiment and control group (students treated with an integrated STEM approach and a traditional instructional method respectively), among the selected secondary school students. Post-test data was collected and all the assumptions for use of MANOVA were not violated, thus, Wilks' lambda was used to interpret the results. The result is presented in **Table 3**.

Table 3 shows MANOVA results of the post-test comparison between the experimental and control group critical thinking skills. The result shows that there is significant difference between the experimental (group that was instructed with integrated STEM approach) and the control group in critical thinking skills, Wilks' Λ = .31, $F(5, 106) = .68, p = 0.00 < 0.05$, partial $\eta^2 = .32$. Therefore, the formulated hypothesis (there is no significant mean difference of secondary school students' critical thinking skill between the experimental and control group) was rejected. The multivariate partial $\eta^2(.324)$ shows that about 32.4% of total multivariate variances of critical thinking scores (dependent variable) is due to the effect of treatment.

Given the findings in **Table 3**, the univariate tests for each subskill and the overall critical thinking skills result are presented in **Table 4**.

Table 4 shows the univariate tests for each subskill the result indicates a significant difference between the experimental and control group in all the subskill of critical thinking skills; inference, recognizing assumption, deduction, interpretation, and evaluation. The *p*-value is less than 0.05 ($p < 0.05$). The overall result of treatment between the experimental and control group in the critical thinking skills were $F(1, 110) = 50.47$, $p = .00 < 0.05$, partial $\eta^2 = .32$. Indicating a significant difference between the means of the experimental and control group. The experimental group estimated mean is 54.48 which is higher compared to the estimated mean of the control group 43.79, the significant difference was in favour of the experimental group. The multivariate partial $\eta^2 (0.32)$ indicates that about 32% of the total variance on the critical thinking skills is attributed to the intervention. The results also indicated that the intervention group perform better than the control group in all the critical thinking sub-skills, inference, recognition of assumption, deduction, interpretation, and evaluation.

Discussion of Results

This study investigated the fostering of critical thinking skills using an integrated STEM approach among secondary school students. The integrated STEM approach provided the leeway to engage in cognitive processes such as drawing an inference, recognizing assumptions, deduction, interpretation, and evaluation. The findings show that the integrated STEM approach students' critical thinking, the magnitude of the effect size was large. This finding concurs with Oonsim and Chanprasert (2017) determined the development of critical thinking skills among grade 11 students using the STEM education approach, their findings indicated that the critical thinking of the STEM education group was improved. The findings also agree with Sumarni and Kadarwati (2020) who investigated the effects of Ethno-STEM project-based instruction on critical and creative skills among secondary school students, the findings indicated that students' critical thinking skills were enhanced.

The outcome of the study also indicated that the students that learn with an integrated STEM approach performed better than the comparison in all the subskills of critical thinking skills of inference, recognition of assumption, deduction, interpretation, and evaluation as well as the overall critical thinking skill score. This result agrees with Mater et al. (2020) who conducted a study on the effects of STEM on critical thinking skills and the Technology Acceptance Model, the findings show that the experimental group who learned the STEM approach have improved critical thinking skills compare to the traditional group. This result also agrees with Han et al. (2016) who concluded that STEM-based instruction enhanced students learning outcomes

The findings of the study could be attributed to the open-ended and real-world problem presented to them, which may have provided a meaningful context that engages the students' higher cognitive abilities such as the generation of ideas and defining problems leading to the development of critical thinking. For example, during the generation of ideas students present their idea and justify their ideas, group members also prompt one another for clarity and explanation. The entire group assessed each idea or claim and draw an early conclusion, thus engaging in evaluation and inference sub-skills. Question prompt by the teacher could have served as a cognitive scaffold that engages the learners' critical thinking skills. Question prompts are very vital to the development of critical thinking skills and deepen understanding of the instructional content among the students. This corresponds with Kim et al. (2013) reported that good questioning may serve as scaffolds to provide students with the opportunity for deeper thought and enhance the development of critical thinking skills.

CONCLUSION

Given the findings that emerged from the data, it will be logical to conclude that an integrated STEM approach enhanced the learners' critical thinking skills of this population. This was probably achieved because the students were actively engaged in the learning process through hands-on and minds-on activities, solving open-ended problem and collaboration, among others. In view of the large effect size, integrated STEM is a viable instructional approach that should be included in the curriculum because if properly implemented in the classroom it will enhance students' thinking skills. The approach is good for human resource development for the 21st century because critical thinking skills is an important skill for meaningful living in this century.

Limitation of the Study

Like any other study, this study is not without limitation, the data collected for this study could be associated with human and could have impacted the outcome of the study. The limitation of the study is in the use of test items that is objective in nature, which could provide the opportunity for students to guess which could impact the findings.

REFERENCES

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher,* 70(1), 30-35.

Creswell, J. W. (2015). Educational research: Planning, conducting, and evaluating quantitative and qualitative research (5th Ed.). Los Angeles, CA: SAGE.

Dorouka, P., Papadakis, S. and Kalogiannakis, M. (2020). Tablets and apps for promoting robotics, mathematics, STEM education, and literacy in early childhood education. *International Journal of Mobile Learning and Organisation*, 14(2), 255-274. https://doi.org/10.1504/IJMLO.2020.106179

Duran, M. and Sendag, S. (2012). A preliminary investigation into critical thinking skills of urban high school students: Role of an IT/STEM program. *Creative Education*, 03(02), 241-250. https://doi.org/10.4236/ce.2012.32038

Duron, R., Limback, B. and Waugh, W. (2006). Critical thinking framework for any discipline. *International Journal of Teaching and Learning in Higher Education*, 17(2), 160-166.

Ezeudu, F. O., Ofoegbu, T. O. and Anyaegbunnam, N. J. (2013). Restructuring STM (Science, Technology, and Mathematics) education for entrepreneurship. *US-China Education Review A*, 3(1), 27-32.

Facione, P. A. (1998). *Critical thinking: What it is and why it counts.* California Academic Press. Available at: http://insightassessment.com/pdf_files/whatandwhy98.pdf (Accessed 10 July 2014).

Facione, P. A. (2011). *Measured reasons and critical thinking.* Millbrae, CA: The California Academic Press.

Grosser, M. M. and Nel, M. (2013). The relationship between the critical thinking skills and the academic language proficiency of prospective teachers. *South African Journal of Education*, 33(2), 1-17. https://doi.org/10.15700/saje.v33n2a639

Halpern, D. F. (2014). *Thought and knowledge: An introduction to critical thinking.* New York, NY: Psychology Press.

Han, S., Capraro, R. M. and Capraro, M. M. (2016). How science, technology, engineering, and mathematics project-based learning affects high-need students in the U.S. *Learning and Individual Differences*, 51, 157-166. https://doi.org/10.1016/j.lindif.2016.08.045

Jacobs, H. H. (2010). Upgrading content: Provocation, invigoration, and replacement, in H. H. Jacobs (ed), *Curriculum 21: Essential education for a changing world* (pp. 30-59). Alexandria, VA: Association for Supervision and Curriculum Development.

Johns, R. A. (2012). What were they thinking. *The Science Teacher*, 79(3), 66-70.

Kalelioğlu, F. and Gülbahar, Y. (2014). The effect of instructional techniques on critical thinking and critical thinking dispositions in online discussion. *Educational Technology & Society*, 17(1), 248-258.

Kek, M. Y. C. A. and Huijser, H. (2011). The power of problem-based learning in developing critical thinking skills: preparing students for tomorrow's digital futures in today's classrooms. *Higher Education Research & Development*, 30(3), 329-341. https://doi.org/10.1080/07294360.2010.501074

Kim, K., Sharma, P., Land, S. M. and Furlong, K. P. (2013). Effects of active learning on enhancing student critical thinking in an undergraduate general science course. *Innovative Higher Education*, 38, 223-235. https://doi.org/10.1007/s10755-012-9236-x

Kivunja, C. (2015). Exploring the pedagogical meaning and implications of the 4Cs "super skills" for the 21st century through Bruner's 5E lenses of knowledge construction to improve pedagogies of the new learning paradigm. *Creative Education*, 6(2), 224-239. https://doi.org/10.4236/ce.2015.62021

Kuhn, D. (2002). What is scientific thinking and how does it develop? in U. Goswami (ed), *Blackwell handbook of childhood cognitive development* (pp. 371-393). Hoboken, NJ: Wiley-Blackwell Publishing. https://doi.org/10.1002/9780470996652.ch17

Kuhn, D. (2010). What is scientific thinking and how does it develop? *Blackwell handbook of childhood cognitive development* (*2nd ed.*). New York; NY: Columbia University. https://doi.org/10.1002/9781444325485.ch19

Mater, N. R., Hussein, M. J. H., Salha, S. H., Draidi, F. R., Shaqour, A. Z., Qatanani, N. and Affouneh, S. (2020). The effect of the integration of STEM on critical thinking and technology acceptance model. *Educational Studies*, 48(5), 642-658. https://doi.org/10.1080/03055698.2020.1793736

Oonsim, W. and Chanprasert, K. (2017). Developing critical thinking skills of grade 11 students by STEM education: A focus on electrostatic in physics. *Rangsit Journal of Educational Studies*, 4(1), 54-59.

P21. (2015). *Framework for 21st century learning. The partnership for 21st century skills.* http://www.p21.org/about-us/p21-framework

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., Kalogiannakis, M. and Vassilakis, K. (2021). Factors that hinder in-service teachers from incorporating educational robotics into their daily or future teaching practice, in B. Csapó and J. Uhomoibhi (eds), *Proceedings of the 13th International Conference on Computer Supported Education* (pp. 55-63). ScitePress. https://doi.org/10.5220/0010413900550063

Phonchaiya, S. (2014). STEM and advanced thinking. *IPST Magazine*, 42(189), 7-10.

Pickering, D. (2010). Teaching the thinking skills that higher-order tasks demand, in R. Marzano (ed), *On excellence in teaching*. Bloomington, IN: Solution Tree Press.

Pitan, O. S. and Adedeji, S. O. (2012). Skills mismatch among university graduates in the Nigeria labor market. *US-China Education Review A*, 1(2012) 90-98.

Retnowati, S., Riyadi and Subanti, S. (2020). The STEM approach: The development of rectangular module to improve critical thinking skill. *International Online Journal of Education and Teaching*, 7(1), 2-15.

Salami, C. G. E. (2013). Youth unemployment in Nigeria: A time for creative intervention. *International Journal of Business and Marketing Management*, 1(2), 18-26.

Schulz, H. W. and FitzPatrick, B. (2016). Teachers' understandings of critical and higher order thinking and what this means for their teaching and assessments. *Alberta Journal of Educational Research*, 62(1), 61-86.

Smith, T. E., Rama, P. S. and Helms, J. R. (2018). Teaching critical thinking in a GE class: A flipped model. *Thinking Skills and Creativity*, 28, 73-83. https://doi.org/10.1016/j.tsc.2018.02.010

Stapleton, P. (2011). A survey of attitudes towards critical thinking among Hong Kong secondary school teachers: Implications for policy change. *Thinking Skills and Creativity*, 6, 14-23. https://doi.org/10.1016/j.tsc.2010.11.002

Suciati, M. N., Ali, C. D., Imaningtyas, A. F. and Anggraini, Z. D. (2018). The profile of XI grade students' scientific thinking abilities on scientific approach implementation. *Jurnal Pendidikan IPA Indonesia* [*Indonesian Science Education Journal*], 7(3), 341-346. https://doi.org/10.15294/jpii.v7i3.15382

Sumarni, W. and Kadarwati, S. (2020). Ethno-STEM project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia* [*Indonesian Science Education Journal*], 9(1), 11-21. https://doi.org/10.15294/jpii.v9i1.21754

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., . . . Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, 3(1), 1-12. https://doi.org/10.20897/ejsteme/85525

Wagner, T. (2008). *The global achievement gap: Why even our best schools don't teach the new survival skills our children need and what we can do about it*. New York: NY: Basic Books.

Wartono, W., Hudha, M. N. and Batlolona, J. R. (2018). How are the physics critical thinking skills of the students taught by using inquiry-discovery through empirical and theoretical overview? *EURASIA Journal of Mathematics, Science and Technology Education*, 14(2), 691-697. https://doi.org/10.12973/ejmste/80632

Watson, G. and Glaser, E. M. (1980). *Watson-Glaser critical thinking appraisal manual*. San Antonio, TX: The Psychological Corporation.

Watson, G. and Glaser, E. M. (2008). *Watson-Glaser critical thinking appraisal: Forms A and B manual*. Upper Saddle River, NJ: Pearson Education.

Watson, G. and Glaser, E. M. (2010). *Watson-Glaser II critical thinking appraisal*®. USA: NCS Pearson.

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Understanding Preservice Science Teachers' Views about Engineers and Engineering in an Engineering-Focused STEM Course

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ABSTRACT

Engineering has been considered as a useful context for successful implementation of STEM education. However, teachers have limited opportunities to develop a sound understanding about engineers and engineering, which is necessary for developing students' engineering practices and design skills. In this case study, the main purpose was to examine 18 preservice science teachers' initial and final views about engineers and engineering in an undergraduate engineering-focused STEM course. Before and after an eight-week implementation including three engineering design activities, data were collected by the adapted version of Views on the Nature of Engineering Questionnaire and reflection papers. Findings revealed four categories: 1) views about engineers and engineering, 2) views about engineering design process, 3) views about the factors that affect engineering, and 4) views about science versus engineering. Based on the codes a scoring rubric was developed to categorize PSTs' views as uninformed, partially informed, and informed. Results showed that PSTs' views become more informed in each category. However, their views were still found as partially informed in some of the categories which shows the need for more emphasis on future research. The changes in their views were discussed with possible reasons and recommendations were provided for further studies.

Keywords: engineering design process, preservice science teachers, STEM, views about engineers and engineering

INTRODUCTION

Science, technology, engineering, mathematics (STEM) education has gained a growing popularity among both developed and developing countries such as USA, Canada, Australia, and Turkey with the motivation to increase student interest towards STEM careers and not to fall behind in the global economic arena (Moore et al., 2016). STEM education is considered to have the potential for fostering students' scientific literacy skills and skills to solve complex problems of the 21st century (NRC, 2014).

Engineering, as one of the disciplines in STEM education, can be defined basically as "the process of designing the human-made world" (NRC, 2009). The potential benefits of teaching engineering in K-12 have been reported, as follows:

1. improved learning and achievement in science and mathematics,
2. increased awareness of engineering and the work of engineers,
3. understanding of and the ability to engage in engineering design,

4. interest in pursuing engineering as a career, and
5. increased technological literacy (NRC, 2009, p. 49-50).

Similarly, in the most recent Turkish middle school science curriculum, there is a clear emphasis on engineering, and developing students' engineering skills and practices are among the aims of the curriculum (MNE, 2018). Moreover, engineering has been defined as central in many of the policy reports and research studies (Moore et al., 2014a, 2014b; Nathan et al., 2013; NRC, 2012, 2014) as it involves scientific and mathematical knowledge and skills (Moore et al., 2014a, 2014b).

Although engineering is one of the STEM fields that teachers are expected to teach in science classrooms, teachers' views of engineering are underestimated as compared to their views of science (Kim and Song, 2021). We believe that along with the investigations into how pre-service science teachers (PSTs) integrate each of the four STEM disciplines, research that concentrates on their views about the nature of each discipline (i.e., nature of engineering) is needed. To effectively incorporate engineering into K-12 education, teachers need to possess developed views of the nature of engineering. Up to now, far too little attention has been paid to explore teachers' views of the nature of engineering, especially at the elementary level (Deniz et al., 2020b). It is important to figure out how PSTs, the future practitioners of STEM education, view engineering to develop a complete understanding of what students ought to know about that discipline, especially in the Turkish context where incorporating engineering into teaching programs is in its infancy. Therefore, the findings of this study would provide contributions to literature on engineering views in Turkish context by revealing PSTs' initial and final views of engineers and engineering in an engineering-focused, semester-long STEM course. Specifically, the present study seeks to answer the research question: "What are PSTs' initial and final views of engineers and engineering in an engineering-focused STEM course?"

Theoretical Background: Nature of Engineering Frameworks

Engineering has been reported to be a part of K-12 education however, there is no consensus definition of the nature of engineering in the related literature. In the Framework for K-12 Engineering Education (NRC, 2012), engineering is defined majorly in terms of engineering practices (problem definition, model development and use, investigation, analysis and interpretation of data, application of mathematics and computational thinking, and determination of solutions) that engineers use as they design and its' commonalities with science. However, this framework lacks a clear identification of engineering knowledge and/or the nature of engineering and how they ought to be understood by the teachers and students.

Studies of Karataş et al. (2011, 2016) were among the first attempts to describe and use the term nature of engineering. In these studies, the researchers determined the elements related to the nature of engineering based on the literature. These elements included:

> "engineering solutions are tentative (Koen, 2003); they involve designing artefacts and systems (Bucciarelli, 2003; Dym et al., 2005; Lewin, 1983; Wulf, 2002); they depend on existing scientific and mathematical theories, as well as failures and successes in the field (Adams, 2004; Petroski, 1985); they are affected by cultural norms and the needs of society (Adams, 2004; Dym, 1999; Dym et al., 2005); they involve stepwise and iterative problem-solving activities (Koen, 2003); they require creativity, imagination, and the ability to integrate different scientific, mathematical, and social values and theories in novel ways (Adams, 2004; Petroski, 1985); they are complex human endeavours that require analytical thinking to make complex problems simpler (Dym et al., 2005; Koen, 2003; Matthews, 1998); and they should involve an holistic, open-system approach that requires the consideration of all aspects and perspectives of not only artefacts and consumers, but also the potential impact on individuals, society, and the environment" (Adams, 2004; Rogers, 1983; Rophl, 2002).

Karataş et al. (2016) measured university students' views of engineering by using an instrument they developed and called Views of Nature of Engineering (VNOE) Questionnaire. The participants' nature of engineering views revealed the categories of; engineering (definition and purpose of engineering), the design process (considerations in design, what engineers do, how do they do it), factors that affect engineering (different, same, depends), characteristics of good engineering, characteristics of a good engineer, and science versus engineering.

Providing a more comprehensive description of the nature of engineering, Pleasants and Olson (2019a) developed a framework based on philosophical, historical and sociological perspectives of the engineering discipline. The framework included nine features of engineering, which were also considered as aspects of the nature of engineering (Pleasants and Olson, 2019a, p. 154):

1. Design in engineering,
2. Specifications, constraints, and goals,
3. Sources of engineering knowledge,

Table 1. The aspects of the nature of engineering framework (Pleasants and Olson, 2019a)

Nature of engineering aspect	Description
Design in engineering	"While engineers might consider esthetics as part of their designs, the technologies they produce are primarily practical or functional in nature" (p. 154). "[engineering design] typically requires the coordinated efforts of teams of engineers, each with various specializations, as well as technicians and scientists" (p. 155).
Specifications, constraints, and goals	"Engineers must translate ill-defined goals into specifications that can be used to guide design work" (p. 155). "Design constraints are limitations placed on the designed technology in terms of safety, reliability, cost, or other factors" (p. 155).
Sources of engineering knowledge	"Engineers utilize knowledge from science and mathematics, but consensus exists that engineering is not merely applied science, and that it has a knowledge base of its own" (p. 156). "When engineers engage in design, they draw on their knowledge of existing technologies" (p. 156). "Unlike scientific theories, which are used to understand natural phenomena, engineering theories are used by engineers for the practical purposes of design" (p. 156).
Knowledge production in engineering	"An important mode of engineering knowledge production … is engineering research, sometimes called 'engineering science'" (p. 156). "The products of engineering science might include knowledge of how particular technologies function, or analytical tools and models that can be applied to a range of technological phenomena" (p. 156).
The scope of engineering	"… the work of engineers includes more than just technological design. Many engineers engage in engineering science rather than design… Other engineers act as overseers of projects… Instead of designing new technologies, engineers might also study existing technologies" (p. 157).
Models of design processes	"… engineering design process models vary in terms of their level of generality" (p. 157). "… there is the question of whether a generic engineering design process model is appropriate, given the breadth of engineering design work" (p. 157).
Cultural embeddedness of engineering	"Society influences engineering work, but engineers also affect society through the technologies they develop" (p. 158). "Even though the ways that technologies affect society are difficult to predict, engineers must nevertheless consider potential consequences" (p. 158).
The internal culture of engineering	"This might include characteristics of engineers such as perseverance and attention to detail, or the sorts of values that tend to underlie engineering work. It might also include typical problem-solving approaches used by engineers…" (p. 158). "Another more visible aspect of engineering culture is the high proportion of men in engineering, who make up 85% of the profession" (p. 158). "Similarly, certain minority groups are underrepresented within the engineering discipline, at least within the United States" (p. 158). "In describing the culture of engineering, an important complexity is that many specializations exist in engineering, each of which have their own subcultures" (p. 159).
Engineering and science	"…science and engineering are not identical. Scientific knowledge has utility for engineers but is not sufficient to guide design work. Engineering science shares many characteristics with the natural sciences but is directed toward different goals and thus uses different approaches" (p. 159).

4. Knowledge production in engineering,
5. The scope of engineering,
6. Models of design processes,
7. Cultural embeddedness of engineering,
8. The internal culture of engineering, and
9. Engineering and science.

The elaborations presented by the researchers on each of the aspects were provided in **Table 1**. Pleasants and Olson (2019b) also developed a quantitative instrument in another study to measure teachers' understanding of the scope of engineering, a particular nature of engineering aspect. The developed instrument specifically focused on the distinctions between engineering and non-engineering.

In a recent study, Deniz et al. (2020a) aimed to discern the aspects of nature of engineering from the existing literature, including the Framework for K-12 Engineering Education (NRC, 2012) and NGSS (2013). According to that study, the nature of engineering has the aspects of

1. "demarcation (What is engineering? What makes engineering different from other disciplines?),
2. engineering design process (EDP),

3. empirical basis,
4. tentativeness,
5. creativity,
6. subjectivity,
7. social aspects of engineering, and
8. social and cultural embeddedness" (p. 638-639).

Similar nature of engineering conceptions can also be found in the documents of National Academy of Engineering (NAE). According to NAE (2010), K-12 engineering education should have a focus on;

1. "EDP,
2. incorporating science, mathematics, and technology knowledge and skills, and
3. promoting engineering habits of mind, aligning with the skills of systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations" (p. 45).

The aspects of the nature of engineering that have been reported in the research studies and policy documents are somehow very similar to each other and there have been some commonalities among the described characteristics of the nature of engineering. That being said, in this study, Karataş et al.'s (2016) framework and the questionnaire developed by them were utilized to interpret PSTs' views of engineers and engineering.

PSTs' Views about Engineers and Engineering

Previous studies on views about engineers and engineering have been emphasized mostly on students' ideas, conceptions, and perceptions of engineering (e.g., Capobianco et al., 2011; Chou and Chen, 2017; Fralick et al., 2009; Karataş et al., 2011), inservice teachers' conceptions of engineering (e.g., Deniz et al., 2020a; Hammack and Ivey, 2017; Pleasants and Olson 2019b; Pleasants et al., 2020) and how in-service teachers' conceptions related to engineering could be developed (e.g., Antink-Meyer and Meyer, 2016; Yoon et al., 2013). Within the limited number of studies on PSTs' conceptions or views of engineer and engineering, Kaya et al. (2017) explored how PSTs' views of engineering changed after enrolling in an elementary science teaching methods course. The researchers included a 3-week-long engineering unit which was around educational robotics in the science teaching methods course and tried to explore how PSTs' nature of engineering views changed after experiencing the engineering unit. PSTs' views on the nature of engineering were examined in terms of the nature of engineering aspects of demarcation, EDP, tentativeness, creativity, and social and cultural embeddedness and PSTs' responses were coded as uninformed, partially informed, or fully informed. According to the findings, the number of PSTs' holding uninformed and partially informed views on the aspect of the nature of engineering were decreased and fully informed views were increased prominently.

Ergün and Kıyıcı (2019) examined how PSTs' perceptions of engineering education and engineers changed after enrolling in a 14-week-long science education laboratory applications course, which was specifically designed to involve engineering design-based applications. In this pre-post design, mixed research study, PSTs' perceptions of engineering education and engineers were measured through Engineering Education Survey and Draw an Engineer Test. According to the quantitative findings, the participants' post scores on the sub-dimensions of importance of engineering, familiarity with engineering, and characteristics of engineering and engineers were significantly higher than the pretest scores. Moreover, the number of participants' who drew engineers as male instead of a woman, and as working individually instead of being a part of a team decreased. In the study, the analyses of PSTs' drawings also revealed that the engineering activities and the materials used by the engineers were mostly related to constructing and repairing at the beginning of the course and changed majorly into designing, developing, calculating, doing research/analysis, and doing experiments at the end of the semester.

In another study by Aydın-Günbatar et al. (2018), the effect of a 12-week design-based STEM course on preservice chemistry teachers' content knowledge, STEM conceptions, and engineering and engineering design views were investigated. The study revealed that prior to the course, almost all preservice teachers' conceptions of engineering and design processes were undeveloped or underdeveloped. Moreover, except one of them, all the participants developed their conceptions of engineering and design process after participating in the STEM course. For instance, the participants' views prior to the course that engineering aims to put something as a product changed into the view that the goal of engineering is to come to an end point such as a product, an idea, or a solution. However, Aydın-Günbatar et al. (2018) reported that the participants failed to recognize the iterative nature of the EDP even after taking the STEM course.

We believe that the number of existing studies exploring PSTs' conceptions and views of engineers and engineering (i.e., nature of engineering) is limited. In this study, we tried to examine PSTs' views through an open-ended questionnaire, which would provide a detailed understanding of future teachers' views about engineering and engineers.

Table 2. The weekly schedule of the implementation

Week	Content	Duration (min)
1	What is STEM? How can science teachers affect students' orientations toward STEM careers? What is engineering? What is EDP?	50+50
2	Talk with a guest engineer on EDP	50+50
3	Environmental-friendly streetlights design activity[a]	50+50
4	Wave machine design activity[b]	50+50
5 & 6	Bridge design activity[c]	50+50+50+50
7 & 8	Designing and presenting a lesson plan including engineering design activities	50+50+50+50

Notes: [a]http://www.fenegitimi.com/; [b]https://merakmakinesi.org/; [c]Taşdemir and Çalık (2017)

METHOD

Research Design and Study Group

This study used single case study design (Creswell, 2007) in order to describe the preservice elementary science teachers' views about engineering and engineers in an engineering-focused STEM course. The content of the course, and the participants taking the course constituted the boundaries of the case. The STEM course and PSTs taking the course were assumed to be a typical case and the lessons learned from this case were expected to be informative about the experiences of an average PST in an average STEM course (Creswell, 2007).

Purposeful sampling was used to reach participants. The study group involved 18 senior PSTs (16 female, 2 male), who have taken the STEM elective course in a public university. These PSTs will be elementary science teachers for grade 3-8 upon graduation. Gender proportion of participants is representative of the proportion in the population (Higher Education Council, 2020).

The Study Context

In Turkey, elementary science teachers are expected to graduate from a four-year undergraduate science education program. All science education departments are following a centralized undergraduate curriculum determined by the Higher Education Council. The science teacher education program consists of coursework including a number of elective and mandatory courses. Although mandatory courses have common content in different universities, the content of elective courses may vary. This study was conducted in an elective course offered in the fourth year of elementary science education program.

Goals of the course were to enhance PSTs' knowledge about STEM education, and to help them gain experience in terms of being engaged in and planning EDP activities. Current literature highlighted the importance of giving explicit instruction of the nature of engineering to students in addition to engaging them in engineering practices to develop students' understanding effectively (Deniz et al., 2020a; Pleasant and Olson, 2019b). Therefore, the content of the course included theoretical instruction, discussions and as well as design activities. The weekly schedule of the course activities was provided in **Table 2**.

The purpose of Week 1 was to provide a theoretical background about STEM and, specifically, engineering. In this week, definition of STEM, the need for STEM education, the brief history of STEM education, and the pedagogical approaches to STEM education were presented theoretically. Moreover, the role of engineering as a unifying context in STEM education was mentioned by introducing current engineering education integration frameworks. Then, the place of engineering in the Turkish science curriculum was discussed. Afterwards, the characteristics of engineers and engineering were discussed in small group and whole class discussions. In addition, some key terms were introduced like engineering habits of mind, product, design, EDP, criteria, constraint, prototype, optimization, and so on. EDP steps of Hynes et al., (2011), "identify need or problem, research need or problem, develop possible solutions, select best possible solution, construct a prototype, test and evaluate solution, communicate the solution, redesign" (p. 9), which were used in the later design activities in the course, were introduced and discussed.

The purpose of Week 2 was to help PSTs learn more about what engineers do in their professional life, namely in engineering companies. For this purpose, an electrical and electronics engineer, who has been working in a company for more than ten years, was invited to the course. PSTs were allowed to ask their questions about engineers and engineering. The guest engineer explained what they do in their company and how they go through EDP. The guest also emphasized the tenets of the nature of engineering, which are definition and purpose of engineering, characteristics of good engineer and engineering, EDP, factors affecting engineering and the similarities and differences between science and engineering by relating them with real life experiences.

The purpose of Weeks 3 to 6 was to engage PSTs in engineering design experiences through three different activities, namely, streetlight, wave machine, and bridge design activities. In these activities, PSTs were firstly expected to define the problem in a given situation. Then, they were asked to do a brief research to collect related information about the problem. They were given time to work on the possible solutions. Each PST was asked to draw a prototype of their own design. They presented their solution to their group members, and they determined the prototype to be tested after an optimization process. After completing the drawing of their groups' prototype, they tried to construct it with provided materials and the course instructor tested each prototype for their efficiency in terms of given constraints and criteria. Then, they were given extra time to revise and retest their prototypes. At the end of the activities, each group presented their design to the whole class and shared their experiences.

The purpose of Weeks 7 and 8 were to foster PSTs' integration of EDP into their own science teaching. For this purpose, they were asked to design a lesson plan for elementary level including engineering design activities. Each PST worked individually and at the end shared their lesson plans with other PSTs to be discussed in the classroom.

As it is suggested in the literature (Deniz et al., 2020a), the course was designed as explicit-reflective in nature. We explicitly introduced EDP steps and NOE aspects to the participants during introductory lectures. Both the instructor of the course and guest electrical and electronics engineer emphasized on the phases of the engineering design and the nature of engineering. Moreover, we asked participants to reflect on their engineering design experiences in terms of NOE aspects. This explicit-reflective emphasis on the nature of engineering and EDP was expected to contribute to the participants' views of NOE.

Data Collection Tool

To reveal PSTs' views about engineers and engineering, an adapted version of the VNOE Questionnaire (Karataş et al., 2016) was administered. VNOE, originally, included 11 open-ended questions related to the definition and purpose of engineering, the similarities and differences between science and engineering, EDP (what and how engineers do to complete a task) and the characteristics of good engineering and good engineers. The questionnaire was translated into Turkish by the authors and a few changes were made. First, participants were not asked to make drawings in the third item. Instead, they were asked to explain their images of engineers and engineering. Second, to ensure proximity of the items, the name of the bridge mentioned in the 8th item was changed with a Turkish bridge. Third, the last item, "Do you think your answers to the previous questions are likely to change if we ask them again next year?" was removed because the questionnaire was administered to the participants at the beginning and end of the semester, and we aimed to detect those changes at different times. Other items were used as in the original version. Two experts from the science education field reviewed the adapted version of the questionnaire and some minor revisions such as changing the wording for some of the items were made accordingly. VNOE was administered to PSTs before and after the 8-week implementation. The approximate time of filling the instrument was 40 min. The PSTs voluntarily agreed to participate in the study.

Data Analysis

The VNOE data obtained at the beginning and end of the course were subjected to a qualitative analysis in three steps. In the first step, the categories and subcategories determined by Karataş et al. (2016) guided our initial data coding process. Both authors performed initial coding based on eleven categories and related subcategories in the six themes (engineering, the design process, factors that affect engineering, characteristics of good engineering, characteristics of good engineering, and science versus engineering) defined by Karataş et al. (2016). In the second step, PSTs' answers given under each category were analyzed inductively in detail. In this process, the codes of Karataş et al. (2016) as well as newly emerged codes were used. Some of the repeating codes and categories were eliminated or merged, and the final categories and codes were determined. For example, PSTs' answers initially coded under the sub-categories of "definition of engineering" and "purpose of engineering" were similar or complementary. Therefore, these two sub-categories were unified and named as "scope of engineering". The final version of the codes and categories together with the sample quotations can be found in **Appendix A**. The categories emerged in our study concerning the nature of engineering are:

1) views about engineers and engineering,
2) views about EDP,
3) views about the factors that affect engineering, and
4) views about science versus engineering.

In this process, 35% of the whole data was analyzed by both researchers according to the coding list they developed. Several meetings were arranged to come to a consensus about the codes. Among the two authors' coding, 85% agreement was obtained.

In the third step, a scoring rubric was created based on the available codes under each category. PSTs' answers were labeled as uninformed, partially informed, or informed (**Table 3**). A science education faculty member provided expert opinion to the created levels and definition of the levels in the rubric. Then, to create profiles of the PSTs' views before and after the STEM course, their answers were scored based on the developed rubric. To

Table 3. Scoring rubric for assessing PSTs' views about engineers and engineering

Category	Sub-category	Uninformed	Partially informed	Informed
Views about engineers and engineering	Scope of engineering	Provide irrelevant/ insufficient description (or could not provide any description at all)	Describe the scope of engineering as only creating a product/system/ knowledge	Describe the scope of engineering as solving real life problems through creating or revising a product/system/ knowledge
	Characteristics of good engineering	Could not mention any specific characteristics of the product, process, or impact of the engineering	Only mention the features of the developed product/system/knowledge such as strength, aesthetic, or originality	Mention the features of product/system/knowledge as well as the process of the design (e.g., methods and tools used), or the impact of the engineering (e.g., to the environment)
	Characteristics of good engineer	Only mention technical skills (e.g., design skills) or intrapersonal skills (e.g., analytical thinking)	Mention technical skills and intrapersonal skills	Mention technical skills, intrapersonal, and interpersonal skills (e.g., cooperation skills)
EDP	Considerations in design	Could mention only one of the criteria (e.g., strength) or constraint (e.g., budget, time)	Mention both criteria and constraints	Mention both criteria and constraints by differentiating them and giving examples
	What engineers do in EDP	Think that engineers build or fix different technologies as skilled laborers (construction workers or technicians) do rather than designing	Think that engineers only design the prototypes and do calculations	Think that engineers have different roles and duties in different parts of EDP beginning from planning, testing to marketing
	How engineers accomplish to complete EDP	Could not provide any clear explanation regarding the completion of EDP	Explain only individual work such as making calculations and planning	Explain that in different parts of the process, there is a need to carefully plan and implement the iterative EDP processes with a team including engineers who have different expertise
Factors affecting engineering		State that two different companies are likely to come up with the same solution for the same engineering problem	State that two different companies may come up with multiple solutions for the same engineering problem without mentioning the factors causing the differences	Emphasize the subjectivity and creativity of engineers, differences in the opportunities and vision of the companies that cause reaching different solutions to the same problems
Science versus engineering		Fail to mention that engineering and science are two different disciplines or that engineering, and science share some similar characteristics	Mention that science and engineering have both commonalities and differences without clearly defining these similarities and differences	Mention the similarities (e.g., methods, techniques, tools used) and differences between (the body of knowledge used and produced) science and engineering as well as the relationship between them

compute inter-rater reliability of the scoring rubric, two commonly used strategies, which are Intraclass Correlation Coefficient (ICC) and Cronbach's alpha, were utilized. Both authors rated twenty percent of the participants' answers. The average measure of ICC was .965 with a 95% confidence interval from .821 to .998 ($F(3,9) = 28.294$, $p < .001$). Based on the 95% confidence interval, ICC scores between 0.75 and 0.90 were found as indicative of good reliability (Koo and Li, 2016). Therefore, a good degree of reliability was found between measurements. Besides ICC, internal consistency was calculated through the most commonly used Cronbach's alpha procedure (Cronbach et al., 1972). Cronbach's alpha reliability was calculated as .965. The results of the ICC and Cronbach's alpha provided evidence for the reliability of the developed rubric. The whole data analysis process was illustrated in **Figure 1**.

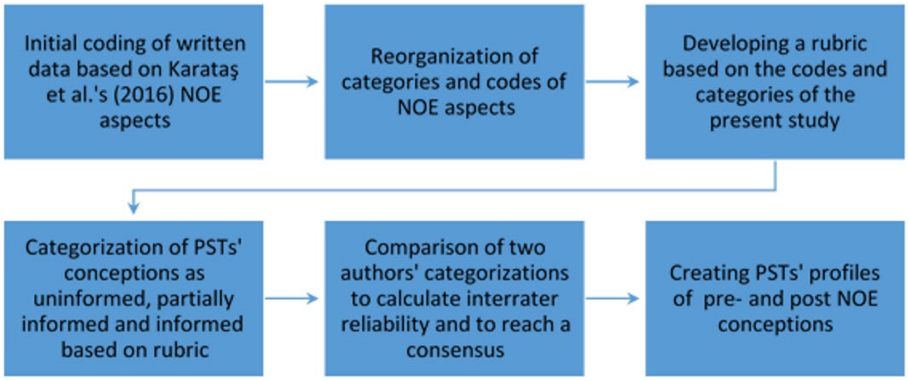

Figure 1. Data analysis process

FINDINGS

Findings are presented for the four categories (views about engineers and engineering, views about EDP, views about the factors that affect engineering, and views about science versus engineering) obtained from the analysis of PSTs' responses to open-ended questions. **Table 4** presents how PSTs' views about engineers and engineering changed across the four categories.

Table 4. Number and percentage of PSTs holding uninformed, partially informed, and informed views about engineers and engineering

Categories/sub-categories	UI [n (%)]		PI [n (%)]		I [n (%)]	
	Pre	Post	Pre	Post	Pre	Post
Views about engineers and engineering						
Scope of engineering	7 (39)	0 (0)	10 (56)	11 (61)	1 (6)	7 (39)
Characteristics of good engineering	4 (22)	1 (6)	12 (67)	13 (72)	2 (11)	4 (22)
Characteristics of good engineer	9 (50)	4 (22)	7 (39)	12 (67)	2 (11)	2 (11)
Views about engineering design process						
Considerations in design	7 (39)	3 (17)	6 (33)	7 (39)	5 (28)	8 (44)
What engineers do in engineering design process	4 (22)	1 (6)	13 (72)	8 (44)	1 (6)	9 (50)
How engineers accomplish to complete engineering design process	7 (39)	3 (17)	11 (61)	7 (39)	0 (0)	8 (44)
Views about the factors that affect engineering	4 (22)	2 (11)	6 (33)	2 (11)	8 (44)	14 (78)
Views about science versus engineering	3 (17)	1 (6)	5 (28)	3 (17)	10 (56)	15 (83)

Notes: UI: Uninformed; PI: Partially informed; I: Informed

Views about Engineers and Engineering

Under the category of views about engineers and engineering, three sub-categories emerged: scope of engineering, characteristics of good engineering, and characteristics of a good engineer. Overall, regarding the views about engineers and engineering, the number of PSTs holding uninformed views decreased majorly and PSTs holding informed views increased in number at the end of the course (**Table 4**). At the beginning of the course, 7 (39%) of the PSTs could not provide a description of the scope of engineering (uninformed views) and more than half of the PSTs (10, 56%) described engineering only as a profession creating new products or systems without further explanation such as how and why the new products and systems are developed (partially informed views). Only 1 (6%) of the PSTs held informed views and could be able to state that engineering aims to solve a real life problem. At the end of the course, the number of the PSTs holding informed views increased to 7 (39%), which indicates that nearly half of the PSTs were able to define engineering as an endeavor to find a solution to a real life problem through creating or revising a product, system, or knowledge. Although some of the PSTs' responses regarding the scope of engineering were still limited at the end of the course, it was apparent that there was an improvement in their responses according to our scoring rubric. Below PST11's definition of engineering before and after the course are provided, respectively:

> "Engineering is an area of complex thinking which utilizes mechanical and electrical materials" (PST11, uninformed, initial view).

> "Engineering is an endeavor to create new products or improve the existing ones by utilizing varying perspectives with the aim to find a solution to a specific problem" (PST11, informed, final view).

Regarding the characteristics of good engineering, the majority of the PSTs were holding partially informed views, which refer- in our scoring rubric- to the views that mention only about the quality of the developed product but not the process or impact of engineering. The number of PSTs in the partially informed category increased slightly from 12 (67%) to 13 (72%). In addition, PST responses mentioning neither the product, process nor the impact of the engineering were coded as uninformed; and their numbers decreased from 4 (22%) to 1 (6%) after the course. The number of PSTs having informed views increased from 2 (11%) to 4 (22%). While only one of the PSTs was holding uninformed views at the end of the course, only the minority of the PSTs emphasized the impact of engineering work and process on environment or society while describing good engineering as well as the quality of the product and the process. PST4 was one of the respondents who described the characteristics of good engineering at the end of the course by emphasizing on all three of the product, process, and the impact of the engineering work. Moreover, PST2's initial response is an example of an uninformed view:

> "I would call it good engineering if it creates a product that meets the needs of people and the criteria of the engineering process; however it would be bad engineering if the impact of engineering on nature was not considered" (PST4, informed, final view).

> "To me, if it provides a solution to a problem then it is good engineering" (PST2, uninformed, initial view).

The final subcategory was related to PSTs' views about characteristics of good engineers. Their responses were categorized as uninformed if they only mention the technical skills of engineers and as informed if they mention both the technical skills/characteristics, and the intrapersonal and interpersonal skills/characteristics of engineers. 9 (50%) of the PSTs were able to mention only technical skills/characteristics of engineers before the course; therefore, their responses were coded as uninformed. After the course the number of PSTs holding uninformed views decreased to 4 (22%). The number of PSTs holding partially informed views increased from 7 (39%) to 12 (67%) and informed views stayed the same at 2 (11%) at the end of the course. The participants in the partially informed category mentioned only the technical and intrapersonal skills/characteristics and neglected the interpersonal skills/characteristics of engineers. Below are the examples of PST responses representing uninformed, partially informed, and informed views before and after the course:

> "Engineers should be patient and diligent" (PST12, uninformed, initial view).

> "Good engineers are creative, have design skills and mathematical knowledge" (PST15, partially informed, final view).

> "Good engineers are expected to be the ones who are patient and creative and also have research and inquiry, problem solving and cooperative skills" (PST8, informed, final view).

Views about EDP

PSTs' views about EDP are categorized under three sub-categories; consideration in design, what engineers do in EDP, and how engineers accomplish to complete EDP. In general, the number of PSTs having uninformed views decreased, while the number of PSTs having informed views increased in all sub-categories. However, a considerable percentage of the participants have partially informed views both before and after the course.

In terms of considerations in design category, 7 (39%) PSTs were able to mention only one or two criteria such as strength, being environment friendly, being aesthetic, and being useful, or one or two constraints such as materials, duration of the process, and cost before the course. Their views were limited in depth, because they could not realize that engineers should consider many criteria as well as constraints caused from availability of time, materials and so on to be successful in an engineering work. The number of PSTs having uninformed views decreased to 3 (16%) after the course. On the other hand, the number of PSTs having informed views increased from 5 (28%) to 8 (45%) after the course. As PST16 mentioned what engineers should consider in planning of new bridge construction, they were able to state various criteria and constraints after the course.

> "Engineers should consider the strength and safety of the bridge. They should also keep in mind the needs of the society for this bridge, like what should be the size of it to reduce the traffic problem. Besides, they should decide the strength of the materials to be used without increasing the budget sharply. They should also consider environmental conditions while selecting appropriate materials and deciding the type of the bridge. They should also have aesthetic concerns while designing. Lastly, they should plan to use human resources carefully" (PST16, informed, final view).

Although the percentage of PSTs having informed views increased, the percentage of PSTs having partially informed views were still around thirty percent after the course. Although they stated that engineers should consider both criteria and constraints, they could not elaborate their answers.

In terms of what engineers do in EDP, PSTs' views become more informed after the course. 4 (22%) participants were imagining engineers as skilled laborers (construction workers or technicians) before the course. Those PSTs mentioned that in a bridge construction process, engineers do the construction part of the bridge like construction workers.

> "Engineers do the constructing part of the bridge. They lay the foundations of the bridge" (PST6, uninformed, initial view).

The number of PSTs having uninformed view decreased to 1 (6%) after the course. On the other hand, the number of PTSs having informed views increased from 1 (6%) to 9 (50%) after the course. They started to realize that engineers have many different roles and duties in different parts of EDP beginning from planning, testing to marketing. Throughout the course what engineers do in EDP is explicitly and implicitly emphasized. Although they did not have a clear idea about what engineers do, they started to understand engineers' duties and job descriptions. However, a considerable number of PSTs have still partially informed views, although their number decreased from 13 (72%) to 8 (44%). These PSTs think that engineers only do calculations and estimations, and design the prototypes as typically PST12 stated:

> "Mathematical calculations, design and modeling is done by engineers" (PST12, partially informed, initial view).

The pattern of the progress in views about how engineers accomplish to complete EDP is also similar to the other two sub-categories. The number of PSTs having uninformed views decreased, while the number of PSTs having informed views increased. However, a considerable amount of them still have partially informed views. The PSTs having partially informed views focus on individual work of engineers like making calculations and planning as typically PST5 stated:

> "I think disciplined work is important. Moreover, engineers should do more research, use their imagination, and make careful calculations to be successful in their work" (PST5, partially informed, final views).

Although none of them consider engineering as a process, requires careful planning and implementation of the iterative EDP processes with a team including engineers who have specialty in different parts of the process at the beginning of the course, 8 (44%) of them understood the iterative process and the importance of group work in the successful completion of EDP.

> "It is not enough just to imagine the product you designed. You need to prototype your design, test it a few times, and eliminate the errors quickly together with a successful team" (PST1, informed, final view).

Overall, PSTs' views about EDP became more informed after the course. Although some of them do not have any idea about what EDP is and what engineers do in this process at the beginning of the course, they started to give more information at the end of the course. They understood the iterative process included in the EDP. However, PSTs should be supported more in understanding EDP, because there are still many PSTs having partially informed views even after the course.

Views about the Factors that Affect Engineering

The participants were asked to envision that if two different engineering firms were given the same task, would the product be more or less the same or not. PSTs' views about the factors affecting engineering developed after taking the course. Although 8 (44%) PSTs had informed views before the course, the number of PSTs having informed views increased to 14 (78%) after taking the course. That means they realized that the end product of engineering is not absolute. There may be multiple solutions to a single problem. According to their statements, the most important factors causing these differences are subjectivity and creativity of engineers, the availability of resources and the vision of the engineering companies. For example, PST9 made an emphasis on the creativity of engineers as an influential factor causing different solutions.

> "Although the criteria are the same, the product would not be the same. In fact, it would be pretty much different. Because engineers' creativity and background are different. Moreover, materials used by them differ" (PST9, informed, final view).

Some of the PSTs still could not explain the reasons causing the difference, although they thought that the end-product would not be the same. However, the number of those PSTs decreased from 6 (33%) to 2 (11%) after the course. Similarly, the number of PSTs thinking that the products would be the same decreased from 4 (22%) to 2 (11%) after the course. These PSTs argued that since the given criteria and constraints are the same, different firms' solutions would be the same.

Overall, PSTs' views developed in this category. Throughout the STEM activities, PSTs were asked to work in groups to find solutions to given problems. They observed how each group member came up with different solutions related to the problem due to the differences in their imagination. Therefore, they started to consider the influence of individual differences on the design process more after the STEM course.

Views about Science versus Engineering

PSTs' views about science versus engineering became more informed after the course. The number of PSTs having informed views increased from 10 (56%) to 15 (83%). More PSTs realized that although engineering is different from science, they also have similarities. Thus, they mentioned both similarities and differences of science and engineering after the course. They stated that both science and engineering use similar methods, and tools. PSTs referred to more general methods of problem solving like reasoning, trial and error, or experimentation rather than any specific scientific method. PSTs stated that both of them do research, and design something like products or experiments. Moreover, more PSTs started to think both science and engineering includes iterative processes. After the STEM course, PSTs realized that engineers use similar methods, techniques, and skills.

In addition to similarities, PSTs stated some differences such as science is theoretical, engineering is practical; science produces knowledge, engineering produces products; ND science is more exhaustive. Moreover, the PSTs realized that constraints have an important role in the product of engineering, although the constraints do not influence the answers reached through the scientific processes but the scientific process itself. PST10 tried to express these issues as follows:

> "It is not necessary to obtain a product in science. It may remain in the form of theory, principle, etc. It cannot reach something that has constraints in line with what is desired in science. In engineering, there must be a product at the end of the process and this product has constraints" (PST10, informed, final view).

The number of PSTs having partially informed views decreased from 5 (28%) to 3 (17%). PSTs having partially informed participants also mentioned science and engineering have both similarities and differences, but they could not clearly explain these similarities and differences. PSTs having uninformed views either considered science and engineering as the same endeavor or totally different disciplines. The number of PSTs having uninformed views decreased from 3 (17%) to 1 (5%) after taking the course.

DISCUSSION

Findings of the study revealed that for all the four categories (i.e., views about engineers and engineering, views about EDP, views about the factors that affect engineering, views about science versus engineering), the number of PSTs holding uninformed views decreased and the PSTs holding partially informed and informed views increased at the end of the semester. Moreover, except for the characteristics of good engineering and engineer, the number of PSTs holding informed views were the highest compared to uninformed and partially informed views in each of the sub-category. Below we presented the discussion of our findings regarding the participants' views of engineers and engineering in the four main categories.

Views about Engineers and Engineering

Regarding the views about the scope of engineering, there were no PSTs holding uninformed views at the end of the course. Moreover, the number of PSTs holding informed views increased considerably. On the other hand, the number of PSTs holding partially informed views stayed nearly the same. These findings indicate that the STEM course was effective for improving PSTs views but not necessarily for each of the PSTs taking the course. More specifically, the STEM course was effective for changing PSTs' uninformed views into informed views, however, it was not effective enough for transforming partially informed views to informed views. In other words, more than half of the PSTs were aware at the end of the course that engineering aims to create products, knowledge, or process but they were not able to mention that the created products, knowledge, or process are for solving a real life problem. Similar findings were obtained by Kaya et al. (2017) that the number of PSTs holding uninformed views about the demarcation of engineering decreased and the number of PSTs holding informed views increased at the end of a 15-week long engineering design intervention. However, the number of partially informed views stayed nearly the same. Moreover, within the context of a semester-long engineering-focused course, Deniz et al. (2020a) reported that elementary teachers' pre and post scores for the views about demarcation of engineering were the lowest among the six aspects of the nature of engineering. Our findings can be interpreted together with the current literature that this sub-category is one of the most difficult sub-categories to be developed among the others. Further studies should focus more on finding alternative ways to develop PSTs' views about the scope of engineering.

PST views about the characteristics of good engineering and engineer mostly evolved from uninformed to partially informed. At the end of the course, all of the PSTs except one were able to mention that good engineering produces a product, system, or knowledge. However, the number of PSTs emphasized on the process of engineering or the impact that the product has on the environment and society while describing the characteristics of engineering was still low. Similar findings were obtained by Kaya et al. (2017) with preservice elementary teachers that the least development in participants' views of engineering was in the social and cultural embeddedness aspect of engineering. In another study by Wheeler et al. (2019), analysis of observational data obtained in five science teachers' classroom practices revealed that ethical aspects of engineering such as impact on environment and society were among the aspects that science teachers allocated less time on. In our study, although one of our EDP activities was specifically about solving an environment-related problem, unexpectedly, a low number of PSTs considered the environmental impact of engineering work. In addition to the emphasis on the quality of the product itself or the steps of EDP, a clear emphasis during engineering design activities on the impact of engineering work on environment and society might have revealed more participants holding informed views. Moreover, using design activities which require using outdoor spaces and collecting real data from the environment might help to develop PSTs' views about the environmental aspects of engineering.

While describing the characteristics of a good engineer, PSTs mostly mentioned intrapersonal and technical skills (and characteristics) of engineers. That is, most of the PSTs view engineers stereotypically as highly competent, hardworking, creative, and smart people However, most of them did not consider interpersonal skills such as leadership or cooperation skills while describing a good engineer at the end of the semester. This finding indicates that the PSTs still considered engineering as an individualistic profession rather than a profession that requires teamwork and collaboration among people with various expertise. Existing studies on preservice and in-service teachers' views of engineers have reported similar findings that the participants emphasize more on individualistic and technical skills and characteristics rather than social characteristics while describing a good engineer (Ergün and Kıyıcı, 2019; Hammack and Ivey, 2017). During the STEM course that was designed and implemented in the present study, the PSTs were totally free in their groups to assign duties to group members. Also, there were times some of the group members were more active than the others in the group. Therefore, they did not experience any negative effects of losing any group members. Designing more structured cooperative learning environments in STEM courses may foster PSTs' views of good engineers and lead to a more comprehensive view of engineers having social skills as well as the individualistic and technical skills.

Views about EDP

At the end of the course, the number of PSTs holding uninformed views of EDP decreased and PSTs holding informed views increased for each of the subcategories of considerations in design, what engineers do in EDP, and how engineers accomplish to complete EDP. Moreover, the number of the participants in the informed category was the highest compared to uninformed and partially informed categories after the course. These findings indicate that the STEM course was effective for the enhancement of PSTs' views of EDP. More specifically, almost all of the participants in this study were aware that engineers consider some criteria and constraints in EDP. Furthermore, at the end of the course, half of the PSTs were able to explain that rather than only doing calculations and designing prototypes, engineers have different roles and duties in different stages of EDP. Also, half of the PSTs were able to explain that engineers accomplish to complete EDP by carefully planning and implementing the iterative EDP processes with a team of engineers. One explanation for the noticeable development in PSTs' views of EDP was that the STEM course was designed as explicit-reflective in nature, that is, EDP steps were introduced explicitly (Deniz et al., 2020a) and the PSTs were supported throughout the course to experience the EDP steps in three different STEM activities related to real life. In other words, the design-based and engineering focused STEM activities might provide PSTs with the opportunity to practically apply EDP skills into the process of finding solutions to real life challenges. That might in turn foster their conceptions and views of EDP. Similar findings were obtained by Aydın-Günbatar et al. (2018) with a group of preservice chemistry teachers. In their study, Aydın-Günbatar et al. (2018) explicitly taught the engineering design stages (brainstorming, research, design, construction and testing, redesign, evaluation) proposed by Wheeler et al. (2014) and exposed the participants to five different chemistry-related STEM activities in an engineering-focused STEM course. They reported that at the end of the course, all of the participants except one developed their views of engineering and EDP in particular.

Both Aydın-Günbatar et al. (2018) study and the analysis of the data obtained from PSTs in the present study provided empirical evidence that explicit teaching of EDP could develop PSTs' views of EDP in terms of considerations in design, what engineers do in EDP, and how engineers accomplish to complete EDP.

Views about the Factors that Affect Engineering

PSTs' views of the factors that affect engineering developed at the end of the STEM course. Most of the PSTs pointed out that the two products produced by different companies would be different. This shows that PSTs realized the subjective nature of engineering. It is emphasized in different VNOE frameworks that there is no single best solution to an engineering design problem (Deniz et al., 2020a; Karataş et al., 2016). When their explanations causing this difference were examined, it was found that most of them highlighted the creativity of engineers. They stated that different engineers in the team of different companies have different states of mind and imagination. Therefore, they understood the major role of creativity and imagination of engineers in solving an engineering design problem. The subjective NOE aspect was the aspect in which students made considerable progress in other similar studies as well (Aydoğan and Çakıroğlu, 2022; Deniz et al., 2020a). Similarly, in our study, this category is one of the categories that almost all of the PSTs have informed views after the STEM course. Only a small minority of them mentioned that the two products would be similar, and the reason was reported as the similarity of the groups' task requirements.

In general, PSTs developed an understanding about subjectivity and creativity in engineering. However, there are also other various factors that might cause differences and similarities between engineering products that were not considered by PSTs. For instance, the majority of the PSTs did not mention the possibility that the two groups of engineers may have to carry out EDP with different constraints and specifications. Yet, which constraints and specifications are determined by engineers to be considered in EDP majorly influence the produced technology (the product or process) (Cross, 2000; Pleasants and Olson, 2019b). Moreover, those who stated that engineers themselves are the critical factor that creates the difference between the two products, mostly focused on imagination and none of them mentioned about the other important characteristics of engineers that may influence EDP such as value systems, social and cultural background, ethical considerations, and communications skills (Adams, 2004; Fromm, 2003). Karataş et al. (2016) found similar results that the engineering students who stated the existence of multiple ways of solving the same engineering problem referred only to the creativity of engineers and did not recognize the other factors causing the diversity in engineering solutions. More emphasis on the other factors causing differences could be beneficial to develop a better understanding.

Views about Science versus Engineering

It is important for science teachers to understand the relationship between science and engineering to be able to teach engineering in science classrooms as indicated in the Turkish science curriculum (MNE, 2018). The number of PSTs having informed views after the STEM course was the highest in this category. The PSTs noticed that science and engineering have both commonalities and differences. Although engineering is different from science, the logic behind the systems engineering approach and the scientific discovery have resemblance (Lewin, 1983). They understood and clearly explained this resemblance. PSTs stated that both of them do research, and design something like products or experiments. Moreover, more PSTs started to think both science and engineering includes iterative processes. In their previous coursework, the PSTs had experience on doing scientific investigations by following iterative processes in different courses such as laboratory applications in science. Therefore, they were already familiar with the methods and skills used and procedures followed in scientific investigations. After experiencing the EDP in the course, PSTs realized that engineers use similar methods, techniques, and skills. They also realized that the steps followed in EDP are not straightforward as in the hypothesis testing process.

PSTs also stated the differences between science and engineering. They mostly thought that science and engineering have different goals so yield different products, and engineers use the products of science (scientific knowledge) to create engineering products (artifacts). However, they failed to recognize that engineering is also concerned with knowledge production, although it is in a different form from scientific knowledge (Pleasant and Olson, 2019b). The knowledge produced in engineering is specifically for use in design, and engineers need this knowledge base specific to engineering (Pleasant and Olson, 2019b).

Overall, PSTs had informed views about science versus engineering after the STEM course. However, the number of PSTs having informed views before the course was also high. Participants of this study were PSTs in their last semester of their teacher education program. They took many courses about the nature of science (NOS). While there are some courses which aim mainly to teach NOS, there are also other courses that utilize NOS and relate it with other concepts. Therefore, although it is not assessed in the scope of this study, they were expected to have informed views about NOS. Therefore, their NOS views would have contributed to their views of NOE.

Investigating the relationship between views of NOS and views of NOE can be enlightening to understand the high levels of understanding revealed in this category both before and after the STEM course.

Limitations and Future Work

This study has some limitations to be considered while interpreting the current results. First, the implementation lasted eight weeks and four of it were devoted to EDP activities. Engineering is an iterative process and exposure to EDP in limited times may not lead to meaningful learning (Schunn, 2009). Students need to be given the opportunity to redesign to develop better views about engineers and engineering (Schunn, 2009). In this study, PSTs were given enough time only in one of the activities (bridge design) to redesign their solutions in the second week. If there would be a chance to let them study on the same project for the whole semester and give enough time for each step of EDP, they would develop a more complete understanding of engineers and engineering. Moreover, the findings of the study are limited to the specific context of this study. There is only one group consisting of volunteer PSTs selecting the elective course. Applying this implementation to a different group of PSTs with a different educational background might yield different results.

In the present study, similar to the previous research (e.g., Aydın-Günbatar et al., 2018; Pleasants and Olson, 2019a; Pleasants et al., 2020) working with other group members and taking continuous feedback from the instructors throughout EDP experiences helped PSTs develop their views of EDP during the STEM elective course. However, it would be speculative if we report that the designed STEM course with more focus on experiencing EDP is fully effective in developing PSTs' views of engineers and engineering for all of the subcategories. Further attempts to develop PSTs' views about engineering and engineers are advised by especially including more explicit references to moral and cultural issues in engineering design activities.

CONCLUSION

This study investigated PSTs' views of engineering and engineers before and after an elective engineering-focused STEM course. The results indicated that overall PSTs views of engineering and engineers improved after the course and the number of PSTs holding uninformed views decreased for each of the subcategories. The PSTs' views became more informed, although there is a need for more improvement. As it was suggested in the related literature, offering courses in preservice education have the potential to help PSTs develop sound views about engineers and engineering (Aydın-Günbatar et al., 2018; Pleasants et al., 2020). This study provides empirical evidence that providing PSTs with explicit NOE instruction and engaging them in EDP activities is effective to develop their views of engineering and engineers. However, there were still stereotypical views of engineers among PSTs at the end of the course. Although most of the PSTs were aware of the cognitive skills required in engineering, they mostly ignored the sociocultural aspect of engineering. Therefore, in order to develop a more complete view of engineers and engineering, the value-added nature of engineering should be taught to PSTs through explicit emphasis on the social and environmental norms in the designed activities.

REFERENCES

Adams, C. C. (2004). The role of humanities in distinguishing science from engineering design in the minds of engineering students. In D. F. Ollis, K. A. Neeley and H. C. Luegenbiehl (eds.), *Liberal education for 21st century engineering: Responses to ABET/EC 2000 criteria* (pp. 91-112). New York: Peter Lang.

Antink-Meyer, A. and Meyer, D. Z. (2016). Science teachers' misconceptions in science and engineering distinctions: Reflections on modern research examples. *Journal of Science Teacher Education*, 27(6), 625-647. https://doi.org/10.1007/s10972-016-9478-z

Aydın-Günbatar, S., Tarkın-Çelikkıran, A., Kutucu, E. S. and Ekiz-Kıran, B. (2018). The influence of a design-based elective STEM course on pre-service chemistry teachers' content knowledge, STEM conceptions, and engineering views. *Chemistry Education Research and Practice*, 19(3), 954-972. https://doi.org/10.1039/C8RP00128F

Aydoğan, B. and Çakıroğlu, J. (2022). The effects of engineering design-based instruction on 7th grade students' nature of engineering views. *Journal of Science Education and Technology*, 31(1), 68-80. https://doi.org/10.1007/s10956-021-09931-2

Capobianco, B. M., Diefes-Dux, H. A., Mena, I. and Weller, J. (2011). What is an engineer? Implications of elementary school student conceptions for engineering education. *Journal of Engineering Education*, 100(2), 304-328. https://doi.org/10.1002/j.2168-9830.2011.tb00015.x

Chou, P. and Chen, W. (2017). Elementary school students' conceptions of engineers: A drawing analysis study in Taiwan. *International Journal of Engineering Education*, 33(1), 476-488.

Creswell, J. W. (2007). Qualitative inquiry and research design: Choosing among five approaches (2nd ed.). Thousand Oaks, CA: SAGE.

Cronbach, L. J., Gleser, G. C., Nanda, H. and Rajaratnam, N. (1972). *The dependability of behavioral measurements: Theory of generalizability scores and profiles*. New York: Wiley.

Cross, N. (2000). *Engineering design methods: Strategies for product design* (3rd ed.). Chichester, NY: Wiley.

Deniz, H., Kaya, E., Yeşilyurt, E. and Trabia, M. (2020a). The influence of an engineering design experience on elementary teachers' nature of engineering views. *International Journal of Technology and Design Education*, 30, 635-656. https://doi.org/10.1007/s10798-019-09518-4

Deniz, H., Yeşilyurt, E., Newman, S. J. and Kaya, E. (2020b). Toward defining nature of engineering in the next generation science standards era. In V. L. Akerson and G. A. Buck (eds.), *Critical questions in STEM education* (pp. 33-44). Springer. https://doi.org/10.1007/978-3-030-57646-2_3

Ergün, A. and Kıyıcı, G. (2019). The effect of design based science education applications of science teacher candidates on their perceptions of engineering education and engineer. *Pegem Eğitim ve Öğretim Dergisi* [*Pegem Journal of Education and Training*], 9(4), 1031-1062. https://doi.org/10.14527/pegegog.2019.033

Fralick, B., Kearn, J., Thompson, S. and Lyons, J. (2009). How middle schoolers draw engineers and scientists. *Journal of Science Education and Technology*, 18(1), 60-73. https://doi.org/10.1007/s10956-008-9133-3

Fromm, E. (2003). The changing engineering educational paradigm. *Journal of Engineering Education*, 92(2), 113-121. https://doi.org/10.1002/j.2168-9830.2003.tb00749.x

Hammack, R. and Ivey, T. (2017). Elementary teachers' perceptions of engineering and engineering design. *Journal of Research in STEM Education*, 3(1/2), 48-68. https://doi.org/10.51355/jstem.2017.29

Higher Education Council. (2020). Eğitim Öğretim Alanları Sınıflamasına Göre Lisans Düzeyindeki Öğrenci Sayıları 2019-2020 [Number of Undergraduate Students according to Classification of Fields of Education and Training, 2019 - 2020]. Available at: http://istatistik.yok.gov.tr (Accessed December 1, 2020).

Hynes, M., Portsmore, M., Dare E., Milto, E., Rogers, C., Hammer, D. and Carberry, A. (2011). Infusing engineering design into high school STEM courses. Available at: https://files.eric.ed.gov/fulltext/ED537364.pdf

Karataş, F. Ö., Bodner, G. M. and Ünal, S. (2016). First-year engineering students' views of the nature of engineering: Implications for engineering programmes. *European Journal of Engineering Education*, 41(1), 1-22. https://doi.org/10.1080/03043797.2014.1001821

Karataş, F. Ö., Micklos, A. and Bodner, G. M. (2011). Sixth-grade students' views of the nature of engineering and images of engineers. *Journal of Science Education and Technology*, 20(2), 123-135. https://doi.org/10.1007/s10956-010-9239-2

Kaya, E., Newley, A., Deniz H., Yeşilyurt, E. and Newley, P. (2017). Introducing engineering design to a science teaching methods course through educational robotics and exploring changes in views of preservice elementary teachers. *Journal of College Science Teaching*, 47(2), 66-75. https://doi.org/10.2505/4/jcst17_047_02_66

Kim, S. and Song, J. (2021). The nature of technology and engineering (NOTE) as perceived by science and technology teachers in Korea. *Research in Science & Technological Education*. https://doi.org/10.1080/02635143.2021.1924656

Koo, T. K. and Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, 15(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Lewin, D. (1983). Engineering philosophy: The third culture?. *Leonardo*, 16(2), 127-132. https://doi.org/10.2307/1574800

MNE. (2018). *Fen bilimleri dersi öğretim programı (İlkokul ve Ortaokul 3, 4, 5, 6, 7 ve 8. sınıflar)* [*Elementary and middle school science curriculum for grades 3, 4, 5, 6, 7 and 8*]. Ministry of National Education, Ankara-Turkey.

Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A. and Stohlmann, M. S. (2014a). A framework for quality K-12 engineering education: Research and development. *Journal of Pre-College Engineering Education Research (J-PEER)*, 4(1), Article 2. https://doi.org/10.7771/2157-9288.1069

Moore, T. J., Johnson, C. C., Peters-Burton, E. E. and Guzey, S. S. (2016). The need for a STEM road map. In J. J. Johnson, E. E. Peters-Burton and T. J. Moore (eds.), *STEM road map: A framework for integrated STEM education* (pp. 3-12). New York, NY: Taylor & Francis. https://doi.org/10.4324/9781315753157-1

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W. and Roehrig, G. H. (2014b). Implementation and integration of engineering in K-12 STEM education. In S. Purzer, J. Strobel and M. Cardella (eds.), *Engineering in precollege settings: Research into practice* (pp. 35-60). West Lafayette, IN: Purdue Press. https://doi.org/10.2307/j.ctt6wq7bh.7

NAE. (2010). *Standards for K-12 engineering education*. Washington, DC: National Academies Press.

Nathan, M. J., Atwood, A. K., Prevost, A., Phelps, L. A. and Tran, N. A. (2011). How professional development in project lead the way changes high school STEM teachers' beliefs about engineering education. *Journal of Pre-College Engineering Education Research*, 1(1), 15-29. https://doi.org/10.7771/2157-9288.1027

NGSS. (2013). *Next generation science standards: For states, by states*. Washington: The National Academies Press.
NRC. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.
NRC. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.
NRC. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. US: National Academies Press.
Pleasants, J. and Olson, J. K. (2019a). What is engineering? Elaborating the nature of engineering for K-12 education. *Science Education*, 103, 145-166. https://doi.org/10.1002/sce.21483
Pleasants, J. and Olson, J. K. (2019b). Refining an instrument and studying elementary teachers' understanding of the scope of engineering. *Journal of Pre-College Engineering Education Research*, 9(2), Article 1. https://doi.org/10.7771/2157-9288.1207
Pleasants, J., Olson, J. K. and De La Cruz, I. (2020). Accuracy of elementary teachers' representations of the projects and processes of engineering: Results of a professional development program. *Journal of Science Teacher Education*, 31(4), 362-383. https://doi.org/10.1080/1046560X.2019.1709295
Schunn, C. (2009). How kids learn engineering: The cognitive science. *The Bridge: Linking Engineering and Society*, 39(3), 32-37.
Taşdemir, A. and Çalık, M. (2017). Fen bilimlerinde STEM uygulamaları. In S. Çepni (ed.), *Kuramdan uygulamaya STEM eğitimi* (pp.293-352). Pegem Akademi: Ankara.
Wheeler, L. B., Navy, S. L., Maeng, J. L. and Whitworth, B. A. (2019). Development and validation of the classroom observation protocol for engineering design (COPED). *Journal of Research in Science Teaching*, 56(9), 1285-1305. https://doi.org/10.1002/tea.21557
Wheeler, L. B., Whitworth B. and Gonczi A. (2014). Engineering design challenge. *Science Teacher*, 81(9), 30-36. https://doi.org/10.2505/4/tst14_081_09_30
Yoon, S. Y., Diefes-Dux, H. and Strobel, J. (2013). First-year effects of an engineering professional development program on elementary teachers. *American Journal of Engineering Education*, 4(1), 67-84. https://doi.org/10.19030/ajee.v4i1.7859

APPENDIX A

Table A1. Subcategories and codes/subcodes for VNOE

Sub-categories	Codes (Sub-codes)	Exemplar
Views about engineers and engineering		
Scope of engineering	Creating/improving products, identifying and solving problems, integration of different disciplines, involving different branches, discovering how and why things work, making things/life easier, contribution to country development	I think engineering is the profession of people who can find practical solutions to the problems by utilizing technology, mathematics, and science.
Characteristics of good engineering	Product oriented (aesthetic, profitable, meeting the needs, strength, usefulness, originality), process oriented (methods and tools, implementation process), impact oriented (environment, society)	[Good engineering] can be determined by the resulting product. The product should be useful. [Good engineering] can be distinguished from the method and algorithm used in works. I would call it good engineering if it gives no harm to the environment in any way.
Characteristics of good engineer	Technical skills/characteristics (adapting to recent developments, scientific and technical knowledge, design skills, inquiry, and research skills), intrapersonal skills/characteristics (hardworking, solution oriented, open minded, dedicated, patient, disciplined, imaginative and creative, diligent, analytical thinking, have an agile mind, problem solver, self-confidence), interpersonal skills/characteristics (leadership, cooperative)	The engineer should follow the developments in his/her field and keep up with these developments. You have to be a very careful and disciplined person in order to complete the work and avoid mistakes. Engineers should be able to cooperate with other workers in the team.
Views about engineering design process		
Considerations in design	Criteria (meeting the needs, environment friendly, strength, usefulness, in harmony with the surrounding, added value of the product, aesthetic), constraints (materials, duration of the process, cost)	It is necessary to determine the deficiencies in existing bridges and accordingly why a new bridge is needed. Engineers should create a product that meets the constraints and criteria at the most affordable cost.
What engineers do in engineering design process	Design, making estimations and calculations (estimations and calculations, strength, cost-effectiveness, time demand), planning and construction, testing prototypes, marketing	The design and modeling of the bridge is done by engineers. It is engineers' responsibility to make the bridge strong and durable.
How engineers accomplish to complete engineering design process	Collaboration of different specializations, testing prototypes through iterative cycles, careful planning, and implementation, as a teamwork	[They succeed] by working in collaboration with other fields. For example, working with an economist or accountant if s/he wants the cost to be less, or with an architect if s/he wants it to be aesthetically pleasing. Engineers would be successful if they work together harmoniously as a team.
Views about the factors that affect engineering		
Factors causing differences	People/engineers (knowledge and skills, imagination, and creativity), company opportunities and resources, vision, and mission of the company	Although the products obtained serve the same purpose, they would not be the same design because the imagination comes into play in design and the products will be different because everyone's imagination is different. The two companies have different practices according to their own purposes.
Views about science and engineering		
Similarities	Progressive, mutual relationship with technology, solving real life problems, requires creativity and imagination, includes curiosity, Inventing, methods, techniques, and skills used, includes iterative processes	Both improve with technology, and both improve technology. They are similar in terms of the methods and techniques (reasoning, experiment, etc.) they use.

Table A1 (Continued).

Sub-categories	Codes (Sub-codes)	Exemplar
Relationships	Science and engineering are complementary, using scientific knowledge to create products	Engineering benefits from science. Science can also benefit from engineering. They are intertwined.
Differences	Science produces knowledge, engineering produces products and solutions, science is theoretical, engineering is practical, tentativeness and subjectivity, science is more exhaustive	It is not necessary to obtain a product in science. It may remain in the form of theory, principle, etc. It cannot reach something that has constraints in line with what is desired in science. In engineering, there must be a product at the end of the process and this product has constraints.

Note. The underlined codes or sub-codes are illustrated in the provided exemplar.

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Case Study of a Mathematical Dance Performance "Point Has No Parts"

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ABSTRACT

This paper describes a process of developing dance performance based and inspired by mathematical concepts and development of mathematics through history. The performance was included in the manifestation of the May month of mathematics in Serbia and prepared in collaboration with mathematicians, choreographers, dancers, science communicators and designers. The mathematical-dance performance was called "Point has no parts" and covered development of several important mathematical concepts and highlighted its influences on the contemporary world saturated with technology.

Keywords: mathematics, dance, performance

INTRODUCTION

The idea of embedding mathematical concepts purposefully into mathematical performance has been previously examined by researchers (Kátai et al., 2016; Parsley and Soriano, 2009; Milner et al., 2019) who highlight some of the essential connections between mathematics and dance, such as pattern recognition and manipulation, defining problems and seeking for solutions. Both disciplines start with concrete problems and strive for abstract ideas, or vice versa and both are genially integrated to cultural values and biases while involving aesthetics (Shaffer and Stern, 2010). Also, authors state that both disciplines require sweating in the meaning of planning, hard work and exercising (Shaffer and Stern, 2010). Even though mathematics is mostly considered as abstract and neutral, there is an increasing tendency of connecting non mathematical concepts to mathematical research and education such as body and mind, experience and thoughts, proofs and imagination (Kátai et al., 2016; Parsley and Soriano, 2009; Milner et al., 2019).

The importance of embodied, multisensory, artistic experiences as a central component in conveying mathematical content has been examined by educators and cognitive scientists, since dance has a great potential for sensory and mathematical engagement (Gerofsky, 2013). The question that remains is how. That was the question that we faced when we got an opportunity to create a mathematical dance performance as a part of manifestation May Month of Mathematic during 2020 and 2021.

The connection between mathematics and art is evident and demonstrated in many ways, through paintings, designs, musical patterns, but also through poetry and dance. Some connections are more evident, than the others, easier to describe or to feel, while others are indescribable or unproved in the scientific and mathematical sense. One of those is the connection between mathematics and dance. Even though choreography could be considered as a mathematical pattern and it usually follows mathematical laws, the question that we tackled in this paper considers dancing and performance as a way of mathematical communication in order to introduce the audience with the development of mathematics and its importance to the everyday world saturated with technology and inventions.

In this paper we describe the process of developing a mathematical dance performance called "Point has no parts", which included embodying mathematical concepts by an artistic, in our case, dance. The importance of embodied and artistic experiences, as educators and cognitive scientists have examined, as a central component in conveying mathematical contents have a great potential for mathematical engagements. In this paper we are trying to answer how this can be achieved. Prejudices about mathematical knowledge are potentially hindering many interdisciplinary collaborations therefore changes in public perceptions of mathematics as a scientific field are needed in order to raise attention as to the importance of mathematics.

CREATION PROCESS

In the creation process, we agreed that the performance would consist of four phases representing references to what some call "big ideas" in mathematics. While researching and developing ideas, we had in mind that many big ideas in mathematics were discovered in the freedom of mind, and by extreme passion, all attributes that can be attached to the art of dance. We made groups of ideas and developed the story around each idea. Those "big ideas" are Euclidean geometry, Theory of numbers, Functions and modern mathematics. Each part of the performance got a title. The Euclidean geometry was called "a point" that was represented with the actual sign "·", as well as a part dedicated to the functions "$y = f(x)$". The theory of numbers has an intriguing questioning title "Is everything a number?", while modern mathematics was called "Trafficappiling", suggesting a new word that explains the influence of mathematics through technology to our everyday life. In order to make the performance closer to the audience we made a leaflet, or libretto that shortly explained the concept. The libretto was the following:

"Point has no parts"–Math dance performance reflections

Mathematics is not a careful walk on the solid roads, but it is a wild travel through ideas. This is dancing research of mathematical ideas whose beauty is in the freedom discovered by passion. Move does not lie. Nor does mathematics (Mlodinow, 2002). Imagine an absolutely incorruptible and free activity of mind. That is what Euclidean geometry is like, an exciting mathematical theory, completed from basic ideas rolled through time, shaken by theological beliefs and philosophical views. Today it leads us to reexamine our own place in the Universe. Development of geometry of simple description delivered mathematical ideals such as point, line and plane. Euclid's Elements says: "Point has no parts, line is length without width". Thousands of years ago people were watching geometry through a window opened by Euclid, which evolved from measurements of land to a discovery tool. Today we know that, besides Euclidean, there are other kinds of geometry.

Is everything a number?

Odd and even numbers, prime and compound, quadratic, friendly, but also perfect and defect, alike to our human virtues and flaws. Numbers are in living beings, and nature of numbers is connected to music or cosmic order. Pythagora says: "Everything is a number".

$$y = f(x)$$

After many centuries Rene Descartes translated space into numbers with his project of universal science. With that he helped that even the most extraordinary things can be explained to the wider audience. Fact that a line or parabola can be defined by an equation opened completely new possibilities for science. Cartesian coordinates can help to determine regularities among data and visualize its functional relations. What is depending on what? By translating our everyday life to mathematical language we can describe finance, pandemics, transport, but also emotions or popularity in the media.

Trafficappiling

"As Google says, 5 exabytes of data was created from the beginning of civilization to 2003. Today, that is the number which is created in 48 hours. Some of the data are useless, some are precious, some we miss, some make our day. Theory of graphs is used for mathematical description of data. Graphs consist of points and lines, known

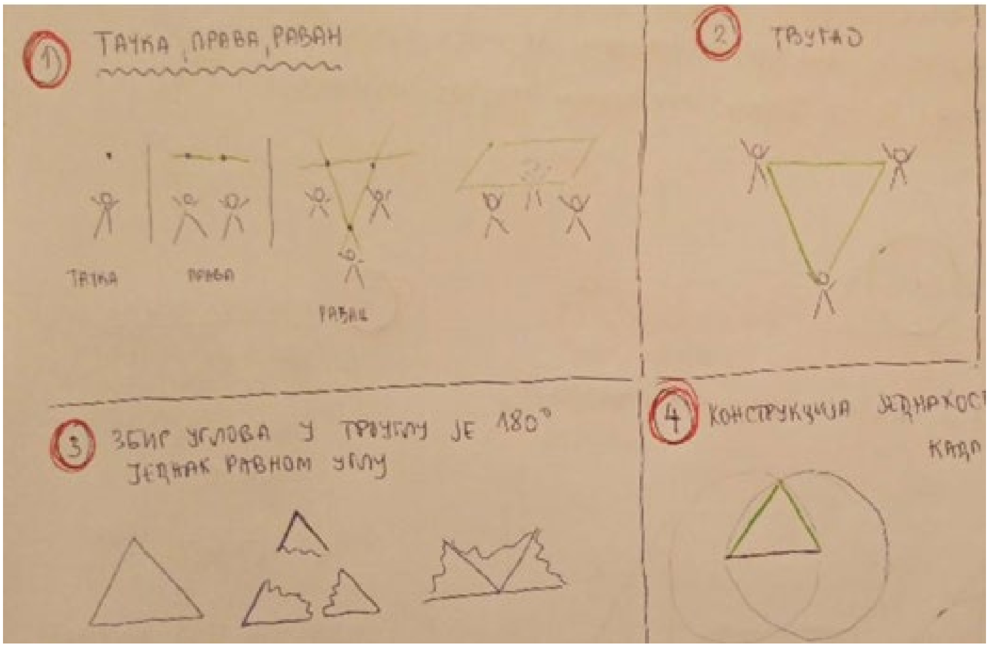

Figure 1. Sketch of mathematical theorems discussed with the choreographer

as knots and branches, which represent internet communication. Imagine that you intercept messages flying wirelessly above your head."

After agreeing on the idea of the performance, the major challenge was to explain deep mathematical concepts to the dancers who are not mathematicians and had no connections to the world of mathematics. Our collaboration started with analyzing geometrical constructions, proofs, and mathematical concepts that could resemble a choreography, and who have an active nature. Many mathematical concepts, for example, geometrical have the visual representation that could be embodied and artistically represented.

We started with Euclidean geometry which we wanted to represent as an absolutely incorruptible and free activity of mind, exciting mathematical theory rolled through times, shaken by theological and philosophical views. The basic inspiration for this part was to reexamine our own place in the Universe from a simple description of mathematical ideals such as point, line and plane. Euclidian, but also many other mathematical proofs are abstract, existing only in the imagination, but people try to represent them. For example, a point is infinitely small, but we draw it with the real size.

This phase of the performance preparation was kind of an icebreaker needed to establish acceptable communication among mathematicians and choreographers in order to understand each other and produce a desirable outcome. For that purpose we chose geometry since the connection to the physical world is the most evident. Shapes, angles or lines are also part of different aspects of dance. Some of the questions that we elaborated are what is the most beautiful, on what to put emphasis, what is practical, what is a clear mathematical explanation to non-mathematicians, what is creative, what is the idea and what is its representation. The idea was to add a visual dimension to the representation of mathematical concepts with dance where the dancer gets an active role and responsibility for clarifying mathematical concepts.

For centuries, people were examining geometry on the Euclides' postulates which evolved to a discovery tool, and today we know that there are other kinds of geometry. In **Figure 1** we can see the sketch of basic mathematical notions, such as point, line, and plane and the mathematical theorem that the sum of the angles of a triangle is equal to the 180 degree angle described to the choreographer, with physical representation. We can see that the points are represented with the sketches of humans, so dancers could easily connect to the topic.

In **Figure 2** we can see the performance of the theorem on the stage. Dancers with their movements represent the angles of the triangle, and by lying on the dance floor they represent a sum of angles. The scene is supported by visual design behind.

The next part of the performance was dedicated to number theory and inspired by Pythagoras' citation "Everything is a number". Pythagoras' citation "Everything is a number" but we presented it as an interrogative sentence, in order to highlight the importance to question mathematics and its place in everyday life. We wanted to tackle an idea that from the mathematical and scientific point of view numbering everything is acceptable, but from a human and artistic point of view it can be even dangerous. The dance scene was created as an ever-emerging vibrant city of digits filled with people who carry their stories. The rigid movement and joint shapes created by dancers addressed this issue of misinterpreted numbers or results. This part of the performance included statements such as: "Most girls lose interest in mathematics at the age of 13." or "140603 is the number on the

Figure 2. Performance of mathematical theorem

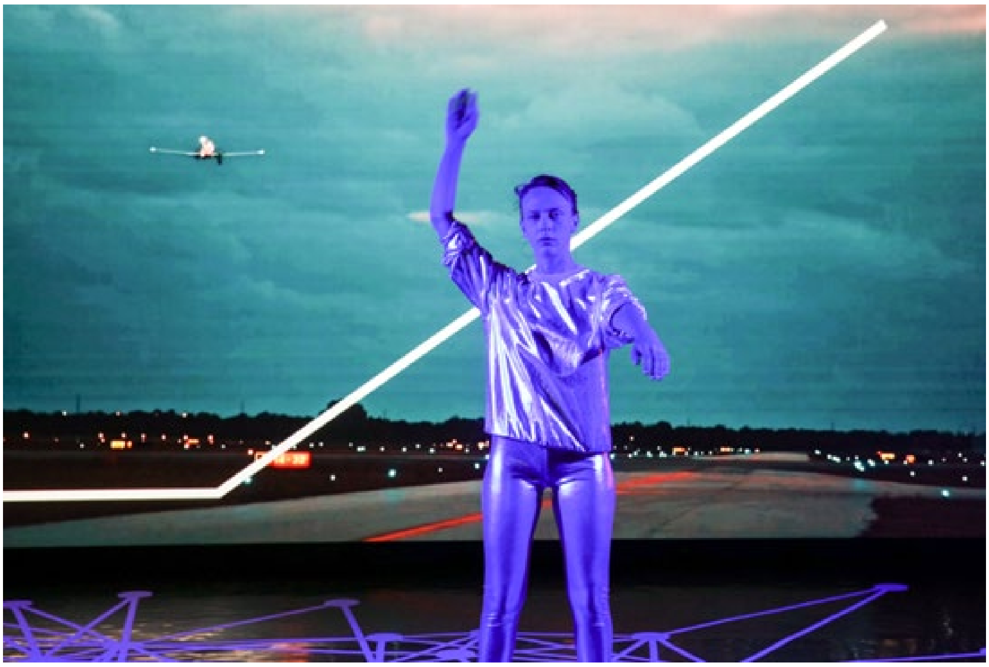

Figure 3. The artistic representation of linear function

hand of Sam Rosenzweig, a surviving Auschwitz victim" in order to illustrate how numbers might strip the richness of the meanings. As above mentioned this is also the most critical, socially engaged scene in the performance.

We are witnessing describing everyday life and events such as pandemics, transport but also popularity into mathematical language with determining regularities among data and visualizing functional relations. Development of mathematics and its use in technology provided us many benefits that we enjoy today. In Figure 3 we can see artistic performance of a linear function, and in Figure 4 we can see a dancer performing an exponential function $y = a^x$, which describes artistic expression of an exponential growth. The notion of functions was explained to dancers by real world examples, due to the fact that functions can be related to relevant concepts from real life such as velocity or bacterial growth. We explained different types of patterns and functional relationships, but also we used simple mathematical models to analyze changes mostly in real context.

Figure 4. The artistic representation of exponential growth

Figure 5. Representation of modern communication based on mathematics at the rehearsal

The most challenging part in the performance creation was to mathematically and simply explain and perform the development of modern mathematics and its influence to the modern world based on the technology. **Figure 5** represents that situation and the moment from a rehearsal. The Internet and reality based on different kinds of communication have mathematical foundations. For example, the theory of graphs is used for mathematical description of data. Our idea was to direct performance to wireless and virtual life that we all experience by using the Internet and that by sending a message there are many mathematical calculations and operations behind the process, for the most part unknown to the user. In order to make this advanced topic close to the dancers we have introduced them with the applicability and usefulness of graph theory, even though in the beginning dancers were reluctant at the beginning of preparation of the final phase of the performance. What was important for the artistic expression was to grasp the fact that graph theory represents a study of relationships. A set of nodes and connections could abstract everything from city layouts to data, simplifying moving parts of dynamic systems. Theory of graphs is used everyday to give answers for many arrangements, networking matching or operational problems. For example, the theory of graphs is one of the bases of informatics. That is why we directed performance to wireless and virtual life expanded by use of the Internet. Repetition of above: The scene of binary code rain intersected in joints of a graph was representing “caught” messages. This scene was driven by a mental experiment. If we imagine one square meter of the air above our head, let us ask ourselves what kinds of messages are transmitted via wireless signals? Some of the possible messages were shown by dancers, such as: “Enjoy the work dear!", "I am having a fever again :(", "Send kisses to grandma and grandpa!", "Would you ever admit I was right?!" or "She is coming out of hospital today!".

Once established the concept and story line, we have dedicated significant time to music that followed performance, where we have taken into account that music should follow the dynamic of movement and the artistic idea. Whole performance was followed by powerful digital stage scenography fully inspired by mathematical concepts.

CONCLUSIONS

During the process of co-creation we faced many challenges and limits. It was quite hard to overcome many prejudices about mathematics. Dancers' previous negative school experiences with mathematics and their perception of mathematics as something hard to understand was quite difficult to overcome in the creation process. At the beginning of the process insecurity inhibited their creative and artistic expression, which we overcame with rehearsals and working on the narrative and storyline. We tried to explore their views about mathematics and tried to build them in the movements, but this remained the strongest challenge in the process.

Performance "Point has no parts" attempted to employ dance as an inspiration for the audience to think about abstract mathematical concepts as a tool for understanding everyday life. We combined intuition and mathematical proof, emotions and technology, humans and machines in order to explore the problems today's world is facing due to overuse or improper use of mathematical achievements. The awareness of this interaction between mathematics and dance could help us understand both areas in a new way, and open possibilities for new research areas. The idea of the performance was to employ a flexibility of mind in combining artistic and scientific methodologies, where mathematics and dance work together in synergy. We have recognized dance as a bridge between general understanding of mathematics and the public view of mathematics. Performance "Point has no parts" was a kind of experimental mathematical communication and it was presented to the wide audience at the open scene at the Kalemegdan fortress in Belgrade in September 2020. We believe that the unusual combination of mathematics and dance art nurtured the materialized conversation between the mathematics, art and general public and provoked continuous challenges to explore things around us and ideas created in our minds in a way of uncommon performance.

We have recognized dance as a bridge between general understanding of mathematics and the public view of mathematics. The performance "Point has no parts" enhanced mathematical communication and provoked understanding of many mathematical concepts to the wide audience at the open scene at the Kalemegdan fortress in Belgrade in September, 2020. We believe that the unusual combination of mathematics and dance art nurtured the materialized conversation between the mathematics, art and general public and provoked continuous challenges to explore things around us and ideas created in our minds in a way of uncommon performance.

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REFERENCES

Gerofsky, S. (2013). Learning mathematics through dance. *Bridges Conference Proceedings: Mathematics, Music, Art, Architecture, Culture*, 337-344.

Kátai, Z., Osztián, E. and Vekov, G. K. (2016). *Promoting computational thinking by artistically enhanced algorithm.* Sapientia University, Infodidact.

Milner, J. S., Duque, C. A. and Gerofsky, S. (2019). Dancing Euclidean proofs: Experiments and observation in embodied mathematics learning and choreography. *Bridges Conference Proceedings: Mathematics, Music, Art, Architecture, Culture*, 239-246.

Mlodinow, L. (2002). *Euclid's Window: The Story of Geometry from Parallel Lines to Hyperspace*. Free Press.

Parsley, J. and Soriano, C. T. (2009). Understanding geometry in the dance studio. *Journal of Mathematics and the Arts*, 3(1), 11-18. https://doi.org/10.1080/17513470902864262

Shaffer, K. and Stern, E. (2010). Workshop on mathematics and dance. *Bridges Conference Proceedings: Mathematics, Music, Art, Architecture, Culture*, 551-554.

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Assessing the Impact of a Project-Based Learning Robotics Course with Integrating of STEM Education Using Content Analysis Method

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ABSTRACT

The National Science Foundation (NSF) proposed in 1996 "Shaping the Future" report that "STEM" (Science, Technology, Engineering, Mathematics) is a set of education methods that focus on learners. The STEM education actively cultivates students' independent thinking and creativity in the learning process. In recent years, the use of STEM education methods in teaching has become a trend in Taiwan's education system. In this study, a content analysis method is used to analyze and observe the knowledge learned and the attitude toward STEM education for a total of 30 junior students, who have no background in robotics-related professional knowledge, after taking a semester of project-based learning (PBL) robotics general course from National Chiayi University, Taiwan. From the study results, it is found that by integrating STEM into the acquisition of robotics, students can use logical thinking, compile different programs, increase their understanding of technical operations, and finally create more methods to complete the project. On the other hand, through PBL, students can stimulate thinking in discussions with their peers, and achieve the effect of problem-solving and stress-less learning. The findings of the study also show that the PBL robotics course provides the learning aids which is beneficial in exercising STEM education learned by learners.

Keywords: project-based learning, robotics, STEM education, content analysis method

INTRODUCTION

For a long time, academia has realized that experimental hands-on education can provide practical meaning for the original abstract knowledge, which provides an excellent motivation for learning new knowledge. Curriculum in robotics has been proven to be one of the best tools for hands-on learning, because it includes not only the machinery and mechanisms of the robot itself, but also the general interdisciplinary of science, technology, engineering, and mathematics, i.e., STEM. Robotics not only is a good learning environment for the application of STEM education (Kim et al., 2015) but it also provides a platform by integrating the STEM education for learners (Barak and Assal, 2018) In the learning theory, project-based learning (PBL) is regarded as an effective means of organization learning. Members participating in project-based learning usually undertake a specific task while focusing on the same goal or product as other project members. As the project develops, participating members must collect, analyze, and synthesize information from various sources to form knowledge, and communicate and share knowledge with team members to produce results through collaboration, and finally display the results or present the final product before the project deadline. Project-based learning not only can involve project members and give them their own tasks and learning responsibilities, but group members can also learn in-depth knowledge most effectively through the project team. This study uses a qualitative content analysis research method to analyze the impacts of project-based learning robotics course for STEM education, and tries to answer the following two questions:

1. How does the application of project-based learning (PBL) for STEM education curriculum help student's learning?
2. How can students benefit from integrating STEM teaching methods into robotics learning classrooms?

LITERATURE REVIEW

Nugent et al. (2010) studied whether teaching robotics in summer camp courses can affect students' STEM learning and found that robotics courses indeed can enhance students' hands-on practice, creativity, and self-learning ability. They also claimed that such STEM-related robotic camp courses provide young learners with an excellent opportunity to get involved in STEM activities and concepts. Through hands-on and inquiry-oriented robotics experimentation and design, such technologies can help youth to translate abstract mathematics and science concepts into concrete real-world applications (Nugent et al., 2010). Karahoca et al. (2011) taught robotics courses to elementary and middle school students aged 10-15 and encouraged them to participate in robotics competitions. The authors found that robotics design courses can enhance the ability of elementary and middle school students in technology and engineering, as well as their self-confidence, and help school children to learn from team design. Since robots and STEM are both interdisciplinary, it is indeed a feasible teaching and learning platform to realize STEM learning using robotics courses. With the rapid development of information technology (IT) and knowledge economy, as well as the rapid development of artificial intelligence and robotics, technology-based universities and colleges are experiencing of information technology paradigm shift from teaching the fundamentals IT knowledge to IT-related industry education (Lenschow, 1998). How to keep up with the development of the IT industry and train students with characteristics related to the information technology industry so that they can adapt to the job market has become one of the most important issues for technical colleges' students. On the other hand, the development of a knowledge society with information technology has also put forward new requirements for higher education, that is, students learn the content of knowledge that he/she is interested in and require professors to provide the required learning resources. Many educators are aware of the urgency of IT education reform to meet the current needs and future trends of the information and artificial intelligence industry and society.

In response to learners' changes in learning paradigms, the academic world has implemented curriculum reforms through work-based learning (WBL) and project-based learning (PBL) in recognizing the field of general learning technology (Gibson, 2003). Different from the traditional classroom teaching/examination method of teaching and student learning, providing industry-related project-based learning courses mean providing students with more industry-related content and self-study opportunities. Therefore, among the curriculum reforms, project-based learning (PBL) has attracted more attention in technology-oriented schools and learning institutions. Rhodes and Garrick (2003) believe that project-based learning is an attempt to integrate learning into project work, so the project results are based on both task and learning. They suggested that the participation of academia and companies in PBL should focus on teamwork, leading practical activities, and promoting reflection in the company's training plans and practical tasks. Therefore, project-based learning seems to be a possible innovative learning strategy to meet the needs of academia and companies in the changing learning paradigm. Project-based learning is also used as an effective means to provide on-the-job training for employees in the industry as well. Keegan and Turner (2001) pointed out that in project-based companies, some influencing factors may hinder project-based learning, such as time pressure, centralization, and delay. Considering that project-based learning has the nature of such influencing factors in the industry, similar influencing factors may also hinder the adoption of project-based learning teaching methods and lesson plans in universities, thus affecting the effectiveness of learning.

METHODOLOGY

In the methods of analyzing and evaluating the results of project implementation and the key factors affecting success, past literature studies have suggested cognitive map representations that can be used to extract and analyze personal mental models (Laukkanen, 1994). Cognitive map, also called cause map, is composed of nodes and arrows linked to each other (Weick and Bougon, 1986). Nodes usually represent "concepts", that is, the phenomenon that the owners subjectively perceive in their domain of knowledge, while the arrows represent their "beliefs" in the relationship that produces effects (causality). Such a cognitive map of interconnected concepts and beliefs can therefore model the causal thinking pattern of individuals or organizations and is often called a mental model. Laukkanen (1994) developed a two-stage information acquisition method and analyzed the acquired data through a series of analysis and linking processes to generate the final cognitive map. Laukkanen (1994) uses cognitive maps to compare management thinking and organizational cognition in real life. Weick and Bougon (1986) link the meaning of the organization with the cognitive map to explain that the consciousness of the organization exists in the thoughts of the participants of the organization, and the existence of the organization is presented in the form of a cognitive map. They suggest that the way of cognition of the organization should start from the participants editing their own organizational experience into a personal knowledge model, and the representation of this knowledge is called a cognitive map, which is composed of the concepts and relationships used by participants to understand the organizational situation. Carley (1997) uses textual analysis technology to extract personal cognitive maps from interview data, locate similarities between maps, and generate team cognitive maps by combining the similarities of various maps. According to her research, each person's cognitive map can be interpreted as the interviewee's mental model. The team mental model can also be generated by combining the similarities of the cognitive maps in the team. The team cognitive map generated by intersecting with individual cognitive maps represents the team cognitive map for effective teamwork. Therefore, this study adopts the qualitative content analysis research method to analyze the key characteristics of a project-based learning educational robotics course for STEM education. Integrating STEM activities and concepts for educational robotics not only help students in solving complex design problem, but it also provides an innovative learning environment in enhancing and building higher order computational thinking skills and programming abilities (Atmatzidou and Demetriadis, 2016). To conduct this research, a "Robotics Computational Thinking and Programming" general course is offered for junior college students with no background in robotics-related professional knowledge from National Chiayi University, Taiwan. Students were invited to answer the following two questions in the final week of the course after accomplishing the course assignments and final contest. And the full text of answers will be analyzed using the content analysis method to construct the cognitive map of each student.

- How does the application of project-based learning (PBL) for STEM education curriculum help student's learning?
- How can students benefit from integrating STEM teaching methods into robotics learning classrooms?

COURSE INFORMATION

A "Robotics Computational Thinking and Programming" general course is offered for junior college students with no background in robotics-related professional knowledge from National Chiayi University, Taiwan in Fall semester, 2020. There were 30 students enrolled in the course, including 9 girl and 21 boy students with ages among 20 to 22 years old. Three students are organized into a team for the "Robotics Computational Thinking and Programming" project-based learning course. After accomplishing all the course assignments and the final contest of S-shape racing track time trial, all students were invited to answer the aforementioned two questions in the final week of the course. Due to the COVID-19 pandemic, the planned interview was replaced with writing answer to the application topics. And there were only 25 students writing the answers and uploading the answering file to our course websites. The educational robotics used for the course is LEGO Mindstorms EV3, the third-generation robotics kit in LEGO's Mindstorms line. It uses a program called LEGO Mindstorms Education EV3-G to write code using software blocks by point-and-click and drag-and-drop instead of lines. (https://en.wikipedia.org/wiki/Lego_Mindstorms_EV3). The example of class assignment by integrating STEM to the EV3 Robotics application is listed in the **Table 1**.

Table 1. Example of class assignment by integrating STEM to the EV3 Robotics application

Assignment #3	To design an EV3 for running 2 meters precisely by using manual operation of EV3.
Allowed time	30 minutes
Principle	The radius of a circle is r, the perimeter of the circle is $2\times\pi\times r$
Requirements	Employing STEM and taking steps of computational thinking to accomplish the assignment
Suggested steps	1. Measuring the radius of the wheel of your EV3 robot car, calculating the perimeter of the wheel, and using a rule to make sure the length of the perimeter
	2. Measuring how many rotations wheel runs with 2 seconds and calculating distance the robot car goes
	3. Estimating how many seconds it will takes for the robot car to go for 2 meters, and run it

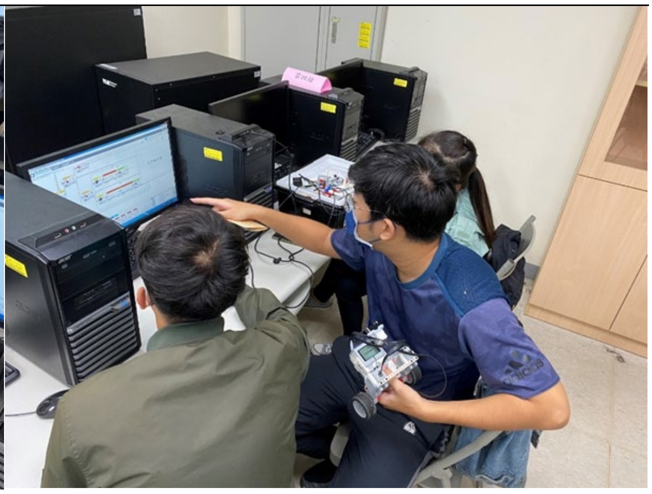
In teaching the **Table 1** assignment for an example, the teacher first explained the theory of motor for driving the robot car, and the STEM activities and concepts listed in **Table 1** were then introduced. The grading policy was that the first team to accomplish the assignment will obtain the highest grade, the slowest obtain the least

Table 2. Rules for the final contest of S-shape racing track time trial

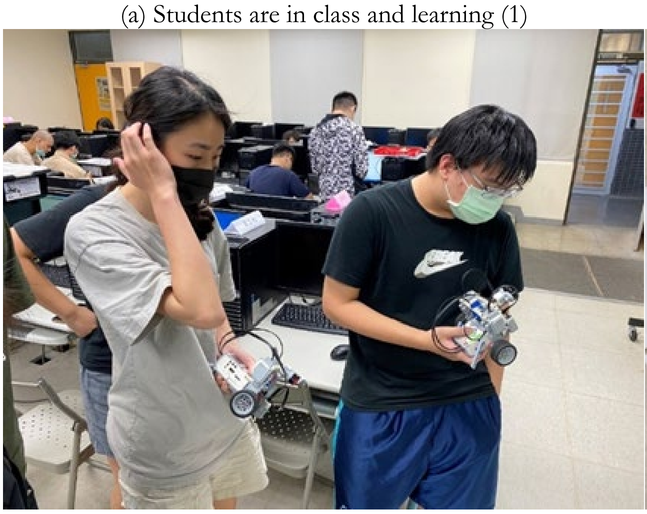
Dimensionality of the robot car	The robot car should be fitted within an A4 size paper
Playing field	80 cm × 60 cm, width of the black S-shape racing track is 2 cm
Rule 1	Each team has two times for racing by following on the S-shape racing track. The shorter time of accomplishing the time trial will be recorded
Rule 2	Each team has the allowable 3 minutes to make changes to their robot car in the preliminary round
Rule 3	The 4 shortest time trial team will be allowed for running in the final run.
Scoring policy	Preliminary round: 85 for accomplishment S-shape racing track time trial, 80 for these failed teams. Final run: 98, 94, 90, and 88, respectively for the first, second, third, and the fourth shortest time trial team.
Notes	The judge will determines whatsoever not mention in this rule

Table 3. The class photos

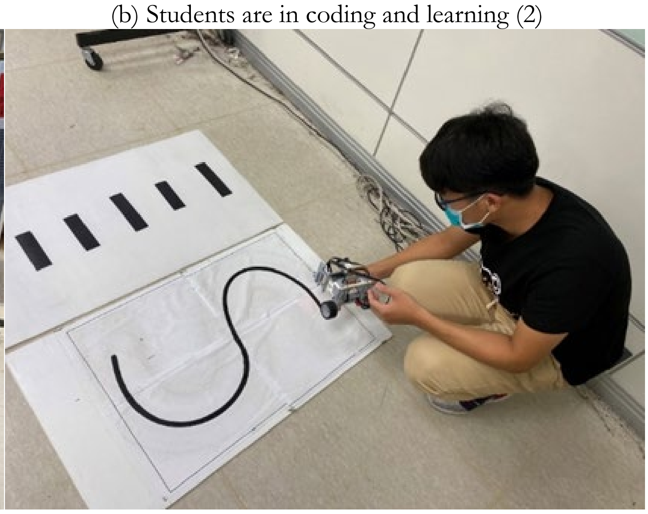
(a) Students are in class and learning (1)



(b) Students are in coding and learning (2)



(c) Students are in preparation for testing



(d) Student is under testing the robot S-shape racing track time trial

grade, and so on and so forth. Team of student was hence motivated to cooperate in group discussion in winning the highest grade. Even though the students are not used to group discussions before.

The rules of the final contest of S-shape racing track time trial are listed and explained as in the **Table 2**. Some of the class photos are shown in **Table 3**.

RESULTS AND FINDINGS

The full text answered by the students were collected from the feedback at the end of the semester. By highlighting keywords and the cause-and-effect relevance in the article, a cognitive map with logical thinking can be constructed.

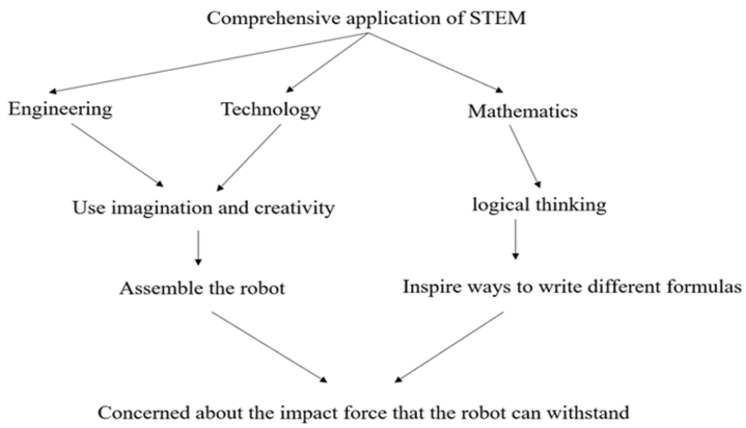


Figure 1. The example cognitive map of student #8

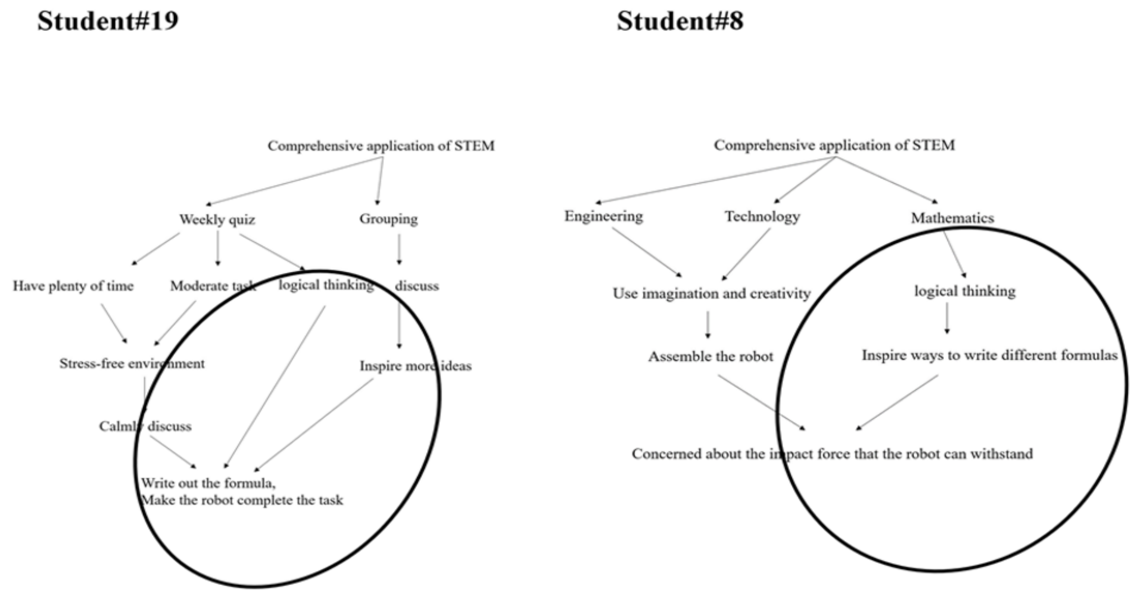


Figure 2. Comparison of cognitive maps of student #19 and student #8

How Does the Application of Project-Based Learning (PBL) For STEM Education Curriculum Help Student's Learning?

Now the issue of "How does the application of project-based learning (PBL) for STEM education curriculum help student's learning?" will be analyzed by examining the individual cognitive map as well as the team cognitive map, and by deciphering the mental model of corresponding cognitive maps. To illustrate how the cognitive map is constructed, the full text and the associated cognitive map of student #8 are listed in the following as an example. The first step in constructing the cognitive map is to extract the concept as the bold words below.

> This course is of great help to **technology**, **engineering**, and **mathematics** in the **comprehensive application of STEM**. Through the formula design, the robot can move forward, backward, rotate, etc. It can be regarded as a kind of **technology**. Assembling robots is part of **engineering**. While **using imagination and creativity**, we also **concerned about the impact force that the robot can withstand**. In addition, the possibility of **inspiring ways to write different formulas** through **logical thinking** is mathematics.

The second step of concept linking is to find out the relevant cause and effect between these keywords and use an arrow to connect the keywords of cause to the keywords of effect, and finally to draw a cognitive map which is shown in **Figure 1**.

It can be seen from **Figure 1** that based on project-based learning, combined with the learning tools of "Engineering", "Technology", and "Mathematics" in STEM, student #8 inspired a variety of different formulas through logical thinking, and was also able to exert imagination and creativity in assembling the robot.

A second and third set of full text data from student #1 and student #19 were analyzed for comparison purpose. Comparison results for the cognitive maps of student #19 and student #8, and for the cognitive maps of students # 19 and student #1are shown in the **Figure 2** and **Figure 3**, respectively.

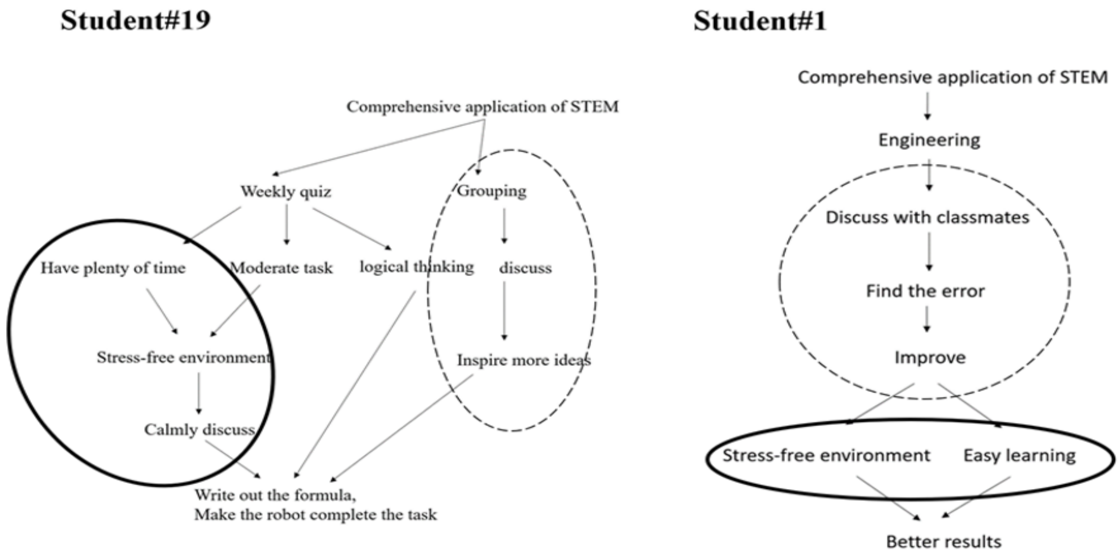


Figure 3. Comparison of cognitive maps of student #19 and student #1

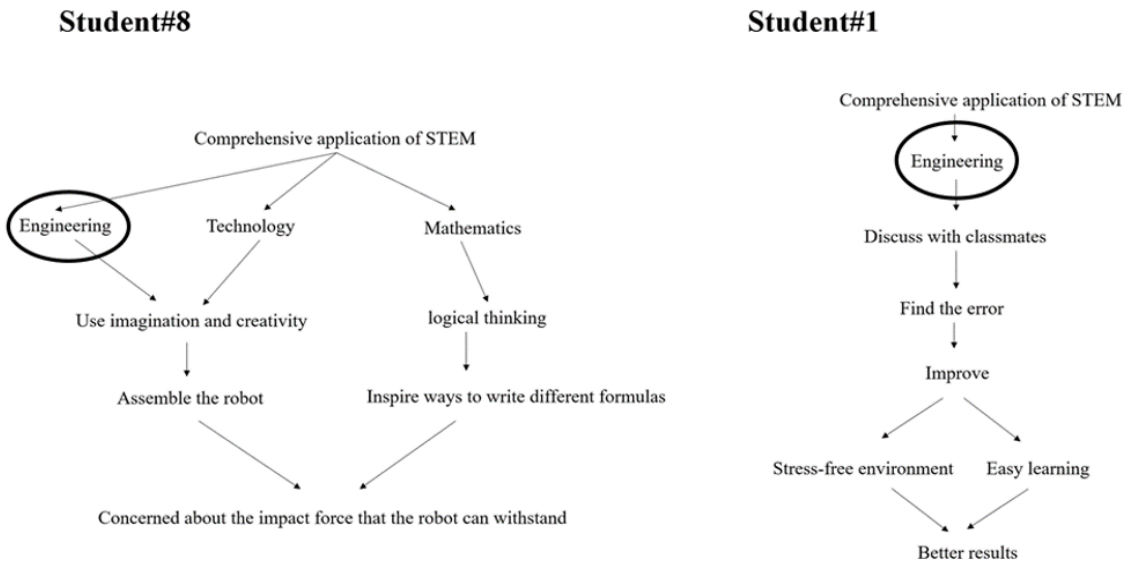


Figure 4. Comparison of the cognitive map of student #8 and student #1

By examining the cognitive map of student #19 as in the left of **Figure 2**, it is found that in one hand through weekly quizzes, student #19 was able to come up with more ideas through group discussions. On the other hand, by appropriate learning tasks and sufficient preparation time to allow students to apply STEM in writing formula and completing robotic task in a stress-free environment. Besides, commonalities can also be found from the dotted line in **Figure 2** for both cognitive maps that through logical thinking the two students have inspired more ideas and created different formulas, and finally completed the robot's task.

By examining the cognitive map of student #1 as in the right of **Figure 3**, it is found that student #1 employed the "engineering" tools in STEM to figure out how to solve the problems and make improvements to show the better robot works by discussing with the teammates in an easy learning and stress-free environment. Commonalities of cognitive maps of student #19 and #1 can be found from the dotted line that both students stimulated more ideas and found mistakes through group discussions. In addition, as indicated by the circles with bold line that given ample discussion time to allow students get better learning results in a relaxed/stress-free environment.

By examining **Figure 4**, it can be seen clearly from the circles with bold line that both students have used engineering in STEM as a tool to complete the assembly of the robot.

The abovementioned comparison results in **Figures 2-4** shown by using the project-based learning method to provide learners with moderate and task-oriented learning, it allows learners to stimulate ideas and solve problems in the process of cooperative learning, and finally complete the comprehensive application of STEM. In other word, the pedagogical method of project-based learning effectively applies the domain knowledge of STEM to the task of designing the robot.

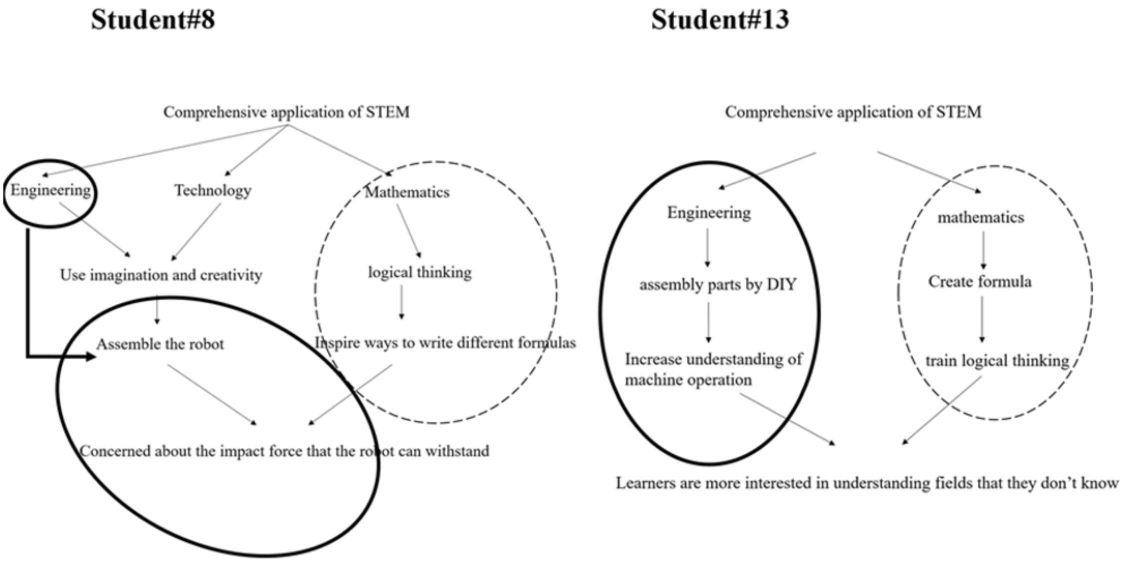


Figure 5. Comparison of cognitive maps of student #8 and student #13

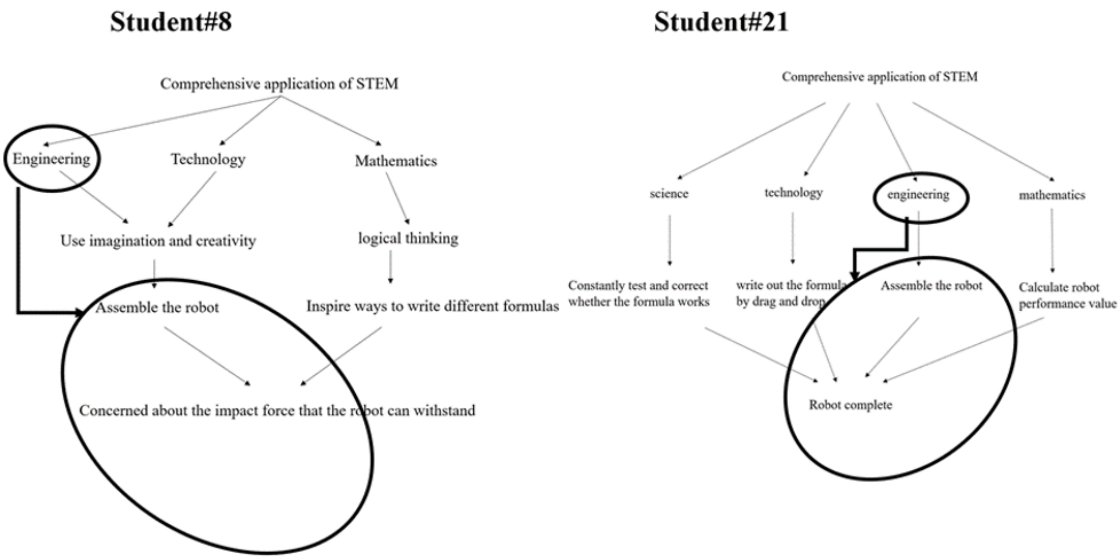


Figure 6. Comparison of cognitive maps of student #8 and student #21

How Can Students Benefit from Integrating Stem Teaching Methods into Robotics Learning Classrooms?

The following figures are comparison of cognitive maps constructed from analyzing the text content answered by three students in the class.

By reading the cognitive map of student #13, as shown in the right of **Figure 5**, one can found that student #13 learned how to assemble parts by employing the "engineering" tool in STEM, which in consequence increase the learner's understanding of mechanical operation. Through the "mathematics" tool in STEM, student #13 also learned how to write formulas and train the ability of logical thinking. Finally, student #13 was able to complete the assembly of the robot and increase their interest in understanding the robotics fields, which are different fields regarding the expertise of student #13. Commonalities among the cognitive maps of student #8 and student #13 can be found from the circles with bold line and dotted line in **Figure 5** that both students have used the tools of "engineering" and "mathematics" in STEM to accomplish the task of robot assembly. On one hand, both learners increased their own understanding of mechanical operation by assembling robot parts, and finally completed the product under consideration of the impact force that the robot can withstand. On the other hand, the arrangement of different formulas is stimulated to complete the robot by both students through logical thinking as shown in the dotted line.

By examining the cognitive map of student #21, as shown in the right of **Figure 6**, one can found that student #21 used the four tools of "science", "technology", "engineering" and "mathematics" in STEM to test whether the formula can work in solving various robotics tasks. Through correcting the formula and assembling the robot

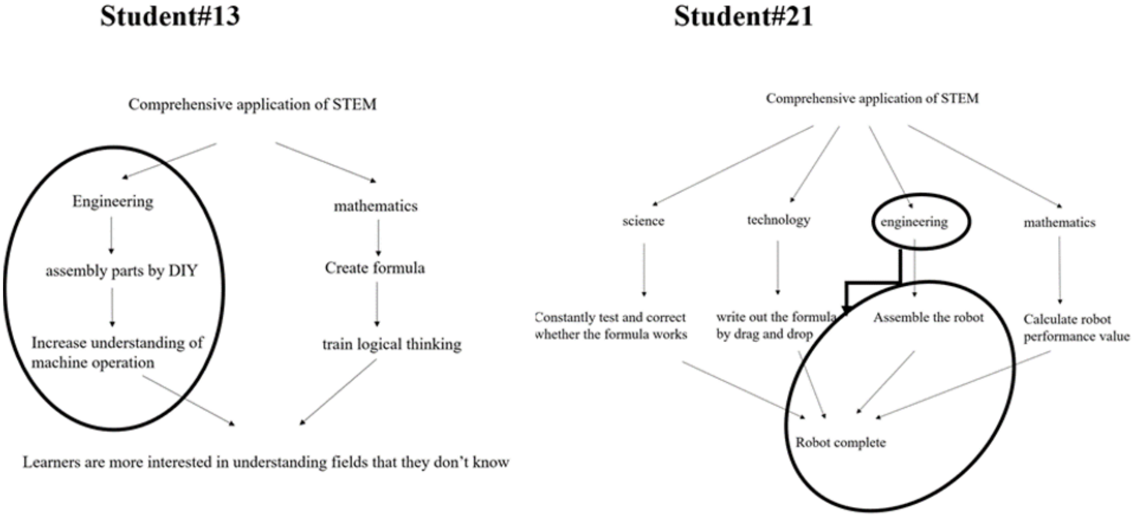


Figure 7. Comparison of the cognitive map of student #13 and student #21

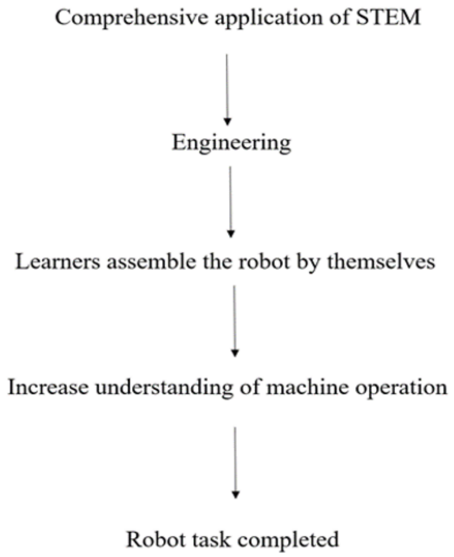


Figure 8. The collective cognitive map of student#8, student#13, and student#21

as well as calculating the robot's performance value, student #21 finally successfully completed the robot task. Besides, common feature can be seen from **Figure 6** that both students use the "engineering" tool in STEM to assemble the robot such that the requirements of the robot can be met.

By reading the cognitive map of student #13 and student #21 in **Figure 7**, one can find that both students used "engineering" tool in STEM to assemble the parts of the robot to increase the learner's understanding of the mechanical operation and to complete the robot works.

Besides, it can be expected that the commonalities can also be found by comparing and examining the pair cognitive maps in **Figure 5** to **Figure 7** among the three learners. As a result, we showed the team cognitive map as in the following **Figure 8**.

It can be clearly observed from **Figure 8** that through "engineering" tool in STEM, students learn how to assemble robots by themselves to increase their knowledge of mechanical operations and finally complete robot tasks.

CONCLUSION AND IMPLICATION

A content analysis technique for extracting and comparing abstractions of individual mental models and generating shared mental model for students from a project-based learning robotics course with integrating STEM education was presented in this study. It can be clearly seen that the application of project-based learning (PBL) robotics in the classroom with STEM as the curriculum framework has significant benefits for learners. Students benefit not only from employing STEM concepts and knowledge in fast and precisely completing various robotics tasks, but students also encourage their team creativity through exercising the PBL robotics. Through the project-based learning, a relaxed environment for learners to do cooperative learning was created for moderately accomplishing educational robotics tasks. By providing sufficient time for group discussions with STEM as the core concept, learners stimulate more ideas by reflecting on themselves and learning from their mistakes in obtaining the knowledge and competency of accomplishing robotics, w course assignment and contest which is also the core value of project-based learning. In addition, the results from the second issue also shows that the integration of STEM teaching methods into the classroom of robotics acquisition has obvious benefits for learners. On the one hand, by using the tools in STEM, learners learn how to develop computational thinking to stimulate more ideas, also know how to apply what they have learned in STEM in accomplishing the robotics tasks. On the other hand, learners not only can learn mistakes from experiments by themselves, but they also assemble robots and complete the tasks, finally inspire their own interest in different fields, which is also the core value of STEM education. Yet this research also has limitation that only a few students' response carried rich information for creating meaningful cognitive map due to the answering of application topics, instead of face-to-face interview. 25 students out of the 30 registered students responded with texted answer, but only about half of the responses bear valuable content for textual analysis. Hence, the larger the volume of students' responses with quality are collected for analysis, the better personal and team cognitive maps can be created for analysis in providing qualitative result with precision.

REFERENCES

Atmatzidou, S. and Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. *Robotics and Autonomous Systems*, 75, 661-670. https://doi.org/10.1016/j.robot.2015.10.008

Barak, M. and Assal, M. (2018). Robotics and STEM learning: Students' achievements in assignments according to the P3 task taxonomy—practice, problem solving, and projects. *International Journal of Technology and Design Education*, 28, 121-144. https://doi.org/10.1007/s10798-016-9385-9

Carley, K. M. (1997). Extracting team mental models through textual analysis. *Journal of Organizational Behavior*, 18(S1), 533-558. https://doi.org/10.1002/(SICI)1099-1379(199711)18:1+<533::AID-JOB906>3.0.CO;2-3

Gibson, I. S. (2003). From solo-run to mainstream thinking: Project-based learning in engineering design. *European Journal of Engineering Education*, 28(3), 331-337. https://doi.org/10.1080/0304379031000108768

Karahoca, D., Karahoca, A. and Uzunboylu, H. (2011). Robotics teaching in primary school education by project based learning for supporting science and technology courses. *Procedia Computer Science*, 3, 1425-1431. https://doi.org/10.1016/j.procs.2011.01.025

Keegan, A. and Turner, J. R. (2001). Quality versus quality in project-based learning practices. *Management Learning*, 32(1), 77-98. https://doi.org/10.1177/1350507601321006

Kim, C. M., Kim, D., Yuan, J., Hill, R. B., Doshi, P. and Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education*, 91, 14-31. https://doi.org/10.1016/j.compedu.2015.08.005

Laukkanen, M. (1994). Comparative cause mapping of organizational cognitions. *Organization Science*, 5(3), 322-343. https://doi.org/10.1287/orsc.5.3.322

Lenschow, R. J. (1998). From teaching to learning: A paradigm shift in engineering education and lifetime learning. *European Journal of Engineering Education*, 23(2), 159-161. https://doi.org/10.1080/03043799808923494

Nugent, G., Barker, B., Grandgenett, N. and Adamchuk, V. I. (2010). Impact of robotics and geospatial technology interventions on youth STEM learning and attitudes. *Journal of Research on Technology in Education*, 42(4), 391-408. https://doi.org/10.1080/15391523.2010.10782557

Rhodes, C. and Garrick, J. (2003). Project-based learning and the limits of corporate knowledge. *Journal of Management Education*, 27(4), 447-471. https://doi.org/10.1177/1052562903255859

Tseng, K.-H., Chang, C.-C., Lou, S.-J. and Chen, W.-P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal Technology Design and Education*, 23, 87-102. https://doi.org/10.1007/s10798-011-9160-x

Weick, K. E. and Bougon, M. G. (1986). Organizations as cognitive maps: Charting ways to success and failure. *The Thinking Organization*, 102-135.

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A Study of Determination of Benchmarks during the New Formation of Integrated STEM Leader Preparation Program

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ABSTRACT

Background: Integrated STEM (Science, Technology, Engineering, and Mathematics) education is crucial for teacher preparation programs that provide effective teaching in an interdisciplinary approach to teacher training. There is a need for a novel program to train pre-and in-service STEM teachers as STEM leaders who's moving a passive STEM teacher into an active STEM leader in their schools. The professional development of new STEM leaders in schools is critical so that the benchmarks of a new school program called STEM-LPP can be met. This program is intended to help develop existing STEM teachers to become more experienced and innovative in their usage of interdisciplinary ideas and team-working. An iSTEM approach (Rosicka, 2016) is more than just the skills, competencies, and knowledge of the four (STEM) domains.
Methods: A content analysis method was conducted by benchmarking the top five university master programs and academic committee meetings. The survey method was applied to design a new STEM preparation program for pre-and in-service teachers. This paper reports the benchmark collection and evaluation as a form of meta-analysis by academic meeting processes and views from existing STEM teachers from various schools how do the top five university master programs factor into your considerations? Data was collected by benchmarking and investigating STEM frameworks, models, and principles called benchmarks. Data were discussed and evaluated with academic meeting members, including two experts, two specialists in the department of curriculum development, three STEM teachers, three stakeholders, three staff professors, and two STEM master students from Suleyman Demirel University located in Almaty, Kazakhstan. Besides, 14 STEM teachers participated in evaluating in various schools. Findings: benchmarks and obtained courses were correlated to determine the relations.
Results: The six benchmarks: educational leadership, engineering/project design and integration, technology integration, multiple discipline integration, research-oriented instruction, and practice/experience-based teaching, were determined. Under these benchmarks, courses, competencies, and learning outcomes were also generated. The developing process of STEM-LPP was also confirmed by analyzing the findings from top university master programs with academic meeting studies and STEM teachers' evaluations. The correlations among the benchmarks and between benchmarks and courses were shown to have a strong correlation and their sufficiency for the criteria of LPP was displayed in the data.
Implications: This type of teacher preparation program has two crucial purposes: at first, providing a way of determining benchmarks during the formation of the teacher preparation program for STEM education program designers and developers. Secondly, it was informative on integrating STEM disciplines with STEM student projects and activity work to develop teachers' knowledge and skills. This study contributed to the construction of teacher preparation programs in universities and assisted STEM teachers in developing their teaching skills in the educational sphere. In future, such studies should be re-analyzed and evaluated by a large sample size of STEM teachers, partners, and other contributors.

Keywords: integrated STEM, STEM leader, STEM education, teacher preparation program

INTRODUCTION

The developmental studies of iSTEM (integrated STEM) teaching training programs are just as crucial as pre and in-service teacher training because of effective teaching with an interdisciplinary approach. STEM teachers in schools are rare in terms of iSTEM (iSTEM) knowledge. To be STEM leaders, they need to be supplied with iSTEM knowledge and field-content knowledge to be STEM leaders. When exploring published literature, iSTEM education has been summarily defined as teaching multidisciplinary integrated knowledge to solve transdisciplinary problems (Nadelson and Seifert, 2017; Rosicka, 2016; Wang et al., 2011). Wang et al. (2011) explained STEM integration as an interdisciplinary teaching approach that removes the barriers between the four disciplines. The iSTEM approach involves the application of knowledge and practices from multiple STEM disciplines (Nadelson and Seifert, 2017). Rosicka (2016) noticed that an iSTEM approach is more than the skills, competencies, and knowledge of the four (STEM) domains. iSTEM contains the engineering design (Sanders, 2013; Wells, 2013), problem-based (Roberts, 2013), and project-based approaches (Wells, 2013) to acquire integrated skills in four disciplines. Researchers indicated the benefits and revealed a positive effect on student achievement (Becker and Park, 2011), demonstrated an increased development of creativity, improved social skills and self-efficacy (Roberts, 2013), and allowed teachers to develop interdisciplinary knowledge, its role, and importance in everyday life (Pawilen and Yuzon, 2019) when iSTEM instruction is implemented through instructional strategies.

In most educational systems used by countries, single and specific discipline teaching without interdisciplinary work has been conducted (Burrows and Slater, 2015). The crucial issue in preparing iSTEM teachers is to train qualified teachers with integrative, interdisciplinary knowledge instead of only single discipline knowledge. Borromeo Ferri (2019) noted interdisciplinary learning and teaching require well-prepared teachers and pointed out the need for teachers, who are open-minded enough not to see only their discipline, but who like to connect several disciplines. Most teacher preparation programs include fundamental science courses and pedagogical courses, which have focused on one field of knowledge rather than interdisciplinary knowledge or integration of two or more disciplines. The current K-12 educational system is discipline-based, not problem-based, except for a few (Nadelson and Seifert, 2017). STEM education is still taught more theoretically than practically or project-based, within core disciplines by school syllabi.

The following issues have been identified; insufficient focus on the challenge of having STEM integrated knowledge of teachers (Dagan et al., 2019), the difficulty of incorporating several disciplines together (Kelley et al., 2021), and having the limited utility of isolated science courses and the insufficiency of general teaching method courses to serve integrated knowledge, are being discussed for future science teachers in higher education. Becker and Park (2011) also emphasized that the implementation of the integrative approaches highly depends on STEM teachers' perceptions toward the integrative approach and delivery methods in schools. In this respect, Dagan et al. (2019) pointed out that STEM teachers are vital people and need to be trained as educational leaders aligned with the vision and principles of integrative STEM education in teacher preparation programs.

LITERATURE REVIEW

Research studies on STEM teacher preparation programs by some scholars focused on the features of STEM teacher preparation programs by describing STEM integration programs' principles, frameworks, standards, and other features. Rosengrant et al. (2019) evaluated and developed two existing STEM education programs; the goal is to provide a series of standards to guide the education of STEM teachers. Rosengrant et al. (2019) presented them, and the first two were focused on content knowledge and pedagogy. They said, *"If an educator is not knowledgeable about their topic, they cannot be very effective"* so that the graduate program whose participants should be had content knowledge and pedagogical skills with teaching strategies. According to Rosengrant et al. (2019) research study, the standards directly related to STEM education were 'practice, use of technology, educational research, engineering by design, and STEM content integration'. "The practice standard" provided practical learning on; how to integrate across other disciplines, supplied educational research to find ways to improve teaching. "The technology standard" was aimed to help students with the use of new technologies. "The standard of engineering by design process" empowered easy integration into other STEM fields, and the final standard of iSTEM content helped to teach interdisciplinary content for both educators and students. Hansen and Gonzalez (2014) further described the four instructional principles that are essential for the teaching and learning of STEM as "*(1) integrate technology, (2) reach across disciplines both within and beyond STEM fields, (3) relate to authentic, or real-world, problems, and (4) be based on project-focused tasks.*" Moore et al. (2014) categorized components of the preparation program into subcategories: STEM practices, STEM technology, STEM content integration, real-world problems based learning and lived experience-based learning.

The important facet in the framework for integration STEM is leadership, and this is critically needed in STEM instruction (Bailey, 2020). Leadership may be described as an experienced teacher, researcher, and role model teacher. Sublette (2013) noticed the STEM-I3 model that ensures the teacher leader is a teacher first and is committed to mastering his or her practice for leadership. Ryu et al. (2019), in the study of “challenges for iSTEM teacher preparation existing programs”, an integrative master’s degree program in STEM, aiming to train educators in Israel, indicated that teachers faced challenges with limited interdisciplinary understanding and a lack of role models when authors developed an iSTEM education methods course which was taught to secondary pre-service teachers in STEM disciplines. In the description of background information by Dagan et al. (2019), they published the relevant objectives: developing leadership with project-based learning experience and advancing the “teacher researcher” approach within STEM teaching through Project-Based Learning (PBL). Research is also needed to prepare STEM teachers to become leaders (Bailey, 2020) and presented this as a standard “accessing research to improve educator development” that was shown in teacher leader standards constructed by Teacher Leadership Exploratory Consortium (TLEC).

Burrows and Slater (2015) illustrated the iSTEM teaching trajectory covered five levels from zero to four, which were ‘single discipline, discipline plus mathematics, multiple disciplines, engineering projects, and constant iSTEM’ for teachers. They particularly noted that teachers and curriculum designers purposefully included engineering and design projects to help students’ learnings while level three engineering project, was described. Project-Based learning with project activities is a key organizing element of STEM programs and curriculum arrangement (Dagan et al., 2019). DiFrancesca et al. (2014) described a STEM-focused elementary teacher preparation program that required pre-service teachers to complete an engineering design process methods class, two mathematics method’ courses and two science methods courses. The goal of this program is to cooperate engineering to a single STEM discipline. Pinnell et al. (2013) also presented application engineering design as the framework in the study of STEM education quality over three years of research and literature review.

Pinnell et al. (2013) articulated the framework ‘technology integration’ which includes instructional computers, robotics, using digital technology tools, technology supported-learning, and technological innovations. Papadakis et al. (2021) noted that educators faced various difficulties in their efforts to include educational robotics (ER) and concluded in their study that teachers need the appropriate training to learn about new forms of educational technology such as ER. The other framework is about practical and experienced teaching that provides the use of theoretical knowledge in practical pedagogical fields. Dailey et al. (2015) examined a program that gives undergraduate candidates by focusing on-field experiences. Corlu et al. (2014) suggested a program that serves practice-based instruction for pre-service teachers and emphasized teaching practice through integrated teaching knowledge may better prepare pre-service mathematics and science teachers for the profession. Another framework is multidiscipline integration that covers effective cooperative studies between science, technology, and math teachers in order to integrate content. Eckman et al. (2016) aimed to evaluate a STEM teacher education model for pre-service teacher preparation which incorporates science or mathematics content and indicate the advantages of the cooperative model that is math-science content cooperation. They focused on the STEM teaching cooperative experiences, which outlined the integration theory and practices for Noyce scholars and concluded that there are important differences, especially confidence of teachers, between the traditional STEM teacher preparation program and the Noyce STEM Scholar Program.

These views underlined by scholars inform about key benchmarks in the teacher preparation program of iSTEM. Each program was focused on various frameworks that consider in accordance with the program goal, objectives, educational standards. All literature reviews and frameworks or approaches reported in the way of fundamental knowledge (Nadelson and Seifert, 2017) for contexts in multiple STEM facets and concepts and opened the way (Burrows and Slater, 2015) to integrate teaching approaches with focusing benchmarks that provide student exploration, learning, clear understanding of how to integrate disciplines, STEM integration. According to the above literature, STEM teachers should be supplied with practical knowledge and teaching strategies in research, project-based, engineering-design oriented, technology knowledge in order to integrate STEM knowledge and implement its knowledge to reflect on design-based projects.

Research Question

It is required to develop a new teacher preparation program within the iSTEM education frameworks, models, and principles (all named benchmarks) which provides inter- and transdisciplinary knowledge and skills at the graduate level in the higher education system. Kirschner et al. (2008) noted that benchmarks had provided informative quantitative markers for annually assessing the implementation of a program. This study addressed the solutions to the following questions:

1. What frameworks, models, principles (all benchmarks) are mainly determined for the well-prepared STEM teacher preparation program?
2. To what degree is the sufficiency of these benchmarks in iSTEM leader preparation program (STEM-LPP)?
3. What is the extent of appropriateness between the benchmarks and courses with competencies and outcomes?

RESEARCH DESIGN

This study was designed in three stages: benchmarking, academic committee meetings, and survey to STEM teachers. STEM programs were examined within the scope of STEM teacher preparation programs by using the content analysis method. According to Trochim (2006), content analysis is the analysis of text documents. As content or document analysis, program information package and program description on university websites were benchmarked by analyzing frameworks, models, and principles. Frameworks, principles, and models (named as benchmarks) related to the STEM teacher preparation program were also investigated from the published relevant literature. In academic community meetings (ACM), 15 community members participated in order to evaluate and discuss the findings of benchmarks and to determine the program's goal with objectives, program outcomes, and courses with competencies. The survey was adapted and conducted in order to evaluate finding benchmarks. The survey was conducted on 14 STEM teachers with teaching experience in schools to gather information about the prepared program (LPP) and learn their opinions. The survey was based on Likert-type research. Creswell (2002) described that Likert-type research is a procedure in quantitative research to describe the attitudes, opinions, behaviours, or characteristics of the population. All variables found from benchmarking, academic meeting evaluations, and survey results were analyzed by using correlations among variables in order to confirm.

Data Collection

The data collection ways were included:

1) benchmarking with document analysis of the STEM teacher or leader preparation programs at the five top universities and investigating related literature,
2) performing academic community meetings during the iSTEM teacher program, and
3) a survey for STEM teachers' views about iSTEM program.

Data was collected by benchmarking content analysis of academic degree programs in the STEM teacher preparation program (n=5) at various universities. The determined benchmarks were considered again by investigating some related literature. The benchmarks were discussed in academic meetings within the participation of academic members. The survey was conducted with STEM teachers in the collaborating high school and professors in universities. The survey was adapted from the suggested frameworks, models, and principles related to STEM to determine the appropriateness of the STEM teacher preparation program. Some items were taken from the published instruments, and some of them were derived from STEM frameworks, principles, and models suggested in the literature. The benchmarks were responded to on a 5-point Likert scale: from strongly agree (5) to strongly disagree (1).

Data Analysis

All STEM-related frameworks, models, principles, and teaching methods from benchmarking various university master program information packages from their websites and the published literature, were documented, investigated, and analyzed. The findings were categorized to recognize as benchmarks that form the STEM-LPP. Qualitative data from the benchmarking results and the community meetings' suggestions were evaluated to identify benchmarks that will form the survey items. Survey item responses were analyzed in considering correlation values among variables. A correlation test was applied to test the relationship among finding benchmarks, program (STEM-LPP) benchmarks, and courses. it was also conducted to assess compatibility between the benchmarks and courses.

RESULTS AND FINDINGS

The first research question was "What frameworks, models, principles (all benchmarks) are mainly determined for the well-prepared STEM teacher preparation program?" For the findings of the first research question, benchmarking was conducted. The second research question was "What degree is the sufficiency of these benchmarks in iSTEM leader preparation program (STEM-LPP)?" For the second research question, the survey was applied to school teachers in order to indicate the sufficiency of the determined benchmarks. The third research question was "What extent of appropriateness between the benchmarks and courses with competencies, and program outcomes?". For the third research question, academic meetings were conducted, and the survey was applied to school teachers in order to indicate appropriateness between the benchmarks and courses with competencies and program outcomes.

Findings of Benchmarking for the First Research Question

The benchmarking method was used as a development process of teacher preparation programs with evaluation and comparison to high-level STEM training programs in five universities. The five programs were the Master of Education - Integrative STEM Education K-12 (California University of Pennsylvania Program), Master of Education in STEM (William Woods University), Master of Science in STEM Education (University of Iowa), Master of Education in Science, Technology, Engineering, Arts & Mathematics (University of San Diego), and Master of Education in Secondary Education with STEM Education program (Southern New Hampshire University). All programs' information was retrieved from the websites of these universities.

The Integrative STEM Education K-12 (California University of Pennsylvania Program) program has focused on training teachers to acquire skills which were teacher leadership skills. These skills are provided to teachers to be acquired in planning, designing, implementing hands-on activities, organizing project-based learning, student-centred learning to become technologically proficient, innovator, and collaborator. Some key benchmarks are interdisciplinary practice, inquiry-based learning, project-based learning, and leadership in educational activities with transforming curriculum, instruction, and assessment. Master of Education in STEM (William Woods University) provides education for researchers, innovators, and leaders teaching these four disciplines. The curriculum integrates technology and project-based learning with real-world problems. It was stated that "students will be able to engage and analyze data, use mathematics and models, and develop solutions." This program leads research, engineering design, integration of computer technology, project-based learning, data analysis, and mathematics. Master of Science in STEM Education (University of Iowa) program combines science and math education that serves research and leadership seminars and experiential learning. Benchmarks were determined as research and leadership, experiential learning, science, and math education combination. Master of Education in STEAM (Science, Technology, Engineering, Arts & Mathematics), (University of San Diego), empowers STEAM integration within a cross-disciplinary approach to employ a project-based learning approach in solving everyday problems. This program provides project-based learning, digital technology-used learning, data analysis, research, leadership, technological innovation. Master of Education in Secondary Education with STEM Education program (Southern New Hampshire University) prepares a teacher to become a secondary school classroom teacher while instilling a transdisciplinary mindset. This program states that it "will help teachers have cross-subject knowledge, authentic assessments, and competency-driven skills for middle and high school level students." Leadership experienced clinical learning, inquiry-based learning, technology-used learning might be accepted as benchmarks.

For findings of the first question, the five programs in indicated universities were investigated to determine the benchmarks covering framework, model, principles, and methodology of STEM education. According to Table 1, the various key benchmarks were determined. They were formulated for the preparation process of STEM- LPP on iSTEM and categorized six directions in order to indicate the main benchmarks (see **Table 1** and **Table 2**). These benchmarks were categorized as leadership, multidiscipline integration, practice/experience-based instruction, research-oriented instruction, engineering design-project-based, and technology integration (**Table 2**).

Table 1. The benchmarking of University STEM teacher preparation programs

Program name	Program aim & objectives	Key benchmarks	Courses
(CUP) California University of Pennsylvania Program: Master of Education-Integrative STEM Education K-12	To learn innovative, relevant, and engaging practices for incorporating STEM principles across disciplines in grades K-12.	Interdisciplinary practice, inquiry-based learning, project-based learning, and leadership in educational activities: transforming curriculum, instruction, and assessment.	Teachers as Leader, Methods of Research, Mathematics as Problem Solving, Foundations of Integrative STEM Education K-12, Integrating Technology in Elementary/Middle School STEM Curriculum, Integrative STEM Pedagogy and Instructional Design, Integrative Project in STEM Education, Building Scientific Literacy and Understanding Through Inquiry
(WWU) William Woods University Master of Education in STEM	The aim is to teach STEM concepts, to remove barriers that separate these four disciplines, integrating them into real-world, rigorous, and relevant learning experiences.	Research, engineering design, integration Computer technology, Project-based learning, STEM education leadership	STEM: Science, Technology, Engineering and Math–An Introduction Research Design Integrating Technology into the Curriculum, STEM: Engineering Design Software Applications for Academic Programs, STEM: Technology and Coding, STEM: Citizen Science-Project Based Learning Appraisal of Student Learning Action Research Capstone
(UI) University of Iowa Master of Science in STEM Education	The aim is to prepare educators to equip the next generation to solve challenging problems, gather and evaluate data, and apply critical thinking skills to make sound decisions.	Research and leadership, experiential learning, science, and math combining education	STEM Research and Leadership Seminar, STEM Experiential Learning, STEM Through Mathematical Modeling Science or Math Graduate-Level Courses, STEM Independent Research, STEM Extracurricular Experience and Capstone Coursework

Table 1 (Continued).

Program name	Program aim & objectives	Key benchmarks	Courses
(USD) University of San Diego Master of Education in Science, Technology, Engineering, Arts & Mathematics	to help your students critically analyze information and to compose, create and collaborate using the latest digital technology	STEAM project-based learning, digital technology-used learning, Analytics, research, leadership, technology innovation	Social Justice and Educational Equity Cognition and Learning Educational Research Methodology Qualitative Methods in Educational Research Capstone Seminar Inclusive Learning: Special Education and Universal Design Literacy and Digital Learning Curriculum and Instruction School Leadership Technology and Innovation
(SNHU) Southern New Hampshire University, Master of Education in Secondary Education with STEM Education Program	The aim is to teach in the growing number of schools that have adopted a competency-based approach to teaching and learning.	Leadership, experienced clinical learning, inquiry-based learning, technology-used learning.	Theoretical Foundations Classroom and Behavior Management Initial STEM Clinical Students with Exceptionalities Secondary Instructional Methods I-II Professional Clinical Experience I-II Assessment for and of Learning Learning through Technology Advanced STEM Clinical Educational Leadership and Change

Table 2. The categorized benchmarks and frequency

Category name	Description	Universities					Frequency (f)
		CUP	WWU	UI	USD	SNHU	
Leadership	Leadership in educational activities, inquiry-based learning, digital technology-used learning	+	+	+	+	+	5
Practice/experience-based	Interdisciplinary practise, experiential learning, clinical experienced learning, science, and engineering practices	+		+		+	3
Engineering/project design-based	Engineering integration and design projects, project-based teaching (STEM & STEAM)	+	+		+		3
Research-oriented	Research-oriented instruction		+	+	+		3
Multiple discipline integration	Multiple discipline integration, science and math education combination, data analysis and mathematics			+			1
Technology integration	Technology integration and computer use, technological innovation		+		+		2

Findings of Survey for the Second Research Question

The second question, "To what degree is the sufficiency of prepared iSTEM-LPP in terms of the following benchmark?" gave information about the sufficiency of categorized benchmarks that followed as educational leadership, multidiscipline integration, research-oriented instruction, practice/experience-based teaching, engineering/project design-based teaching, and technology integration. Before the survey, the information of iSTEM-LPP was introduced to 14 STEM teachers by exploring the program aim, objectives, competencies, and target outcomes. At that time, the indicated teaching courses with contents and course purposes were also presented to STEM teachers. To this, together, the preparation stages of the iSTEM-LPP were mentioned to give information about the program. Two main questions were answered by the Likert type, five-point scale with the following scale type: 1–most insufficient; 2–insufficient; 3–uncertain; 4–sufficient; 5–most sufficient.

The results with frequencies and percentages are shown in **Table 2** and **Table 3**.

According to **Table 3**, for question 1 that asked the sufficiency of benchmarks STEM leader preparation program, the highest-rated sufficient benchmark at 64% of total sufficient and most sufficient choice was "Engineering integration and design projects". The lowest rated sufficient benchmark at 43% of total sufficient and most sufficient choice was "Multiple discipline integration". The middle level rated benchmarks at 57% of total sufficient, and the most a sufficient choice was "educational leadership, practice/experience-based teaching, research-oriented instruction, and technology integration".

Table 3. STEM teachers' opinions about the sufficiency of iSTEM-program benchmarks

Benchmarks	Survey responses						
	1	**2**	**3**	**4**	**5**	***f***	**%**
Leadership in educational activities, including instruction of problem/project-based, inquiry-based, digital technology-used	0	2	4	6	2	8	57
Interdisciplinary practice, experiential learning, clinical experienced learning, science, and engineering practices	0	2	4	6	2	8	57
Engineering integration and design projects	0	2	3	6	3	9	64
Research work, thesis/project work	0	1	5	5	3	8	57
Multiple discipline integration within science and math combination, data analysis and mathematics	0	3	5	3	3	6	43
Technology integration and computer use, technological innovation	0	1	5	4	4	8	57

Notes: The sufficiency rate for benchmarks was calculated by the percentage of the total sum of sufficient and most sufficient choice number (*f*). Responses: 1-most insufficient; 2-insufficient; 3-uncertain; 4-sufficient; 5-most sufficient.

Findings of Academic Committee Meetings' Evaluations and STEM Teachers' Survey for the Third Research Question

The Academic Committee Meeting (ACM) was recommended on formative components of the academic program for adding, expanding, or deleting benchmarks and determining courses within competencies/learning outcomes. The ACM included 15 community members who were two program experts, two university program developers, three staff professors from the science and math education department, two STEM master students, three STEM teachers, and three stakeholders. The participants' years of experience in the field of education ranged from 2 to 51 years, with a mean of 43.58 years. Committee members pointed out university strategy and academic policy during the preparation of STEM-LPP with aim, objectives, competencies, outcomes, and principles. In the light of the mentioned information, the iSTEM frameworks, models, and principles were particularly discussed. The participants recommended and discussed some stated benchmarks in determining target courses within competencies and learning outcomes. Committee members noticed that courses should be contributed to pre-service STEM teachers to be iSTEM leaders in terms of the stated benchmarks and recommendations. They are also assigned to the courses with prerequisites or corequisites and their lecture, practice, and laboratory hours that treat core knowledge and the knowledge of the iSTEM disciplines. The student performance assessment criteria were specified in the all-course outline by the faculty members during the meeting. ACM indicated that the program should be included practical works, hands-on activities and minds-on projects that support the skills of school teachers to be a good STEM leader. This program should be based upon practices, activities, and projects that assist teachers in becoming qualified iSTEM teachers in their schools. STEM-LPP should also be offered in the fields of engineering and computer science education. In the results of ACM study, some principles and objectives were accepted. In the frameworks of the recommendations, ACM studies and the six categorized benchmarks about STEM integration education, the competencies, courses, outcomes, and matrix of formation of the program was determined and presented in **Table 4**.

Table 4. Matrix of formation of teaching courses, outcomes on competency models

<table>
<tr><th>Recommended courses</th><th>Competence</th><th>Outcomes</th><th>Propositional learning outcomes</th></tr>
<tr><td>Nature of Science & Science History, Managerial Psychology, Higher Pedagogy, Cyber Pedagogy, STEM Teaching Methods, STEM Education Technology</td><td>Professional skills</td><td>1, 2, 5, 6, 7, 8</td><td rowspan="6">1-Demonstrates in-depth knowledge of professional disciplines of STEM
2-Uses modern information and digital technologies to solve specific and applied problems
3- Critically analyzes research studies in STEM, as well as organizes and conducts independent research
4-Design projects for professional problem-solving using STEM interdisciplinary research results
5-Organizes STEM training courses and programs in a formal and online format
6-Develops fundamental scientific and practical innovations aimed at the systematic solution of problems of inter and transdisciplinary education
7-Communicates effectively in professional and social environments to solve problems and make decisions
8-Carries out reflection and self-assessment of the research and project activity defines directions of further professional development</td></tr>
<tr><td>Robotics, Electronic Technologies, 3-D Design and Modelling, Cyber Pedagogy, IT Technology in STEM Education</td><td>Digital skills</td><td>2, 4, 5, 6</td></tr>
<tr><td>STEM research, Pedagogical Diagnostics, Research Methods & Data Analysis, Statistical Mathematics, Big Data, Graduation Thesis</td><td>Research skills</td><td>1, 2, 3, 4, 6, 7, 8</td></tr>
<tr><td>Commercialization, Patenting</td><td>Entrepreneurial skills</td><td>3, 8</td></tr>
<tr><td>Managerial Psychology, Industrial Design</td><td>Managerial skills</td><td>1, 2, 4, 6, 7</td></tr>
<tr><td>Industrial Design, 3-D Design and Modelling, Science Projects, Analysis of Eco- Projects, Data Analysis, Statistical Mathematics, Big Data</td><td>Personal skills: Creativity, analytical thinking, decision making, designing</td><td>1, 2, 3, 4, 5, 6, 7, 8</td></tr>
</table>

The third question "Is it appropriate for the following courses to perform the indicated benchmarks to get knowledge among STEM disciplines integration." The question-3 asked the STEM teachers (n=14) to indicate the appropriateness between presented courses and iSTEM-program benchmarks.

According to **Table 5**, the highest-rated sufficiency at 64% of total sufficient was "research-oriented courses". The lowest rated sufficiency at 43% of total sufficient and most sufficient choice was "Multiple discipline integration". The other of the rated sufficient courses at 57% of total sufficient choice was "educational leadership and engineering/project design courses, and the middle-order rated sufficient courses at 50% of total sufficient choices were practice/experience-based teaching and technology integration courses". The results with frequencies and percentages are shown in **Table 5**.

Table 5. STEM teachers' opinions about the sufficiency between courses and benchmarks

Coursework variables related to benchmarks	Courses	Survey responses (n=14)						
		1	2	3	4	5	*f*	%
Fundamental and educational leadership courses	Nature of Science & Science History, Managerial Psychology, Higher Pedagogy, Cyber Pedagogy, STEM Methods, STEM Education	0	1	5	4	4	8	57
Interdisciplinary practice-based teaching courses	ISTEM Lab Works, Science Projects, Analysis of Eco-Projects, Internship	0	2	5	5	2	7	50
Engineering/project design courses	Industrial Design, 3-D Design and Modelling, Science Projects, Eco- Projects, Patenting Commercialization,	0	2	4	6	2	8	57
Research-oriented courses	STEM Research, Pedagogical Diagnostic, Research Methods & Data Analysis, Statistical Mathematics, Big Data, Graduation Thesis	0	1	4	7	2	9	64
Multi disciplines integration courses	Robotics, Electronic Technologies, 3-D Design and Modelling, Cyber Pedagogy, IT Technology	0	2	6	4	2	6	43
Technology integration courses	Robotics, Electronic Technologies, 3-D Design & Modelling	0	2	5	5	2	7	50

Notes: Teachers responded with more than one choice. The rate of sufficiency *frequency (f)* was calculated by the percentage of the total sum of sufficient and most sufficient one. Responses: 1-most insufficient; 2-insufficient; 3-uncertain; 4-sufficient; 5-most sufficient.

All findings and results were also confirmed by analysis of correlation results. Correlation values were checked to understand the adequacy relationship of the benchmarks. Correlation values were analyzed among FUP (Frequency from University STEM programs), PRSB (Percentage of responses of the sufficiency benchmarks), and PRSC (Percentage of responses of the sufficiency of courses). Correlations between FUP and PRSB, FUP and PRSC, PRSB and PRSC are equal to 0.59, 0.65, and 0.68, respectively (see **Table 6**).

Table 6. Evaluation values and correlations among FUB, PRSB, and PRSC values

Benchmarks	FUP	Evaluation values by STEM teachers		Correlation values among variables
		PRSB	PRSC	
Leadership in educational activities	5	57	57	*Correlation between FUP and PRSB-0.59
Practice/experience-based teaching	3	57	50	
Engineering-design and project-based teaching	3	64	57	*Correlation between FUP and PRSC-0.65
Research-oriented teaching	3	57	64	
Multidisciplinary integration	1	43	43	*Correlation between PRSB and PRSC
Technology integration	2	57	50	

Notes: FUP: Frequency from university STEM programs; PRSB: Percentage of responses from the sufficiency benchmarks; PRSC: Percentage of responses from the sufficiency of courses.

Accordingly, values between 0.49 and 1.0 indicate a strong relationship between the benchmarks made as a result of the comparisons with the programs in different universities and the evaluation values from STEM teachers.

DISCUSSION

In the light of findings of benchmarking, literature reviews, academic meetings, and surveying data, this study presented the determination benchmarks by the formation of a new program (STEM-LPP) for teachers. The benchmarks are as follows: leadership, engineering/project design, technology integration, practice/experience-based, research-oriented, and multiple discipline integration. According to the findings of the benchmarking frequency (see **Table 1**) from five university programs, the benchmark with the highest frequency was "leadership", and the benchmark with the lowest frequency was "multidiscipline integration". According to surveying STEM teachers (see **Table 3**), the highest-rated sufficient benchmark at 64% of total sufficient was "Engineering integration and design projects". The lowest rated sufficient benchmark at 43% of total sufficient was again "Multiple discipline integration". According to the STEM teachers' evaluations about courses, the highest-rated sufficiency at 64% of total sufficient was "research-oriented courses". When we look at the sufficiency rate of courses of the engineering/project design and educational leadership, they are in the second rate but close to the first. The lowest rated sufficiency at 43% of total sufficient courses was about "Multiple discipline integration".

Despite the sequencing difference, the most prominent benchmarks were engineering design, leadership, and research. Technology integration and practice-based teaching were at an intermediate level. Multidisciplinary integration is seen at the lowest level. The program certainly seemed inadequate in terms of multidiscipline integration. Accordingly, STEM-LPP benchmarks and courses together had been discussed.

Leadership

Leader preparation is a central purpose of developing STEM educators (Wells, 2013). As "the inspiring component of the model" by Sublette (2013), STEM teacher leaders should inspire through coaching and/or mentoring other teachers, leaders, and students with skills of collaboration, communication, and assistance in establishing a relationship. The inquiry component of the Sublette (2013) model recommended that STEM teacher leaders should maintain ongoing learning and development as resource providers to other teachers by maintaining an ongoing teacher leader network professional learning community. STEM leaders also should be the actors to establish the relationship between industry leaders and the school and classroom. This allows the teacher leaders to stay connected as well as critique and develop through one another and further develop the practice of the STEM teacher leader. In this respect, the courses of "STEM education", "STEM teaching methods", "managerial psychology", and "Internship" help to promote leadership for STEM teachers in STEM-LPP. These courses are more beneficial for making connections, collaboration, and communication with partners, industrial places, and other related communities in order to train teachers (Francis et al., 2018). "STEM Education" course also emphasized an integrative approach for pre-service teachers in order to improve STEM education. Honey et al. (2014) supported the idea that STEM education programs frequently aim to build teachers' subject-matter and pedagogical content knowledge relevant to individual STEM subjects and to make connections between and among them. Besides, STEM educational knowledge provides connections among STEM disciplines in preparation for teachers as project leaders in schools (Dagan et al., 2019).

Engineering/Project-Design

An industrial design or engineering design course was placed on STEM-LPP to enable teachers in developing solutions to problems, items or products of projects that will be beneficial for teachers' design skills, hands-on ability, creativity, and engineering knowledge. The engineering design course will involve defining problems, modelling, planning, analyzing, interpreting, designing, and managing information. Engineering design was provided that the learners would experience planning, doing projects, solving problems, communicating ideas, constructing models, and designing and creating in engineering (Pawilen and Yuzon, 2019). Aydin-Gunbatar et al. (2018), in their study the results revealed that the design-based STEM courses helped pre-service teachers deepen their content knowledge. Lin et al. (2021) also believe that incorporating the engineering design process into the training of pre-service technology teachers is beneficial for developing pre-service technology teachers' schema of design thinking. Morgan et al. (2013) concluded that the design process provides a structure for approaching complex problems while encouraging creativity in achieving project goals. As the way of science and engineering integration, engineering-based projects that could solve industrial problems were considered as the essential issue for iSTEM teaching. Because engineering-based or science technology-based projects will provide STEM teachers to gain engineering-based content knowledge, Hudson et al. (2014) stated the importance of this that the teaching of engineering contents could not yet be sufficiently included in STEM curricula although it provides meaningful learning, makes connections with other scientific fields easier and understood scientifically. Strimel and Grubbs (2016) also indicated this for the technology and engineering education profession and suggested that teachers must be properly prepared to teach engineering content. Therefore, STEM-LPP included the courses of "Engineering design", "STEM science projects", "Ecological projects analysis" that support teachers to establish the science and engineering content integration. The crucial educational way of engineering knowledge is to do engineering and science projects because of the strong relevancy of the actual collaboration within the STEM fields. STEM is particularly suited for project/problem-based learning (PBL) because of the natural overlap between the fields of science, technology, engineering, and mathematics (Capraro and Jones, 2013). Solving problems of society and environment within the boundaries of STEM fields is also possible with STEM projects focused on real-world issues (Capraro and Jones, 2013). Morgan et al. (2013) also notified that engineering PBL inherently addresses the connections of knowledge and skills in one topic area to another area and in real-life applications to the knowledge learned.

Research-Oriented

The research-oriented courses were central for developing STEM educators and scholars (Wells, 2013). The STEM-LPP courses: STEM research, statistical mathematics, research methods, data analysis, big data, pedagogical diagnostic, internship, and graduation thesis assist in acquiring research skills, analytical thinking, scientific literacy, and data analysis skills. The course of "STEM research" provides to teachers STEM literacy, novel research background and give information about future studies of the iSTEM disciplines and STEM career. Milner-Bolotin (2018) recommended that teacher candidates should have an opportunity to experience the value of education research for their teaching practice and engage in designing and implementing research-based pedagogies. The courses also promote the integrative knowledge of teachers to become STEM leaders. One of these was the "Pedagogical Diagnostic" course that provides to evaluate the achievements of STEM activities projects on the teaching-learning process and gives feedback to STEM teachers.

Technology Integration

Berson et al. (2000) noted that appropriate training focuses on integrating various types of technology to make lessons better, rather than learning technology simply to get technological skills. Milner-Bolotin (2018) exampled this idea that the courses of technological pedagogical STEM teaching methods such as video records focused on specific STEM concepts, pedagogy, and educational technology, promote the growth of teacher candidates' knowledge for STEM teaching. The technology courses: Electronic technologies, Robotics, 3-D Design and Modelling, Cyber pedagogy and doing some STEM projects help teachers how to integrate technology tools: basic mechanical, electrical tools, sensors, computer programming, educational robotics, and daily-life objects. Francis et al. (2018) focused the developmental challenges of the course of "STEM Education" on their study, and the course assignments include design, robotics and coding, and STEM integration. Robotics helps to develop STEM technology knowledge and practical skills that were noted by Honey et al. (2014) as one of the learning competencies providing combination practices from two or more STEM disciplines to solve a problem or complete a project. Robotics also help to increase scientific, mathematical, and technological competencies (Leonard et al., *2016*). Papadakis et al. (2021) defined educational robotics (ER) as knowledge-based approaches within activities using simple and standard electronic components in their study. They informed the benefits of ER that it could help teachers expand their interest in STEM concepts and contribute more to a student's emotional and intellectual engagement than other commonly used educational tools. Learning with robots can integrate all the STEM elements, as well as teach problem solving and teamwork.

Practice/Experience-Based

STEM-LPP includes lab works, design-based and eco-projects, research activities, and internships that serve practice-based and experienced learning to be STEM practice-leader. Anderson et al. (2019) concluded that students were particularly engaged by the "hands-on" activities in the STEM projects by students' responses. These practical activities also promote teacher experience by generating integrated projects to solve real-life problems. Bailey (2020) noted that effective practices for STEM teachers include creativity, collaboration, inquiry through real-world problems, and reflection. The pedagogical internship also supplied pedagogical experience that contributed to STEM pedagogy and teaching in schools.

Multiple Discipline Integration

The combination of STEM disciplines provides opportunities for understanding four STEM disciplines, collaborative-integrative knowledge production, problem-solving, and decision making. Kelley et al. (2021) indicated that the STEM Content and Practices Integration model is a trans-disciplinary model that focuses on science and engineering practices in schools. They implemented the collaborative model to implement iSTEM lessons using engineering design and science inquiry practices, biomimicry, and 3D printing to enhance learning STEM content. As an appearance to the above courses, the multidiscipline connection within practices and projects have a positive impact. Honey et al. (2014) argued the teaching STEM in a more connected manner and then notified that the connection can be made the disciplinary practices within the individual STEM disciplines. Accordingly, it is possible to connect disciplines with experienced teachers who have content matter knowledge and pedagogical skills. The specific integrated course is difficult and problematic in a single program because of limited course credit and teacher. Thus, there should be integrated content instead of specific courses by cooperative studies of content teachers with practical activities, projects, and lab works on the curriculum. Nadelson and Seifert (2017) promote a greater mixture of the segregated foundational knowledge STEM with integrated project-based STEM to effectively apply the STEM knowledge and practices. Eckman et al. (2016) indicate that the STEM pre-service teachers in the cooperative teaching model were more confident about their teaching skills, more comfortable with their content knowledge, and prepared to work effectively with high-needs students. In LPP, it was seen that it was also sufficient to conduct practice, problem-led, and various project learning activities supplied courses such as STEM education, STEM methods, projects, electronic technologies, and robotics.

CONCLUSION

This study concludes the experiences, frameworks, principles, models, and approaches named all as benchmarks for the STEM teacher preparation program for pre-and in-service teachers to be iSTEM leaders in the school. The preparation of a new STEM leader program presented as the way of determination of benchmarks while designing? a teacher preparation program. The forming process of LPP was conducted by analyzing benchmarks from top university master programs and STEM teachers' evaluations and correlating these benchmarks and courses. The correlations (greater than 0.49) among benchmarks and between benchmarks and courses were shown as a strong relationship and their sufficiency of benchmarks for the criteria of LPP. The correlations among benchmarks and courses have shown there is a strong relationship and the sufficiency of benchmarks for the LPP. After the graduate of LPP, for teachers or leaders, it was guided to implement STEM integration activities, the various integrated projects, and STEM courses in their schools. Participant teachers to STEM-LPP will help to accept iSTEM knowledge and literacy. In this program, pre-service and in-service teachers perform to design knowledge for STEM instructional activities, courses, works, and projects in schools. Weinberg et al. (2021) noted that transformations to STEM educators could be traced by the following activities: problem-solving, individually preparing to teach and developing courses, and collaborating on STEM education with writing projects proposals. In future, such studies will be replicated to determine benchmarks in detail and evaluate benchmarks for the existing programs in the various implementation of STEM teacher preparation.

Implementations

This type of teacher preparation program is provided to inform program designers and developers about program formation steps and program formation practices. In most schools, the crucial issue is how to integrate four disciplines. The prepared program study illustrates how to prepare a program to contain effective communication, collaboration, and novel teaching approach such as research-oriented, practice-based, project-based instruction. It also provided general information to school teachers, administrators, and faculty members for program improvement and development.

This study contributes to studies of the design of teacher preparation programs in universities and the existing research on STEM leader or teacher development programs. Roberts (2013) noted that efforts to create models of teacher preparation for integrated instruction might serve as key examples for developing STEM teacher preparation programs. The program designer has identified the iSTEM leader preparation model as an effective model that assists the existing teachers to become a leader in the integration of disciplines, subjects, and topics. This leader preparation model can present ideas about the preparation methods of teacher programs, the role of leaders, and the process of developing STEM teacher leaders. STEM-LPP has contributed for pre-service and in-service school teachers in STEM disciplines to learn new STEM projects, technology/engineering design practices, STEM teaching methods and techniques, and some integrative courses such as robotics electronic technologies.

Limitations

The main limitation of this study was regarding sample size of the STEM teachers (n=14). This may be re-evaluated with a large sample size of STEM teachers, and not only teachers but school administrators, university academic members, researchers, and stakeholders should assess the whole program in terms of benchmarks, courses, and other teaching activities. Besides, The STEM-LPP was re-evaluated in terms of school needs and STEM capacities of existing teachers. It appeared that the benchmark "multidisciplinary integration" was slightly questioned by STEM teachers. It was mostly considered as curriculum integration during the instruction of each discipline with strong collaboration for each grade in school. However, it can be diversified into integration methods such as design projects, research studies, problem-based assignments. In future research studies, the alternative methods to provide integration disciplines should be investigated. Generally, all benchmarks, especially multidiscipline integration that seemed less rated, should be needed to raise to a sufficient level re-analysis and re-evaluating with a large sample size of STEM teachers, other members of STEM education such as stakeholders, graduates, administers, researchers, academicians, and graduate students in future studies

REFERENCES

Anderson, J., Wilson, K., Tully, D. and Way, J. (2019). "Can we build the wind powered car again?" Students' and teachers' responses to a new integrated STEM curriculum. *Journal of Research in STEM Education*, 5(1), 20-39. https://doi.org/10.51355/jstem.2019.61

Aydin-Gunbatar, S., Tarkin-Celikkiran, A., Kutucu, E. S. and Ekiz-Kiran, B. (2018). The influence of a design-based elective STEM course on pre-service chemistry teachers' content knowledge, STEM conceptions, and engineering views. *Chemistry Education Research and Practice*, 19(3), 954-972. https://doi.org/10.1039/C8RP00128F

Bailey, C. A. (2020). *STEM teacher leadership* [Doctoral dissertation, The University of North Carolina at Greensboro].

Becker, K. H. and Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education: Innovations and Research*, 12(5-6), 23-37.

Berson, M., Diem, R., Hicks, D., Mason, C., Lee, J. and Dralle, T. (2000). Guidelines for using technology to prepare social studies teachers. *Contemporary Issues in Technology and Teacher Education*, 1(1), 107-116.

Borromeo Ferri, R. (2019). Teacher education and teacher development. In B. Doig, J. Williams, D. Swanson, R. Borromeo Ferri and P. Drake (eds), *Interdisciplinary mathematics education* (pp. 259-261). Springer, Cham. https://doi.org/10.1007/978-3-030-11066-6_16

Burrows, A. and Slater, T. (2015). A proposed integrated STEM framework for contemporary teacher preparation. *Teacher Education and Practice*, 28(2/3), 318-330.

Capraro, M. M. and Jones, M. (2013). Interdisciplinary STEM project-based learning. In R. M. Capraro, M. M. Capraro and J. R. Morgan (eds), *STEM project-based learning* (pp. 51-58). Rotterdam: Sense Publishers. https://doi.org/10.1007/978-94-6209-143-6_6

Corlu, M. S., Capraro, R. M. and Capraro, M. M. (2014). FeTeMM eğitimi ve alan öğretmeni eğitimine yansımaları [STEM education and its reflections on field teacher education]. *Eğitim ve Bilim* [*Education and Science*], 39(171).

Creswell, J. W. (2002). *Educational research: Planning, conducting, and evaluating quantitative*. Upper Saddle River, NJ: Prentice-Hall.

Dagan, O., Ragonis, N., Goldman, D. and Wagner, T. (2019). Integrative STEM education-A new M. Ed. program: Development, objectives, and challenges. *PATT*, 37, 125.

Dailey, D., Bunn, G. and Cotabish, A. (2015). Answering the call to improve STEM education: A STEM teacher preparation program. *Journal of the National Association for Alternative Certification*, 10(2), 3-16.

DiFrancesca, D., Lee, C. and McIntyre, E. (2014). Where is the "E" in STEM for young children? *Engineering Design Education in an Elementary Teacher Preparation Program. Issues in Teacher Education*, 23(1), 49-64.

Eckman, E. W., Williams, A. and Silver-Thorn, B. (2016). An integrated model for STEM teacher preparation: The value of a teaching cooperative educational experience. *Journal of STEM Teacher Education*, 51(1), Article 8. https://doi.org/10.30707/JSTE51.1Eckman

Francis, K., Yáñez, G. A., Chapman, O., Cherkowski, G., Dodsworth, D., Friesen, S., Gereluk, D., Cockett, P. K., Babb, A. P. P., Shanahan, M.-C., Takeuchi, M., Thomas, C. and Turner, J. (2018, April). Forming and transforming STEM teacher education: A follow up to pioneering STEM education. In *Proceedings of the 2018 IEEE Global Engineering Education Conference (EDUCON)* (pp. 686-693). IEEE. https://doi.org/10.1109/EDUCON.2018.8363297

Hansen, M. and Gonzalez, T. (2014). Investigating the relationship between STEM learning principles and student achievement in math and science. *American Journal of Education*, 120(2), 139-171. https://doi.org/10.1086/674376

Honey, M., Pearson, G. and Schweingruber, H. A. (eds). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research (Vol. 500)*. Washington, DC: National Academies Press.

Hudson, P., English, L. and Dawes, L. (2014). Curricula integration: Identifying and locating engineering education across the Australian curriculum. *Curriculum Perspectives*, 34(1), 43-50.

Kelley, T. R., Knowles, J. G., Han, J. and Trice, A. N. (2021). Models of integrated STEM education. *Journal of STEM Education: Innovations and Research*, 22(1), 34-45.

Kirschner, P., Wubbels, T. and Brekelmans, M. (2008). Benchmarks for teacher education programs in the pedagogical use of ICT. In J. Voogt and G. Knezek (eds), *International handbook of information technology in primary and secondary education* (pp. 435-447). Boston, MA: Springer. https://doi.org/10.1007/978-0-387-73315-9_26

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T. and Almughyirah, S. (2016). Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology*, 25(6), 860-876. https://doi.org/10.1007/s10956-016-9628-2

Lin, K. Y., Wu, Y. T., Hsu, Y. T. and Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop pre-service technology teachers' engineering design thinking. *International Journal of STEM Education*, 8(1), 1-15. https://doi.org/10.1186/s40594-020-00258-9

Milner-Bolotin, M. (2018). Evidence-based research in STEM teacher education: From theory to practice. *Frontiers in education*, 3, 92. https://doi.org/10.3389/feduc.2018.00092

Moore, T. J., Johnston, A. C. and Glancy, A. W. (2020). STEM integration: A synthesis of conceptual frameworks and definitions. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore and L. D. English (eds.), *Handbook of research on STEM education* (pp. 1-62). Routledge. https://doi.org/10.4324/9780429021381-2

Morgan, J. R., Moon, A. M. and Barroso, L. R. (2013). Engineering better projects. In R. M. Capraro, M. M. Capraro and J. R. Morgan (eds), *STEM project-based learning* (pp. 29-39). Rotterdam: Sense Publishers. https://doi.org/10.1007/978-94-6209-143-6_4

Nadelson, L. S. and Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, 110(3), 221-223. https://doi.org/10.1080/00220671.2017.1289775

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D. and Kalogiannakis, M. (2021). Attitudes towards the use of educational robotics: Exploring pre-service and in-service early childhood teacher profiles. *Education Sciences*, 11(5), 204. https://doi.org/10.3390/educsci11050204

Pawilen, G. T. and Yuzon, M. R. A. (2019). Planning a science, technology, engineering, and mathematics (STEM) curriculum for young children: A collaborative project for pre-service teacher education. *International Journal of Curriculum and Instruction*, 11(2), 130-146.

Pinnell, M., Rowley, J., Preiss, S., Blust, R. P., Beach, R. and Franco, S. (2013). Bridging the gap between engineering design and PK-12 curriculum development through the use of the STEM education quality framework. *Journal of STEM Education*, 14(4), 28-35.

Roberts, A. S. (2013). *Preferred instructional design strategies for the preparation of pre-service teachers of iSTEM education* [PhD dissertation, Old Dominion University].

Rosengrant, D., Hensberry, K. K., Vernon-Jackson, S. and Gibson-Dee, K. (2019). Improving STEM education programs through the development of STEM education standards. *Journal of Mathematics Education*, 12(1), 123-140.

Rosicka, C. (2016). Translating STEM education research into practice. *Australian Council for Educational Research*. Available at: https://research.acer.edu.au/professional_dev/10

Ryu, M., Mentzer, N. and Knobloch, N. (2019). Pre-service teachers' experiences of STEM integration: Challenges and implications for iSTEM teacher preparation. *International Journal of Technology and Design Education*, 29(3), 493-512. https://doi.org/10.1007/s10798-018-9440-9

Sanders, M. E. (2013). *Integrative STEM education defined*. Available at: https://vtechworks.lib.vt.edu/handle/10919/51617

Strimel, G. and Grubbs, M. E. (2016). Positioning technology and engineering education as a key force in STEM education. *Journal of Technology Education*, 27(2), 21-36. https://doi.org/10.21061/jte.v27i2.a.2

Sublette, H. (2013). *An effective model of developing teacher leaders in STEM education* [Doctoral dissertation, Pepperdine University].

Trochim, W. M. (2006). *The research methods knowledge base*. Available at: https://pdfs.semanticscholar.org/ca82/06e94c0beb7d63e10d04131966233f3d2a70.pdf

Wang, H. H., Moore, T. J., Roehrig, G. H. and Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER)*, 1(2), 2.

Weinberg, A. E., Balgopal, M. M. and Sample McMeeking, L. B. (2021). Professional growth and identity development of STEM teacher educators in a community of practice. *International Journal of Science and Mathematics Education*, 19(1), 99-120. https://doi.org/10.1007/s10763-020-10148-9

Wells, J. G. (2013). *Integrative STEM education at Virginia Tech: Graduate preparation for tomorrow's leaders*. Available at: https://vtechworks.lib.vt.edu/handle/10919/93964

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Addressing Math Anxiety in a STEM World: Preventative, Supportive, and Corrective Strategies for the Inclusive Classroom

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ABSTRACT

Mathematics teachers may at times take on the role of counselors to address the "math anxious" in their classrooms. Today math anxiety is real and is a factor in attracting young people to many STEM fields. By the time many young people reach middle school, they have developed certain dispositions toward mathematics. What strategies will lessen the negative disposition and anxiety many students have toward math? The strategies included in this article are applicable for both general and special education teachers, especially when used together to prevent and reduce math anxiety. It is important that all students feel confident in their ability to do mathematics in an age that relies so heavily on problem solving, technology, science, and mathematics. In a STEM world it really is a school's obligation to see that their students value and feel confident in their ability to do math, because ultimately, all decisions individuals make and choices of careers may be determined in part by their attitudes toward mathematics.

Keywords: inclusion, math anxiety, strategies, reduction, STEM

INTRODUCTION

> Children are not limited in what they can do when they have mathematics skills because to a mathematician, "real life" is a special case.
>
> -Author Unknown

It is peculiar that individuals who cannot read are often ashamed of this; however, many individuals are quick to admit that they are not good at math or do not like it. A negative attitude toward math causes some math teachers to assume the role of counselors, motivators, and even cheerleaders in their classrooms to address the needs of students who dislike or are fearful of mathematics. When it comes to statistics or even mathematics in general, students unfortunately do not leave their K-12 classroom with a positive mind-set concerning math and math instruction. As Stoehr (2019) points out that math anxiety can begin with elementary-aged students and if not corrected and addressed early can be carried with them for life. Many leaders and advocates for STEM often neglect to realize that the one major reason so few people go into STEM fields is because their lack of confidence in doing mathematics, many people today have math anxiety, preventing them from pursuing STEM areas as careers. Núñez-Peña et al. (2013) found that university students who demonstrated mathematical anxiety and negative attitudes toward math also demonstrated lower performance scores in a university research design course. This finding is interesting given the reality that Research Design is typically taught as a non-numerical course, rather a problem-solving course that would involve math concepts.

Skagerlund et al. (2019) found in their research that math anxiety leads to an impairment of a students working math ability. As Boaler (2008) points out, it is critical to ensure are confident and well prepared in mathematics if they are going to compete for such high-tech jobs today and in the future. Today, the United States is working to lead more young people into the fields of Science, Technology, Engineering, and Mathematics (STEM) so we as a country can compete globally. If we are to build math confidence in our students, math teachers need to address head on the issue of math anxiety, which often manifests itself as hesitancy or learned helplessness in observed math achievement. This may require teachers to be much more than counselors, motivators, and cheerleaders to change math attitudes; they need to consider how they THINK about teaching math to lessen the anxieties often connected to mathematics instruction. Choe et al. (2019) found in their research that greater levels of math anxiety were linked with a propensity to select easier, low-reward problems over harder problems. They contend that addressing this robust math anxiety-avoidance connection has the possibility to increase interest and success in related STEM fields. This paper will look at the issue of math anxiety and provide research- based suggestions for preventing and reducing such anxiety.

Issue-Problem Statement-The Truth is that Math Anxiety does exist in our World

As math teachers, we hear it all the time when our young students readily volunteer a litany of stories about how bad they are at math and what a hard time they had in previous classes. Many have had bad experiences and dislike math because of previous teachers or just not being able to "get it." Some voices from young people about mathematics include the following:

> "I really don't like math, but I do okay."--Julie, 14
>
> "I just don't like math, it's the same thing and big numbers, and I don't like big numbers."--Brian, 13
>
> "I have lots of math anxiety, for me math is very confusing."--Samantha, 19
>
> "Frustration, sweaty palms, and fear are words I would use to describe what math does to me."--Heather, 34
>
> "When I hear the word math I get goosebumps."--Starry, 19
>
> "Math makes me shake."--Seth, 13
>
> "When I think of math I don't get nervous I get bored."--Chad, 14

How representative are these comments from young people about their math anxieties? A study in 2004 by Perry indicated that 85% of students in an introductory college level math class claimed to have experienced anxiety when presented math problems. Jackson and Leffingwell (1999) showed another perspective in this study, with only 7% of the college students (N=157) in their study not expressing math anxiousness. The prevalence of math anxiety in empirical studies is confounding; however, the effect of math anxiety is well documented (dos Santos Carmo et al., 2019; Haase et al., 2019; Ramirez et al., 2018). Dowker et al. (2019) found that even students form poor attitudes toward math at very young ages in their first years in school based on success with arithmetic early on. Klee and Miller (2019) found that even as students advance in age from elementary to middle school and upward, students can bring such negative feelings about math with them, and it can influence future choice and motivation toward studying the subject as they progress throughout varies grade levels. Even in populations of students where math is a foundational skill (e.g., engineering majors in college), researchers have found math anxiety to be present (Hembree, 1990; Ruffins, 2007). Sparks (2011) feels that as the STEM fields becomes more important for our students to study, our schools and teachers need to do more to address math anxiety so that our students are confident to study areas related to STEM. If math anxiety occurs frequently, then attention to the methods that are effective at overcoming math anxiety are important for teacher preparation as well as for in-service math teachers. Today with the push to educate using the Common Core State Standards (CCSS) (National Governors Association, 2010) math teachers are challenged to reach all students with much higher and rigorous levels of mathematics for US students. Educators today really need to work a lot harder to break the cycle of dislike and discomfort with learning and doing mathematics to better prepare young people for the STEM fields.

MATH ANXIETY DEFINED

Math anxiety may be defined as an *"…inconceivable dread of mathematics that can interfere with manipulating numbers and solving mathematical problems within a variety of everyday life and academic situations*" (Buckley and Ribordy, 1982, p. 1). NCTM (1989, 1995) recognized math anxiety as a problem and specifically included in its assessment practices. Standard #10 (NCTM, 1989, see **Appendix A**) prompts teachers to assess their students' mathematical dispositions; such as: confidence in using math to solve problems, communicate ideas, and reason mathematically. Math anxiety is often caused by a combination of external and internal factors; however, we cannot change internal factors within the student, so as teachers it makes more sense to focus on what we can control (Chernoff and Stone, 2014). Math anxiety is a well-documented phenomenon that has affected our society for over sixty years, and not enough is being done to address it in our classrooms or in the way we teach math (Beilock and Willingham, 2014; Boaler, 2008; Dowker et al., 2016; Geist, 2010; Metje et al., 2007; NCTM, 1995). Negative attitudes toward mathematics and math anxiety are serious obstacles for students in all levels of schooling today (Geist, 2010). Beilock and Willingham (2014) state that "Because math anxiety is widespread and tied to poor math skills, we must understand what we can do to alleviate it" (p. 29).

As educators, we need to know what causes this dread of mathematics so that it can be prevented and/or reduced. Causes of math anxiety may vary from socioeconomic status and parental background to the influence of teachers and the school system. Some educators believe that teachers and parents who are afraid of math can pass on math anxiety to the next generation, not genetically, but by modeling behaviors of their own discomfort with the subject. Research by Oberlin (1982) found that some teaching techniques actually cause math anxiety: (a) assigning the same work for everyone, (b) covering the book problem by problem, (c) giving written work every day, (d) insisting on only one correct way to complete a problem, and (e) assigning math problems as punishment for misbehavior.

Ineffective teaching practices are not the ONLY cause of math anxiety. A student's lack of success with math may also be a cause of math anxiety and be heightened by any one of several factors; poor math instruction, an insufficient number of math courses in high school, unintelligible textbooks, or misinformation about what math is and what it is not. Many people often blame their failures on their lack of a mathematical mind, the notion that men are better than women are at math, or that they have poor memories or learning disabilities. Sheila Tobias, a guru on the topic of math anxiety since the 1980's, contends that there are two myths about mathematics that need to be eliminated. One is that higher-level math is too difficult for otherwise intelligent students to master, and another is that without mathematics you can live a productive intellectual and professional life (Tobias, 1993). Math anxiety is also prevalent in the population of students with disabilities. Some students in special education have specific math related disabilities; this number is estimated to be between 4 and 7% for school-aged students (Lewis et al., 1994). Often there are other students in special education who claim a math disability to cover up anxiety about school in general. Regardless of the student description, engineering students and students in special education alike need a teacher's help to overcome their fears of mathematics and be challenged to take higher-level math courses. Willis (2010) math teacher and neurologist in her book, *Learning to Love Mathematics,* gives over 50 strategies you can use right away in any grade level to: (1) rehabilitate negative attitudes about math; (2) reduce mistake anxiety; and (3) relate math to students' interests and goals. Find out how a better understanding of your students' brains can help you build foundational skills in math and other subjects and develop your students' long-term memory of academic concepts. Explore classroom interventions that help you: (1) change your students' math intelligences by incorporating relaxation techniques, humor, visuals, and stories into your teaching; (2) eliminate stress and increase motivation to learn math by using errorless math, estimation, and achievable challenges; and (3) differentiate your strategies to students' skill levels by using scaffolds, flexible grouping, and multisensory input. Find out how a better understanding of your students' brains can help you build foundational skills in math and other subjects and develop your students' long-term memory of mathematical understanding.

MANAGING MATH ANXIETY

Because math anxiety can be seen in daily living activities as well as in class work or assignments, the need to have a multi-pronged approach is crucial to addressing it. Applying anxiety-lessening techniques in a variety of activities and frequently throughout instructional activities helps to address a variety of student needs. This is like the idea of applying different management and organizations skills suited the situation. As Skagerlund et al. (2019) found that math anxiety can impair math ability, they suggest students need to learn strategies to manage this so that it is not affecting their working memory and number processing when they do math. Applying different techniques BEFORE teaching a math activity allows the teacher to set a more focused and less anxious tone for a math activity. Again, applying techniques that lessen anxiety and provide support JUST

Table 1. NCTM recommendations for preventing math anxiety (NCTM, 1995)

No	Recommendation
1	Accommodate different learning styles
2	Create a variety of testing environments
3	Design positive experiences in math classes
4	Remove the importance of ego from classroom practice
5	Emphasize that everyone makes mistakes in mathematics
6	Make math relevant
7	Let students have some input into their own evaluations
8	Allow for different social approaches to learning mathematics
9	Emphasize the importance of original, quality thinking
10	Characterize math as a human endeavor

prior to beginning the math activity, as well as DURING the activity help cue the anxious students to a more positive approach to math class work. Taking a cue from classroom management practices (Furner and Duffy, 2002), the next section of this paper explains how: to apply specific strategies to PREVENT math anxiety while planning for a math activity; to SUPPORT positive math attitude just before teaching a math activity; and to CORRECT or redirect a student when they get off track from a positive math attitude is critical in developing mathematically confident students ready for STEM field careers. The following proposed methods to break the math anxiety cycle include the following preventative, supportive, and corrective steps to chart as follows:

Prevention Tactics: Planning to Diminish Math Anxiety

There are many things schools can do to help prevent math anxiety. Both teachers and parents play a critical role in helping to develop positive dispositions toward math. As with most intervention programs, early assessment, and action help to develop positive math attitudes. The field of math education has recently made the push to increase and encourage math literacy, and along with that push has developed some useful materials to encourage math competence. Mammarella et al. (2018) found in their research that it is important as educators to separate the math from the anxiety and in their research results they found that children with severe math anxiety, but with no developmental dyscalculia were specifically impaired in the proactive interference task, while children with developmental dyscalculia (with or without math anxiety) failed in the working memory tasks. Their findings argue for the importance of distinguishing the cognitive processes underlying the profiles of a child, which may have factors as educators address preventative and reduction tactics as it relates to math anxiety. One program developed by the Southeastern Consortium for Minorities in Engineering (SECME) is used in schools with high minority populations to motivate and get students interested in math, science, and engineering. SECME was originally an acronym for *Southeastern Consortium for Minorities in Engineering*. SECME is a nonprofit organization originally established in 1975. The organization is based out of Atlanta, Georgia at the Georgia Institute of Technology. SECME is a strategic alliance to renew and strengthen the professional capacity of K-12 educators, motivate and mentor students, and empower parents so that all students can learn and achieve at higher levels. (SECME, n. d.) Many teachers find this program very useful to turn young people on to math and motivate them to like math more. The elementary and middle school years are critical to developing positive perceptions toward mathematics in children. The NCTM (2000, 1995, 1989) provided recommendations for preventing math anxiety with recommendations and as summary is presented in **Table 1**.

The recommendations from NCTM are words to the wise for mathematics teachers. We have turned the NCTM tactics into a short lesson plan/unit checklist that can be used to check the "Mathitudes" of a lesson or unit. The key to all the NCTM recommendations is to plan wisely and make the instruction welcoming for students. A lesson that engages students with all types of learning styles and learning needs sends a message to everyone in the class that the expectation is for all to be successful. The same is true for a teacher who includes in his lesson plan time to talk about different ways to solve a problem. These underscores, as NCTM advises, that there are different social approaches to learning math, not just the one in the text. Prevention of math anxiety is all about teacher planning and using the best possible practices in math instruction (dos Santos Carmo et al., 2019). The way we fix math anxiety in our schools. To put it simply: better teaching. Finlayson suggests the constructivist style of teaching which emphasizes these ideas:

- "Begin with the whole–expanding to parts
- Pursuit of student questions/interests
- Primary sources/manipulative materials
- Learning is interaction–building on what students already know
- Instructor interacts/negotiates with students

- Assessment via student works observations, points of view, and tests. Process is as important as product
- Knowledge is dynamic/change with experiences
- Students work in groups" (Finlayson, 2014).

Supportive Tactics: Reducing/Overcoming Math Anxiety

Reducing math anxiety is much different from preventing math anxiety. While every educator would like to prevent a student from experiencing math anxiety, some come to school already worried about being skilled at math. Ooten (2003) in her book, *Managing the Mean Math Blues,* outlines a four-step method for managing a persons' math anxiety. Ooten contends that a person who suffers from math anxiety needs to first lay the groundwork by coming to terms with their feelings and challenge their current beliefs and realize they are not alone; second, one must change their thoughts and negative thinking and use intervention strategies to improve one's thinking that they can be successful at math; third, one needs to know thyself, it is important that one knows his/her learning style/mode and that he/she apply approaches to doing math by successful people; and lastly fourth, once one has gained some confidence and strategies for doing mathematics they then must apply what they learned and actually do the math. All Ooten's techniques require the teacher to first be aware and second to support the student in turning around their anxiety. Another problem for those who suffer from math anxiety is the nature of anxiety itself. According to Rubinsten et al. (2015), anxious individuals tend to focus on negative stimuli more than positive stimuli, essentially making themselves more anxious. The same thing is true of individuals with math anxiety; the only difference is that for people with math anxiety, math is the negative stimuli (Rubinsten et al., 2015). This suggests that math anxiety could be handled through therapies designed to lessen anxiety, such as cognitive behavioral therapy and exposure therapy (exposing a person little by little to that which they are afraid) (Rubinsten et al., 2015).

We can see these support techniques played out in a variety of ways in counseling settings. For example, some researchers (Furner, 1996; Hembree, 1990; Olson and Gillingham,1980; Ramirez et al., 2018; Schneider and Nevid, 1993; Trent, 1985); all propose systematic desensitization as an effective approach for helping people reduce their math anxiety. Systematic desensitization in the context of math anxiety may be defined as a gradual exposure to the mathematical concepts that are causing students to become distressed and teaching them how to cope with that fear. Through systematic desensitization, a common practice in counseling, students come to understand that their anxiety is a learned behavior, one they were not born with, and they can be taught to overcome it by consistently implementing their self-monitoring strategies to become less anxious. Other researchers, Davidson and Levitov (1999) advocate the use of relaxation in conjunction with repeated positive messages and visualizations to reduce math anxiety.

How is math anxiety reduced in the classroom setting? Teachers must help students understand how their math anxiety was created in the first place. According to Hackworth (1992), the following activities will assist in reducing math anxiety: (a) discuss and write about math feelings, (b) become acquainted with good math instruction as well as study techniques, (c) quality studying; recognize type of information learning, (d) be an active learner and create problem solving techniques, (e) evaluate your own learning, (f) develop calming/positive ways to deal with fear of math and doing math: visualization, positive messages, relaxation techniques, and frustration breaks, and (g) gradual repeated success in math builds confidence (see **Appendix A**). Tobias (1987) suggests that one way for students to reduce math anxiety is to recognize when panic starts, to identify the inactiveness in their analytic and retrieval systems, and to clear up the static without ceasing to work on the problem.

Working from the academic perspective, Zemelman et al. (2012) and Furner et al. (2005) have compiled evidence based practices for teaching math which include: (a) use of manipulatives (make learning math concrete); (b) use cooperative group work; (c) use discussion when teaching math; (d) make questioning and making conjectures a part of math; (e) use justification of thinking; (f) use writing in math for: thinking, feelings, and prob. Solving; (g) use problem-solving approach to instruction; make content integration a part of instruction; (h) use of calculators, computers, and all technology; (i) being a facilitator of learning; and (j) assess learning as a part of instruction. Also, see **Appendix A** for a summary, which includes strategies/key ideas for overcoming/preventing math anxiety. Each of these best practices make math more "accessible" to students who enter the math instruction situation with trepidation.

Corrective Tactics: Working on Building Math Confidence

Teachers and specialists can work together to do many things in classrooms to help build their students math confidence. One practical idea for teachers and students is for teachers to assess their students' dispositions toward math at the beginning of a school year by having them complete the following *Mathitude Survey* (Furner, 2007):

Mathitude Suvery

1. When I hear the word math I ……
2. My favorite thing in math is ……
3. My least favorite thing in math is ……
4. If I could ask for one thing in math it would be ……
5. My favorite teacher for math is …… because ……

Journal writing in math classrooms has become an everyday event for many students. Students use journals to express their understanding of mathematical concepts. Journal writing can also be used to allow students to share feelings and experiences with math. Students are rarely asked how they feel about learning about different concepts and branches of mathematics. Teachers can get really get a better understanding and feel for any frustration student are feeling and can be a corrective strategy for helping student develop math confidence and deal with any previous math anxiety.

The following sample list of journal/discussion question may be used for students to write about alone or to discuss and share together as a class. Teachers must realize that for students to overcome or have their math anxiety reduced, they must first initiate this form of therapy by allowing as a corrective strategy, students to express their true feeling about math and how they arrived at such a disposition:

Journal/Discussion Questions for Students in Groups

1. Pretend that you must describe mathematics to someone. List all the words or phrases you can think of that you could use.
2. Imagine yourself doing or using math either in or out of school. What does doing or using math feel like? Describe.
3. If math were a color, an animal, music, or food what would it be?
4. For me math is most like. Why?
5. Describe how you feel in a math class.
6. Are you the type to do well in math class? Why or why not?

The picture book, *Math Curse*, (Scieszka and Smith, 1995) addresses the issue of math anxiety. It is an excellent example of how educators have come to terms with the fact that not all people feel confident in their ability to do math. When Mrs. Fibonacci, an elementary school teacher, tells her class that they can think of almost everything as a math problem, one student becomes overwhelmed by the scope of math. His math anxiety becomes a real curse. However, the student eventually realizes that math is everywhere and there is no way of escaping it in daily life; therefore, the math anxious youngster recognizes math as a means of making one's life easier. *Math Curse* may be used as a form of bibliotherapy to prompt discussion on the topic of math anxiety and allow other students to discuss their feelings on the topic to compare to the character in the book. Isdell (1993) wrote another great book, *A Gebra named Al*, about a young girl who struggles with her feelings toward math at the middle school level. This is also a wonderful book to incorporate in a bibliotherapy lesson to address math anxiety with students.

Hebert and Furner (1997) outline specific lessons and activities to help in reducing math anxiety with activities such as: role playing feelings and experiences with math classes/teachers; using a math journal for students to write in, so they may describe their feelings while doing math problems, writing letters to the main character of the book *Math Curse (*Scieszka and Smith, 1995) writing math anxiety poems and rap songs about math and/or their anxiety toward mathematics; writing a letter to Anne Landers or Dear Abby about their math anxiety; designing anti-math anxiety bumper stickers to be plastered on their school lockers, providing students with a daily self-affirmation statement; providing students an opportunity to create original radio or television advertisements for a national anti-math anxiety campaign; and providing students an opportunity to select an artistic medium (i.e. magazine photo collage, penciled sketch) to illustrate their math anxiety to name a few. Hebert and Furner feel that teachers need to take the time in their math instruction to address such affective aspects of learning mathematics so that students can come to terms with their feelings toward mathematics.

In a study by Jackson and Leffingwell (1999), they cited that only seven percent of the population in their study reported having positive experiences with mathematics from kindergarten through college. The study cited that there are many covert, as well as, overt behaviors exhibited by the math instructor in creating math anxiety in students. Things like difficulty of material, hostile instructor behavior, gender bias, perceptions of uncaring teacher, angry behavior, unrealistic expectations, embarrassing students in front of peers, communication and language barriers, quality of instruction, and evaluation methods of the teacher. Math instructors' behaviors and teaching methods can be hurtful and negative to students learning math. Math teachers need to take an active role in reducing performance anxiety in math. It is not uncommon that a student will say, "I like the class because of the teacher." It is often because the teacher knows how to present developmentally the subject matter, creates a learning environment conducive to learning with compassion, has high expectations for all students without regard to gender, race, or language barriers, and uses a variety of assessment methods and teaching styles to better reach all students. It is the teacher's obligation to see that all students are prepared for a high-tech society where one cannot afford to not feel confident in their ability to do math, math teachers need to use corrective strategies to support students' math anxiety and help them work toward becoming more confident in doing mathematics. Geist (2010) feels that negative attitudes toward mathematics and what has come to be known as "math anxiety" are serious obstacles for children in all levels of schooling today. In his paper, the literature is reviewed and critically assessed in regards to the roots of math anxiety and its especially detrimental effect on children in "at-risk" populations such as, special education, low socioeconomic status, and females; he feels that an anti-anxiety curriculum is critical in building students' confidence when working with mathematics.

SUMMARY

Teachers of mathematics need to look deeper at their students' needs and address the math anxious students they have in their classrooms. While some of these math anxious students will be students with special needs, math anxiety is not limited to that group alone. By working with school specialists like special education teachers, inclusion support specialists and school counselors, classroom teachers will find support for themselves as well as their students. These specialists can provide both emotional and academic support strategies for the teachers first when they plan lessons and units and later as they teach those lessons. It is helpful to understand that solving math anxiety is not a one-shot practice, rather it requires considerations and accommodations in the planning stages, during the lesson and then again if the anxiety becomes evident during the lesson. It really is a teachers' obligation to see that their students' value and feel confident in their ability to do math, because ultimately a child's life: all decisions they will make and careers choices may be determined based on their disposition toward mathematics. As educators we must make the difference in our children's' attitudes toward math. It would be nice to hear more young people and adults when asked how they feel about math say, "Math is my favorite subject" or "I am great at stats!" or "I can solve any word problem!" Through math confidence building sessions with the teacher and counselor, schools can produce more mathematically confident young people for the 21st Century.

REFERENCES

Beilock, S. L. and Willingham, D. T. (2014). Math anxiety: Can teachers help students reduce it? *American Educator*, 38(2), 28-32.

Boaler, J. (2008). *What's math got to do with it? Helping children learn to love their least favorite subject--and why it's important for America*. New York, NY: Penguin Group (USA) Inc.

Buckley, P. A. and Ribordy, S. C. (1982). *Mathematics anxiety and the effects of evaluative instructions on math performance* [Paper presentation]. The Mid-western Psychological Association, Minneapolis, MN.

Chernoff, E. and Stone, M. (2014). An examination of math anxiety research. *OAME/AOEM Gazette*, 29-31.

Choe, K., Jenifer, J. B., Rozek, C. S., Berman, M. and Beilock, S. L. (2019, May 20). *Calculated avoidance: Math anxiety predicts math avoidance in effort-based decision-making*. https://doi.org/10.31234/osf.io/afj37

Davidson, R. and Levitov, E. (1999). *Overcoming math anxiety*. Reading, MA: Addison Wesley.

dos Santos Carmo, J., Gris, G. and dos Santos Palombarini, L. (2019). Mathematics anxiety: Definition, prevention, reversal strategies and school setting inclusion. In D. Kollosche, R. Marcone, M. Knigge, M. Penteado and O. Skovsmose (eds.), *Inclusive mathematics education* (pp. 403-418). Springer, Cham. https://doi.org/10.1007/978-3-030-11518-0_24

Dowker, A., Cheriton, O., Horton, R. and Mark, W. (2019). Relationships between attitudes and performance in young children's mathematics. *Educational Studies in Mathematics*, 100(3), 211-230. https://doi.org/10.1007/s10649-019-9880-5

Dowker, A., Sarkar, A. and Looi, C. Y. (2016). Mathematics anxiety: What have we learned in 60 years? *Frontiers in Psychology*, 7, 508. http://doi.org/10.3389/fpsyg.2016.00508

Finlayson, M. (2014). Addressing math anxiety in the classroom. *Improving Schools*, 17(1), 99-115. https://doi.org/10.1177/1365480214521457

Furner, J. M. (2007) *Mathitudes: Research, activities, websites, and children's literature toward a mathematically confident society* [Research and activities presentation]. The National Council of Teachers of Mathematics Southern Regional Conference, Houston, Texas, November 30, 2007.

Furner, J. M. (1996). *Mathematics teachers' beliefs about using the National Council of Teachers of Mathematics Standards and the relationship of these beliefs to students' anxiety toward mathematics* [Unpublished doctoral dissertation]. University of Alabama.

Furner, J. M. and Duffy, M. L. (2002). Equity for all students in the new millennium: Disabling math anxiety. *Intervention in School and Clinic*, 38(2), 67-74. https://doi.org/10.1177/10534512020380020101

Furner, J. M., Yahya, N. and Duffy, M. L. (2005). 20 ways to teach mathematics: Strategies to reach all students. *Intervention in School and Clinic*, 41(1), 16-23. https://doi.org/10.1177/10534512050410010501

Geist, E. (2010). The anti-anxiety curriculum: Combating math anxiety in the classroom. *Journal of Instructional Psychology*, 37(1), 24-31.

Haase, V. G., Guimarães, A. P. L. and Wood, G. (2019). Mathematics and emotions: The case of math anxiety. In A. Fritz, V. Haase and P. Räsänen (eds.), *International handbook of mathematical learning difficulties* (pp. 469-503). Springer, Cham. https://doi.org/10.1007/978-3-319-97148-3_29

Hackworth, R. D. (1992). *Math anxiety reduction*. Clearwater, FL: H & H Publishing Company.

Hebert, T. P. and Furner, J. M. (1997). Helping high ability students overcome math anxiety through bibliotherapy. *The Journal of Secondary Gifted Education*, 4(8), 164-178. https://doi.org/10.1177/1932202X9700800403

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education*, 21, 33-46. https://doi.org/10.2307/749455

Isdell, W. (1993). *A Gebra named Al*. Minneapolis, MN: Free Spirit Publishing Inc.

Jackson, C. D. and Leffingwell, R. J. (1999). The role of instructor in creating math anxiety in students from kindergarten through college. *Mathematics Teacher*, 92(7), 583-586. https://doi.org/10.5951/MT.92.7.0583

Klee, H. L. and Miller, A. D. (2019). Moving up! Or down? Mathematics anxiety in the transition from elementary school to junior high. *The Journal of Early Adolescence*, 39(9), 027243161882535. https://doi.org/10.1177/0272431618825358

Lewis, C., Hitch, G. J. and Walker, P. (1994). The prevalence of specific arithmetic difficulties and specific reading difficulties in 9- to 10-year-old boys and girls. *Journal of Child Psychology and Psychiatry*, 35, 283-292. https://doi.org/10.1111/j.1469-7610.1994.tb01162.x

Mammarella, I. C., Caviola, S., Giofrè, D. and Borella, E. (2018). Separating math from anxiety: The role of inhibitory mechanisms. *Applied Neuropsychology: Child*, 7(4), 342-353. https://doi.org/10.1080/21622965.2017.1341836

Metje, N., Frank, H. L. and Croft, P. (2007). Can't do maths—understanding students' maths anxiety. *Teaching Mathematics and its Applications: An International Journal of the IMA*, 26(2), 79-88. https://doi.org/10.1093/teamat/hrl023

National Governors Association. (2010). *Common core state standards*. Washington, DC.

NCTM. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: National Council of Teachers of Mathematics.

NCTM. (1995). *Mathematics anxiety* [Supplemental brochure]. Reston, VA: National Council of Teachers of Mathematics.

NCTM. (2000). *Principles and standards for school mathematics*. Reston, VA: National Council of Teachers of Mathematics.

Núñez-Peña, M. I., Suárez-Pellicioni, M. and Bono, R. (2013). Effects of math anxiety on student success in higher education. *International Journal of Educational Research*, 58, 36-43. https://doi.org/10.1016/j.ijer.2012.12.004

Oberlin, L. (1982). How to teach children to hate mathematics. *School Science and Mathematics*, 82, 261. https://doi.org/10.1111/j.1949-8594.1982.tb17187.x

Olson, A. T. and Gillingham, D. E. (1980). Systematic desensitization of mathematics anxiety among preservice elementary teachers. *Alberta Journal of Educational Research*, 26(2), 120-127.

Ooten, C. (2003). *Managing the mean math blues*. Upper Saddle River, NJ: Pearson Education, Inc. of Prentice Hall.

Perry, A.B. (2004). Decreasing math anxiety in college students. *College Student Journal*, 38(2), 321-324.

Ramirez, G., Shaw, S. T. and Maloney, E. A. (2018). Math anxiety: Past research, promising interventions, and a new interpretation framework. *Educational Psychologist*, 53(3), 145-164. https://doi.org/10.1080/00461520.2018.1447384

Rubinsten, O., Eidlin, H., Wohl, H. and Akibli, O. (2015). Attentional bias in math anxiety. *Frontiers in Psychology*, 6. https://doi.org/10.3389/fpsyg.2015.01539

Ruffins, P. (2007). A real fear. *Diverse Issues in Higher Education*, 24(2), 17-19.

Schneider, W. J. and Nevid, J. S. (1993). Overcoming math anxiety: A comparison of stress inoculation training and systematic desensitization. *Journal of College Student Development*, 3(4), 283-288.

Scieszka, J. and Smith, L. (1995). *Math curse*. New York, NY: Viking.

SECME. (n. d). *Southeastern Consortium for Minorities in Engineering (SECME)*. Available at: http://www.secme.org (Accessed October 25, 2021).

Skagerlund, K., Östergren, R., Västfjäll, D. and Träff, U. (2019). How does mathematics anxiety impair mathematical abilities? Investigating the link between math anxiety, working memory, and number processing. *PloS ONE*, 14(1), e0211283. https://doi.org/10.1371/journal.pone.0211283

Sparks, S. D. (2011). "Math anxiety" explored in studies. *Education Week*, 30(31), 1.

Stoehr, K. J. (2019). Moments of mathematics anxiety in the elementary classroom. *Teaching Children Mathematics*, 25(4), 197-200. https://doi.org/10.5951/teacchilmath.25.4.0197

Tobias, S. (1987). *Succeed with math: Every student's guide to conquering math anxiety*. New York, NY: College Board Publications.

Tobias, S. (1993). *Overcoming math anxiety revised and expanded*. New York, NY: Norton Publishing.

Trent, R. M. (1985). *Hypnotherapeutic restructuring and systematic desensitization as treatment for mathematics anxiety* [Paper presentation]. The Annual Convention of the Southwestern Psychological Association (31st, Austin, TX, April 18-20, 1985).

Willis, J. (2010). *Learning to love math: Teaching strategies that change student attitudes and get results*. Alexandria, VA: Association for Supervision and Curriculum Development.

Zemelman, S., Daniels, H. and Hyde, A. (2012*). Best practice: Bringing standards to life in America's classrooms*. (4th ed.). Portsmouth, NH: Heinemann.

APPENDIX A: STANDARDS AND STRATEGIES TO ADDRESS MATH ANXIETY FOR ALL STUDENTS

Standards and Strategies to Address Math Anxiety

Mathematics teachers need to be counselors too …

What NCTM says about Mathematics Anxiety and Dispositions Toward Mathematics

Standard 10: Mathematical Disposition (NCTM, 1989)
As mathematics teachers it is our job to assess students' mathematical disposition regarding:

- confidence in using math to solve problems, communicate ideas, and reason,
- flexibility in exploring mathematical idea and trying a variety of methods when solving,
- willingness to persevere in mathematical tasks,
- interests, curiosity, and inventiveness in doing math,
- ability to reflect and monitor their own thinking and performance while doing math, and
- value and appreciate math for its real-life application, connections to other disciplines and cultures and as a tool and language.

A Synthesis on How to Reduce Math Anxiety

1. Psychological Techniques like anxiety management, desensitization, counseling, support groups, bibliotherapy, and classroom discussions.
2. Once a student feels less fearful about math he/she may build their confidence by taking more mathematics classes.
3. Most research shows that until a person with math anxiety has confronted this anxiety by some form of discussion/counseling no "best practices" in math will help to overcome this fear.

A Synthesis on How to Prevent Math Anxiety

1. Using "Best Practice" in mathematics such as: manipulatives, cooperative groups, discussion of math, questioning and making conjectures, justification of thinking, writing about math, problem-solving approach to instruction, content integration, technology, assessment as an integral part of instruction, etc.
2. Incorporating the NCTM Standards and your State Standards into curriculum and instruction.
3. Discussing feelings, attitudes, and appreciation for mathematics with students regularly.

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How Diverse Is Diversity? An Exploration of References to Diversity in the Recent Literature in STEM Higher Education

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ABSTRACT

Since STEM knowledge and skills are increasingly being sought after in our information and technology driven economies, it is pivotal that ideas and human resources that foster these economies also reflect the STEM population. Although it is evident from earlier research that specific demographics are clearly underrepresented, little is known about who constitutes as 'diverse', which makes it challenging to develop and assess effective policies aimed at increasing diversity in STEM. Through content analysis, we explore in recent STEM education literature, which groups of students and faculty are referenced in relation to diversity, i.e., groups that are underrepresented. The results reveal 180 uniquely defined references to underrepresented groups in STEM. Our main results show that across articles, the majority of the references to diversity are related to gender (69%), and a considerable portion of references (12%) can be classified under 'other unspecified minorities'. Consequently, the analyzed articles portray a narrow understanding of diversity, and a variety of groups remain unspecified when it comes to background characteristics. To change this, clear definitions of the target groups are necessary and more consensus among the research community about the justifications to include or exclude these groups is needed.

Keywords: diversity, STEM, higher education, policy, content analysis

THEORY AND INTRODUCTION

In recent decades the demand for Science, Technology, Engineering and Mathematics (STEM) students has been growing. In the USA, for example, it is estimated that in the next decade, the number of STEM jobs will grow by 8%, which is double the amount compared to non-STEM jobs (Zilberman and Ice, 2021) and overall employment in STEM occupations has grown approximately 79% between 1990 and 2018 (Funk and Parker, 2018). In the EU, there is evidence of skills shortages in STEM fields and demand is expected to grow, i.e., by 2025 some 7 million job openings are expected (Caprile, Palmén, Sanz and Dente, 2015).

Traditionally, efforts to increase the number of students in STEM have primarily been directed towards increasing the number of female students, since female students are long known to be underrepresented in these fields (Yazilitas, Svensson, De Vries and Saharso, 2013). More recently, attention and efforts have expanded from merely attracting more female students in STEM fields to having a more diverse STEM population all together (Benish, 2018).

The call for more diversity is not exclusive to STEM fields or education but is currently vocalized in various domains, including media, politics, management, and government. It fits a general trend that is characterized by growing concerns over socioeconomic inequality between various groups in society, which has recently been fuelled due to the COVID-19 pandemic crises. An important way to counterbalance these inequalities and to create more equity and more equal opportunities is through education and career opportunities, i.e., the notion of education as the great equalizer as Horace Mann stated (see Bernardi and Ballerino, 2016). The need for more equity and more equal opportunities is particularly crucial in STEM fields since the availability of STEM knowledge, skills and human resources is becoming more and more indispensable in information and technology-driven economies (Atkinson and Mayo, 2010). The objective to have a more diverse STEM population and retain all talents in STEM follows naturally from this development. However, it is currently very unclear which groups are referred to when talking about diversity in STEM and what their main characteristics are.

The meaning of diversity varies between focus areas. Dependent on the needs within the field, the conceptualization of diversity differs. For example, in management research diversity variables can range from "highly job-related diversity", including educational and functional background to "less job-related diversity," such as age, sex, and other related demographic indicators. to measure the effects of diversity on team performance (Bell et al., 2011). The Interactional Model of Cultural Diversity (Cox Jr., 2013) describes that diversity directly effects organizational effectiveness.

Often, social processes such as similarity attraction (Harrison and Klein, 2007) are at the basis of the frameworks. The aforementioned authors define three diversity types: separation, variety, and disparity. However, demographic diversity, most often studied, can be conceptualized in all three types.

In educational research, especially in the US, college diversity experience is an issue of growing importance. There are several types of college diversity experience, such as structural diversity within the representation of students in a larger group, informal interactions with diverse peers and learning about diverse peers in a classroom context. Meta studies show that while diversity experiences are positively related to cognitive outcomes, but the effect varies depending on the type of diversity experience, cognitive outcomes, and study design (Bowman, 2010).

In this article, we explore the terminology that is used in reference to diversity in recent literature on STEM higher education as a first step to understanding what is meant by a more diverse STEM population. This is important because a clear understanding of the groups that fall under this definition will enable researchers to better design and assess the effectiveness of programs targeted at creating more diversity in STEM. Therefore, we focus specifically on diversity in STEM education in the context of higher education, including both students and faculty members. Higher education students are the main focus of this research for the reason that they represent the future generation of STEM employees. Faculty are included because they can serve as role models for students (Weber, 2011).

This research will help to discover which groups are most often referred to in relation to diversity in the recent research literature on increasing diversity in STEM higher education and what the implications are for future research.

METHODOLOGY

We conducted an exploratory study on academic literature, combining quantitative and qualitative content analysis in which we assessed which groups are most often referred to in recent research literature on increasing diversity in STEM fields, in the context of higher education. Various steps were followed to identify which articles should be included in the research.

The first step involved the choice of a primary database and defining search criteria. The Web of Science core collection was used as our primary database since it is one of the largest databases and contains a wide variety of articles that are relevant to our topic of interest. The search criteria (in March 2021) were as follows: (a) the article had to mention 'STEM', 'Science', 'Technology', 'Engineering', 'Mathematics', 'higher education' and 'diversity' in their abstract and/or title and (b) the article had to be peer-reviewed. This first step yielded a total of 51 articles ranging from the year 2009 to 2020.

The second step involved reading the abstract and the introduction of the papers. An article was included when its main topic was on increasing diversity in STEM higher education, including faculty.

The third step involved classifying the articles based on citation, as a measure of impact on the field, starting with the articles that had the highest citation score. Articles that were cited ten times or less, were excluded from this research as they were considered to have low impact within the field of STEM research. This third step resulted in 10 articles, with citations ranging from 62 times (highest) to being cited 12 times (lowest) (**Appendix B**).

The fourth step was to open code the abstract, introduction, theoretical framework and discussion using *Atlas.ti cloud*. Initially, all groups of people that were mentioned in the context of diversity and STEM higher education were assigned an individual label, including groups that were almost identical. For example, the groups 'underrepresented minorities' and 'underrepresented groups' were coded separately even though they are quite similar. The inclusion of these groups was based on our interpretation of the context in which a group was mentioned. In the case of, for example, "... *increasing and retaining the number of female students enrolled in STEM disciplines can help to alleviate part of the challenges faced by women in STEM fields.*" (Botella, Rueda, López-Iñesta and Marzal, 2019, p. 1) both "female students" and "women" were included since the focus is on the representation of these groups in STEM disciplines. This prevents terms such as 'women's representation' to be included in the analysis since, within the previously mentioned context, they do not refer to women as a group but to the representation of women. This yielded a total of 180 individually labelled groups (**Appendix A**).

Step five consisted of checking for transparency of the codes by including a second coder to code two articles independently from the first coder and to discuss any inconsistencies. Agreeance was approximately 83%. In this step codes that were formulated slightly different were merged together and codes that were agreed on being out of context were excluded.

The final and sixth step, was to further categorize the groups. For example, the groups labelled as 'women students' and 'young women' were both classified as *women*, whereas 'female students' and 'female professionals' were classified as *females*. Both *women* and *females* were then classified under gender. All references were also counted. The subcategories and the distribution of references will be discussed in more detail in our results below.

RESULTS

Table 1 shows an overview of the titles included in the research, the target group of the paper, the year of publication (YOP), and number of citations of the article by March 2021. References to the included articles are included in **Appendix B**. The target group is the main group of interest that is referred to in relation to increasing diversity in STEM according to the article. When reviewing the target groups and titles, it stands out that 7 out of 10 ten articles are aimed towards including more women or females in STEM fields and higher education (**Table 1**).

Table 1. Overview of the articles included in the analysis ranked on times cited

No	Title	Target group	YOP	Cited
1	Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success	Women of colour students	2017	62
2	Female peers in small work groups enhance women's motivation, verbal participation, and career aspirations in engineering	Undergraduate female students	2015	61
3	Enhancing diversity in undergraduate science: Self-efficacy drives performance gains with active learning	Higher education underrepresented minority students	2017	42
4	Now hiring! Empirically testing a three-step intervention to increase faculty gender diversity in STEM	Women	2015	42
5	Diverse faculty in STEM fields: Attitudes, performance, and fair treatment	Women and ethnic or racial minorities	2009	31
6	Toward inclusive STEM classrooms: What personal role do faculty play?	Diverse (STEM) students	2016	23
7	The gender gap in high school physics: Considering the context of local communities	Female high school students or women	2014	14
8	Gender diversity in STEM disciplines: A multiple factor problem	Female students or women	2019	15
9	Gender diversity strategy in academic departments exploring organizational determinants	Women	2014	13
10	The equity ethic–Black and Latinx college students reengineering their STEM careers toward justice	Black and Latin students	2017	12

Distribution of the Subcategories

Four subcategories were distinguished: 1) gender, 2) ethnicity and/or race, 3) a combination of ethnicity and/or race and gender and, 4) other unspecified minorities. The first subcategory includes references that solely refer to a group indicated by gender, including 'women' and 'females' as one of the most occurring references. The second subcategory includes references to groups indicated by ethnicity and/or race. Frequently occurring groups include 'ethnic or racial groups', 'Black', 'Latinx'–a term which is used to cover both Latina's and Latino's -, and 'people of colour'. The third subcategory includes references to groups indicated by ethnicity and/or race and gender and includes references such as 'women of colour', women from ethnically or racial groups specified as 'black women', 'white women', and 'African American women'. The fourth subcategory includes references to groups that are indicated by general terms of underrepresentation but are not specified in terms of gender, race and/or ethnicity. Some examples of the most occurring references here are: 'underrepresented minorities', 'underrepresented groups', 'underrepresented students', and 'marginalized groups'.

Looking at the distribution of the subcategories, it is clear that gender is by far the most referenced subcategory (**Table 2**), with almost half of the total number of references across the sample. This is even more so when we also take into account the subcategory ethnicity and/or race and gender, together making up almost 70% of all references that can be linked to gender.

Table 2. Distribution of the subcategories across ten articles

Group	Total times mentioned	Percentage (%)
Gender	573	49
Ethnicity or race	223	19
Ethnicity or race, and gender	232	20
Unspecified minorities	146	12
Total	**1,174**	**100**

Distribution of the subcategories per article

Regarding the distribution of the subcategories per article, it is evident that gender is most referred to (**Figure 1**). Despite article 1 containing some more specific references to ethnicity and/or race in combination with gender, it still relates to gender as well. This is not a surprising finding since most articles are targeted towards increasing the number of women in STEM higher education.

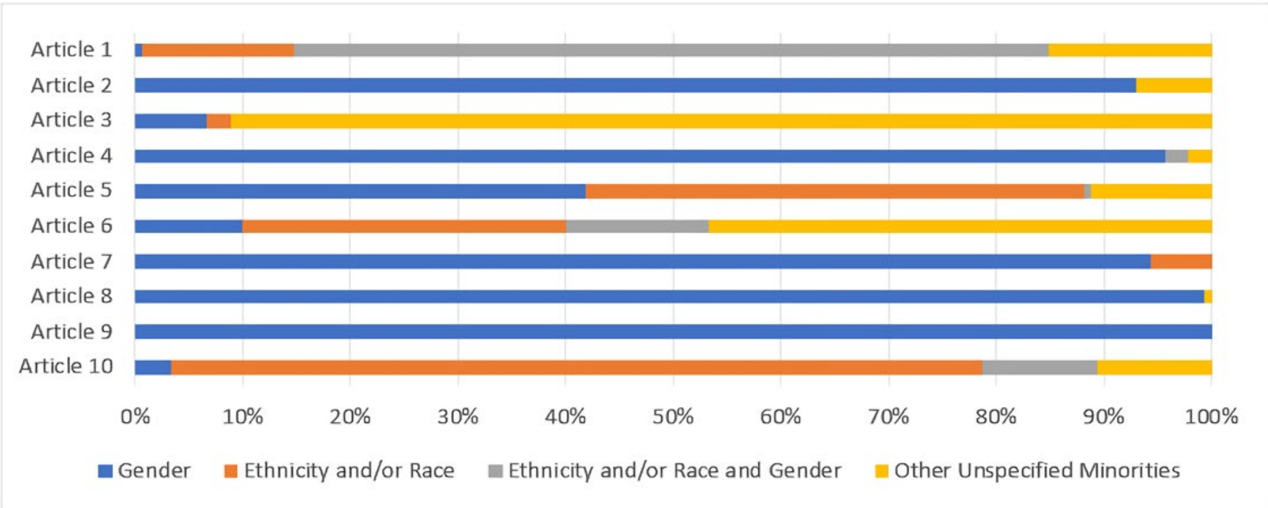

Figure 1. Distribution of the four subcategories per article (the distribution is a relative distribution; total number of references vary between articles)

Distributions differ when considering the articles that are not directed towards women in STEM specifically, including articles 3, 6 and 10. Article 3 mainly contain references to Ethnicity and/or Race while article 10 refers mainly to other unspecified minorities, whereas article 6 shows a more equal distribution of group references. In the next paragraphs, we will elaborate on the smaller categories that fall under the four subcategories (**Table 2**).

Gender

When zooming in on the subcategories and the distribution of particular groups within each subcategory, there are clear trends as well. Starting with the distribution of groups within the subcategory gender, by far the most often referred group within this subcategory is 'women', which corresponds with 74% of the references related to gender. 'Females' make up 17%, 'women or female faculty' 5% and 'girls' correspond to 4% of the references (**Figure 2**).

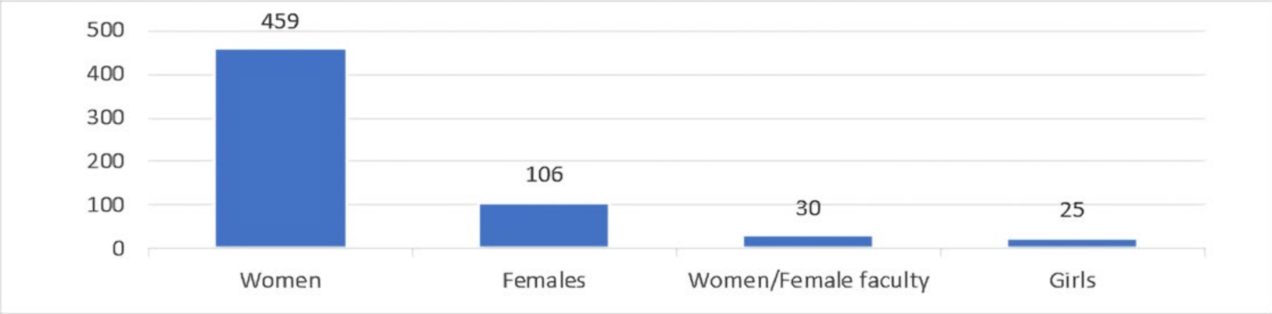

Figure 2. Distribution of groups within the category gender n=620

Ethnicity and/or race

The distribution of references within the subcategory ethnicity and/or race is less skewed than in the case of gender (**Figure 3**). Specific groups that are mentioned most frequent include' ethnic or racial groups' (29%), 'Black' (22%) and 'Latinx' (17%)–where Latinx comprises both Latina and Latino people. 'Other groups' make up for 12% of the references. The latter includes references to 'African American', 'Hispanic', 'Mexican American' and 'Hispanic American', which are all mentioned no more than twice in the whole sample.

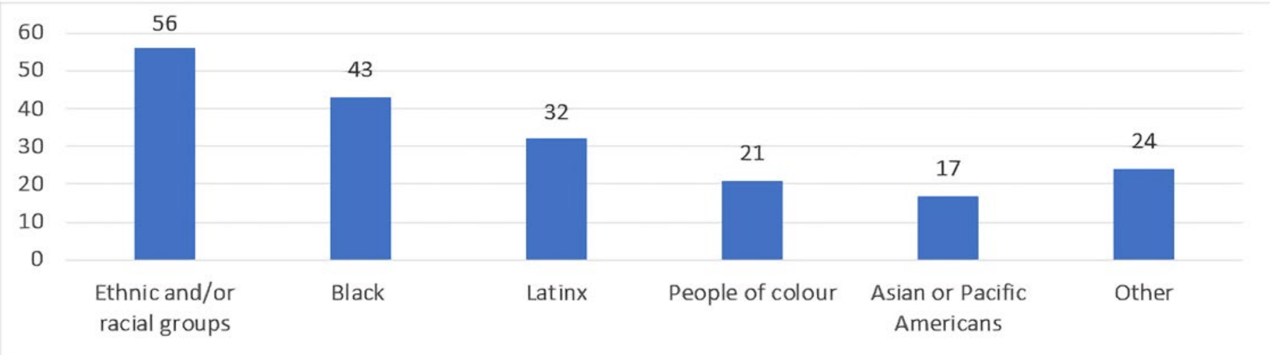

Figure 3. Distribution of groups within the category ethnicity or race n=193

Ethnicity and/or race and gender

In relation to specific groups within the subcategory ethnicity and/or race and gender, 'women of colour' is the vast majority with 93% of the references (**Figure 4**). This particular group is composed of various similar references, including 'women of colour', 'coloured women' and 'women of colour students'. Besides women of colour, two other groups were mentioned in this context, as can be seen in **Figure 4**, although their share is limited to 7% of the references within this subcategory. The category' other ethnicity or race women' consists of a wide variety of references that are mostly mentioned only once within the whole sample, such as 'African American women', 'Multicultural women', 'white females' and 'women from multiple racial or ethnic backgrounds.'

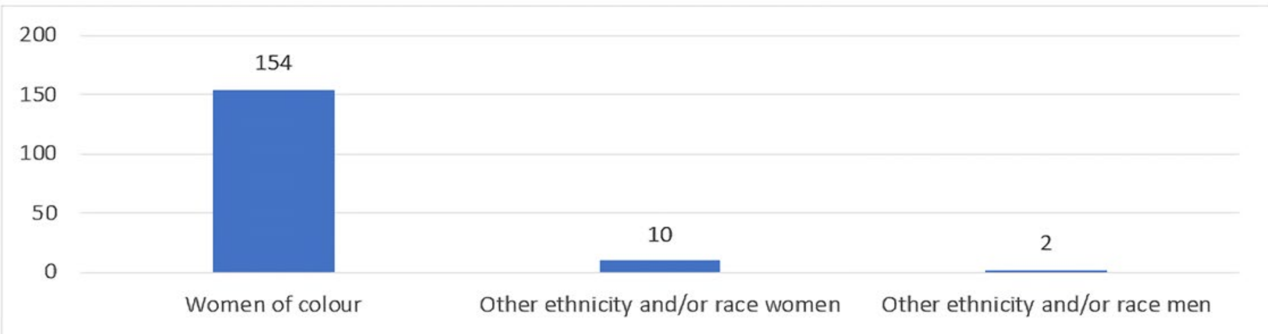

Figure 4. Distribution of groups within the category ethnicity and/or race and gender n=166

Other unspecified minorities

The most frequently mentioned group within the category of other unspecified minorities is 'underrepresented minorities' (hereafter 'URM'), representing 60% of all the references (**Figure 5**).

Figure 5. Distribution of groups within the category other unspecified minorities n=120

URM itself is comprised of specific references such as 'underrepresented minority students', 'underrepresented minority groups' and 'minorities.' The group' underrepresented groups or students' is the second most frequently referred, and only group next to URM, representing 40% of all references within the subcategory. The group is comprised of a wide variety of references, including 'marginalized groups', 'underserved groups', 'non-dominant groups', 'non-traditional groups', 'students at risk', and 'low socioeconomic status students', each of which is mentioned two times or less across articles.

DISCUSSION AND CONCLUSION

The underrepresentation of female students in STEM has been an important theme in the research on diversity in STEM in the last ten years (Li et al., 2020). Recently there has been a shift towards promoting more diversity in the STEM population in more general terms. While the meaning of diversity has been studied in other fields such as management, it has largely been left unclear which groups are and should be targeted in promoting more diversity in STEM education. To get a better understanding of which groups are currently targeted, we performed content analysis among recent literature within the topic of diversity in STEM higher education.

First of all, our results demonstrate that 'women' are by far the most often mentioned group across articles and that in our sample the overwhelming majority of references to diversity in STEM higher education can be linked to gender. This is followed by an intersection of ethnicity and/or race, an intersection of ethnicity and/or race and gender and a category that we refer to as unspecified. The primary focus on gender is in line with previous literature, which has mainly focused on increasing female participation in STEM (Caprile et al., 2015; Yazilitas et al., 2013). At the same time, the finding is somewhat surprising considering recent efforts and calls to have a more diverse and inclusive STEM population, i.e., one that is a better reflection of the various groups of people in modern-day, Western societies (Bernish, 2018).

Our results also show that there is a lot of variety, other than the ones that are linked to gender, used to refer to underrepresented groups in STEM higher education. The previous is evinced by a large number of unique references (180) in the sample we explored and the wide variety of groups that they comprised. This existence of so many references can be considered as a lack of specificity. The majority of articles in our sample did not further specify their target group. On the one hand, some did specify by referring to women's ethnicity or race as in the case of 'black women' or 'women of colour'. Although more specific, the question remains, which group of women is targeted. On the other hand, more general references were used, such as 'underrepresented groups' or 'underserved minorities', without further explaining or defining factors such as gender, race, ethnicity, or socioeconomic status.

Finally, our study reveals some important discrepancies in the use of references across our sample, which suggest that researchers–besides seemingly having a narrow practical definition of diversity–differ widely in their understanding of the concept of diversity. For example, some articles in our sample refer to 'white women' being underrepresented in STEM which is incongruent to the finding that 'black women' are one of the main underrepresented groups. In the case of white women, one can argue that the reference is too general, and that the specific context matters a great deal in considering the person or group to belong either to the under- or overrepresented group.

The lack of agreement or consensus among researchers, even about quite specific ethnic groups, combined with the lack of specificity mentioned before and the overwhelming focus on gender, prevents real progress in this research field.

Limitations

Because of the novel character of this research, some limitations arise. For the data collection, due to time limitations, we solely used Web of Science and selected the ten most cited articles for a first exploration. Ideally, multiple databases should be used to get a wider scope on what literature is available within the context of increasing diversity in the field of STEM higher education. Furthermore, we have chosen to select articles based on number of citations as a measure of impact on the field. However, it would be interesting to see if there is more consensus and a broader scope of diversity in newer articles. Furthermore, by selecting on number of citations, we might have excluded publications from minority academic institutions, overrepresenting the scope of more Western oriented academics. Finally, by including 'STEM' and all terms' Science' 'Technology', 'Engineering' and 'Mathematics' as search terms for the abstract, we might have missed relevant articles that chose not to use the abbreviation, or the terms written out.

This research also assessed the terms that were mentioned across articles quantitatively. This does not always give a good indication of what groups are mentioned, since the data was heavily skewed across articles. We tried to counterbalance this by using relative scales, but it is difficult to generalize these results as they give a limited view of how references are used in literature.

Finally, although we are aware of a broad availability of frameworks on diversity (Cox Jr., 2013; Harrison and Klein, 2007; Bowman, 2010) we did not build upon an existing theoretical framework. This work is a first exploration of existing research and references in STEM education with respect to (demographical) diversity. In further research we highly recommend to research connections between these terms and, for example, diversity experience.

Recommendations

More cohesion and specificity in terminology is needed in future research to effectively create policies to increase diversity in STEM higher education. Defining clear target groups are in our opinion the biggest challenge in effectively addressing the lack of diversity in STEM higher education and assessing future policies. In order to change this, several strategies can be followed. These should in our opinion at least include the following four components.

Firstly, a clear definition of the target groups and the main criteria of selection on which these target groups have or have not been included in the sample should be included in the introduction.

Secondly, target groups differ per country and over time. Taking into account these country differences and specific context is pivotal in better understanding the current state of affairs in relation to the representation of various groups within the STEM population and changing these in another direction.

Thirdly, it would benefit the research field if the research objective was more linked to earlier policy initiatives, and for example, include a (short) overview of (earlier) policy efforts in order to better understand the current or future situation in relation to increasing diversity in STEM. Too often, the research objective, i.e., increasing diversity in STEM is unlinked to earlier policy initiatives, resulting in misunderstanding or misevaluation of the effects of current policies.

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REFERENCES

Atkinson, R. D. and Mayo, M. J. (2010). Refueling the US innovation economy: Fresh approaches to science, technology, engineering and mathematics (STEM) education. *The Information Technology & Innovation Foundation, Forthcoming*. Available at: https://files.eric.ed.gov/fulltext/ED521735.pdf

Bell, S. T., Villado, A. J., Lukasik, M. A., Belau, L. and Briggs, A. L. (2011). Getting specific about demographic diversity variable and team performance relationships: A meta-analysis. *Journal of Management*, 37(3), 709-743. https://doi.org/10.1177/0149206310365001

Benish, S. (2018). Meeting STEM workforce demands by diversifying STEM. *Journal of Science Policy & Governance*, 13(1), 1-6.

Bernardi, F. and Ballarino, G. (2016). Education as the great eequalizer: A theoretical framework. In F. Bernardi and G. Ballarino (eds), *Education, occupation and social origin. A comparative analysis of the transmission of socio-economic inequalities* (pp. 1-19). Cheltenham Glos: Edward Elgar Publishing. https://doi.org/10.4337/9781785360459.00006

Botella, C., Rueda, S., López-Iñesta, E. and Marzal, P. (2019). Gender diversity in STEM disciplines: A multiple factor problem. *Entropy*, 21(1), 30. https://doi.org/10.3390/e21010030

Bowman, N. A. (2010). College diversity experiences and cognitive development: A meta-analysis. *Review of Educational Research*, 80(1), 4-33. https://doi.org/10.3102/0034654309352495

Caprile, M., Palmén, R., Sanz, P. and Dente, G. (2015). Encouraging STEM studies labourmarket situation and comparison of practices targeted at young people in different member states. *European Parliament, Directorate General For Internal Policy, Policy Department A, Economic and Scientific Policy*. Available at: http://www.europarl.europa.eu/studies

Cox Jr., T. (2013). Interactional model of cultural diversity. In E. Kessler (ed.), *Encyclopedia of management theory* (pp. 390-394). SAGE. https://doi.org/10.4135/9781452276090.n136

Funk, C. and Parker, K. (2018). Women and men in STEM often at odds over workplace equity. *Pew Research Center*. Available at: http://hdl.handle.net/10919/92671

Harrison, D. A. and Klein, K. J. (2007). What's the difference? Diversity constructs as separation, variety, or disparity in organizations. *Academy of Management Review*, 32(4), 1199–1228. https://doi.org/10.5465/amr.2007.26586096

Li, Y., Wang, K., Xiao, Y. and Froyd, J. E. (2020). Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education*, 7, 11. https://doi.org/10.1186/s40594-020-00207-6

Weber, K. (2011). Role models and informal STEM-related activities positively impactfemale interest in STEM. *Technology and Engineering Teacher*, 71(3), 18.

Yazilitas, D., Svensson, J., de Vries, G. and Saharso, S. (2013). Gendered study choice: Aliterature review. A review of theory and research into the unequal representation of male and female students in mathematics, science, and technology. *Educational Research and Evaluation*, 19(6), 525-545. https://doi.org/10.1080/13803611.2013.803931

Zilberman, A. and Ice, L. (2021). Why computer occupations are behind strong STEM employment growth in the 2019-29 decade. *U.S. Bureau of Statistics*. Available at: https://www.bls.gov/opub/btn/volume-10/why-computer-occupations-are-behind-strong-stem-employment-growth.htm

APPENDIX A

Table A1. Colours are solely for the purpose of making clear where the subthemes start and end

Subcategories	Codes
I. Ethnicity and/or race	African American
	African American professionals
	Asian
	Asian minorities
	Asian or Pacific American
	Asian or Pacific American faculty members
	Asian American
	Students who identify as African-American, Latino or Latina, Asian-American, White
	Mexican
	Ethnically diverse group(s)
	Ethnic minority group
	Ethnic minority students
	Demographic groups
	Black students (& students who are black)
	Latino families
	Latino men
	Latino STEM degree holders
	Latina women
	Latinx
	Latinx college students
	Latinx individuals
	Latinx students
	Latinx undergraduate students
	Latinx workers
	Marginalized Latinx students
	Latina or Latino students
	Black undergraduate students
	Black workers
	Black
	Black college students
	Black individuals
	Black scientists
	Faculty of colour
	Non-white
	Racial groups
	Black (PhD) students
	Black Americans
	Black families
	Black graduates
	Black peers
	Black people
	Black STEM degree holders
	Black STEM majors
	Hispanic Americans
	Hispanic STEM majors
	Students of colour
	Professionals of colour
	People of colour
	Marginalized black students
	Non-white students
	African American or Black
	Ethnic or racial group
	Ethnic or racial minorities
	Ethnic or racial minority groups

Table A1 (Continued).

Subcategories	Codes
I. Ethnicity and/or race	Groups that are racially or ethnically heterogeneous
	Hispanic
	Hispanic or Latino or Mexican American
	Latina or Latino students
	Latino families
	Latino men
	Latino STEM degree holders
	Latino or Latina
	Latinx
	Latinx college students
	Latinx graduates
	Latinx individuals
	Latinx peers
	Latinx students
	Latinx undergraduate students
	Latinx workers
	Marginalized Latinx students
	Minority undergraduates referring to Black, Latinx, American Indian, Asian
	Non-Asian racial or ethnic minority groups
	Other racial or ethnic groups
	Other racial or ethnic groups (outside of Black PhD)
	Racial or ethnic minority
	Racial or ethnic minority faculty
	Racial or ethnic minority group
	Racially and ethnically diverse groups
	Racially or ethnically underrepresented groups
	Racially or ethnically underrepresented students
	Students from racially or ethnically underrepresented groups
	Underrepresented racial or ethnic groups
II. Gender	Faculty women
	Female academics
	Female chairs
	Female department chairs
	Female experts
	Female faculty
	Female faculty members
	Female high school graduates
	Female high school students
	Female leaders
	Female managers
	Female MBA students
	Female peers
	Female STEM professionals
	Female students
	Females
	Graduated women
	Girls
	Graduated female students
	High school girls
	Highly or moderately qualified women
	Same-sex experts
	Same-sex peers
	Women
	Women academics
	Women administrators

Table A1 (Continued).

Subcategories	Codes
II. Gender	Women advanced college career
	Women chairs
	Women faculty
	Women students
	Young women
III. Ethnicity and/or race and gender	Women of colour who self-identify as Asian American, Black, Latina or Latino, Native American, Mixed race or ethnicity
	Women of colour referring to African American, Asian American, Latina, Native American and Pacific Islander
	Women of colour
	Women of colour in higher education as students
	Women of colour students
	Black women
	Black men
	White women
	White females
	Underrepresented students particularly women of colour
	Latino
	Multicultural undergraduate women
	Non-traditional groups including mixed race or ethnicity, Women, Racially or ethnically underrepresented students, women of colour
	Often Marginalized groups referring to Women, Ethnical or racial minorities
	Women from historically underrepresented racial or ethnic group
	Women of colour from varying racial or ethnic backgrounds
	Women of colour who self-identify as Asian American, Black, Latina or Latino, Native American, Mixed race or ethnicity
	Women from multiple racial or ethnic groups
IV. Other unspecified minorities	University students from low-socioeconomic backgrounds
	Historically underrepresented groups
	Historically underrepresented minority (URM) students
	Historically underrepresented students
	Historically underserved groups
	Historically disadvantaged groups (referring to women and ethnic minorities)
	Marginalized groups
	Marginalized groups that do not reflect the gender, race, or ethnicity conventionally associated with STEM mainstream success
	Marginalized group members
	Marginalized groups
	Marginalized higher education students
	Marginalized individuals
	Marginalized participants
	Often Marginalized groups
	Other Marginalized groups
	Traditionally Marginalized groups
	Underrepresented minorities referring to (PhD) students, doctoral and postdoc
	Groups that are more traditionally Marginalized in American culture
	Marginalized university faculty
	Traditionally marginalized students
	Underrepresented (minority) groups
	Members of other underrepresented groups
	Members of underrepresented groups
	Minority students
	Underrepresented groups
	Underrepresented minority (URM) students
	Underrepresented minority groups
	Underrepresented minority postdocs
	Underrepresented minority students
	Underrepresented minority (STEM) students (mostly referring to Black & Latin students)
	Underrepresented people

Table A1 (Continued).

Subcategories	Codes
IV. Other unspecified minorities	Underrepresented students
	Underrepresented or disadvantaged groups
	Other underrepresented groups
	Other underrepresented students
	Underrepresented minority scientists
	Model minorities
	Underrepresented minority individuals
	Negatively stereotyped group (not sure)
	Stereotyped group (not sure)
	Students at risk
	Students from historically underrepresented backgrounds
	Underserved groups
	Other non-dominant groups
	Diverse students
	Individuals who are demographically different
	Students over age 25
	Young students

APPENDIX B: REFERENCES OF DATASET

Ballen, C. J., Wieman, C., Salehi, S., Searle, J. B. and Zamudio, K. R. (2017). Enhancing diversity in undergraduate science: Self-efficacy drives performance gains with active learning. *CBE–Life Sciences Education*, 16(4), ar56. https://doi.org/10.1187/cbe.16-12-0344

Blackwell, L. V., Snyder, L. A. and Mavriplis, C. (2009). Diverse faculty in STEM fields: Attitudes, performance, and fair treatment. *Journal of Diversity in Higher Education*, 2(4), 195-205. https://doi.org/10.1037/a0016974

Botella, C., Rueda, S., López-Iñesta, E. and Marzal, P. (2019). Gender diversity in STEM disciplines: A multiple factor problem. *Entropy*, 21(1), 30. https://doi.org/10.3390/e21010030

Dasgupta, N., Scircle, M. M. and Hunsinger, M. (2015). Female peers in small work groups enhance women's motivation, verbal participation, and career aspirations in engineering. *Proceedings of the National Academy of Sciences*, 112(16), 4988-4993. https://doi.org/10.1073/pnas.1422822112

Killpack, T. L. and Melón, L. C. (2016). Toward inclusive STEM classrooms: What personal role do faculty play? *CBE–Life Sciences Education*, 15(3), es3. https://doi.org/10.1187/cbe.16-01-0020

McGee, E. and Bentley, L. (2017). The equity ethic: Black and Latinx college students reengineering their STEM careers toward justice. *American Journal of Education*, 124(1), 1-36. https://doi.org/10.1086/693954

Ong, M., Smith, J. M. and Ko, L. T. (2018). Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success. *Journal of Research in Science Teaching*, 55(2), 206-245. https://doi.org/10.1002/tea.21417

Riegle-Crumb, C. and Moore, C. (2014). The gender gap in high school physics: Considering the context of local communities. *Social Science Quarterly*, 95(1), 253-268. https://doi.org/10.1111/ssqu.12022

Smith, J. L., Handley, I. M., Zale, A. V., Rushing, S. and Potvin, M. A. (2015). Now hiring! Empirically testing a three-step intervention to increase faculty gender diversity in STEM. *BioScience*, 65(11), 1084-1087. https://doi.org/10.1093/biosci/biv138

Su, X., Johnson, J. and Bozeman, B. (2015). Gender diversity strategy in academic departments: Exploring organizational determinants. *Higher Education*, 69(5), 839-858. https://doi.org/10.1007/s10734-014-9808-z

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Integrated STEM Education: The Effects of a Long-Term Intervention on Students' Cognitive Performance

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ABSTRACT

Integrated Science, Technology, Engineering and Mathematics (iSTEM) education is a promising approach to attracting more qualified and better motivated students to STEM fields. In this study, we respond to one of the salient challenges facing integrated STEM educational research, namely investigating its educational impact. We developed a large-scale intervention where all STEM components are integrated and examined the impact this integrated STEM curriculum has had on cognitive performances regarding physics, mathematics, technological concepts, and integrated physics and mathematics. In total, 859 grade 9 students, distributed across 39 Flemish different schools, participated in a long-term study. The results of multilevel analyses show that iSTEM education had positive effects on cognitive performance in terms of mathematics knowledge and application and technological concepts. Also, differential intervention effects were found with regard to student characteristics. Since the impact was only apparent after two years, we stress the importance of a long-term integrated STEM approach.

Keywords: STEM, integrated STEM, cognitive performance, longitudinal research

INTRODUCTION

Generating a sufficient number of qualified professionals in science, technology, engineering and mathematic (STEM) areas is a matter of international concern (Thibaut et al., 2018a; Hernandez et al., 2014; Bøe, Henriksen, Lyons and Schreiner, 2011). Awareness of the problem with regard to young people's increasing reluctance to participate in STEM emerged in the early 1990s, and this has been a growing problem to this day (Bøe et al., 2011; Moore and Smith, 2014; Keith, 2018; Hermans et al., 2022; De Loof et al., 2022), as national reports continue to identify shortages of STEM graduates. The World Economic Forum (2016) predicted an increased demand for specialists in the STEM field for the years to come and stated that the pace of technology adoption is expected to remain unabated and may accelerate in some areas (World Economic Forum, 2020). The current knowledge-based society demands a large number of students graduating from STEM-related fields (National Academies of Science, 2007). Countries need a sound economy and need to find solutions for societal and environmental matters, such as sustainable energy production in a world with shrinking resources, adequate healthcare in an aging society, and well-considered technology development (Wang, Moore, Roehrig and Park, 2011; Kjærnsli and Lie, 2011; Bøe et al., 2011). Integrated STEM can play a central role in motivating students to choose a STEM study or profession and has the potential to improve students' learning (Honey, Pearson and Schweingruber, 2014; Becker and Park, 2011).

Integrated STEM

STEM is an integration of the four subjects: science, technology, engineering, and mathematics (Wang et al., 2011). However, as the term is widely used, there is no consensus about the nature and range of the concept. Some researchers and educators use the term STEM to refer to one or more of its components, others use it only in the integrated sense (Wang et al., 2011; English, 2016). As we are discussing the term in the integrated sense, we will use 'integrated STEM' (iSTEM) in this paper. Sanders (2009) defines iSTEM approaches as "Approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects" (Sanders, 2009: 21). According to Honey et al. (2014), iSTEM education includes a range of different experiences that involve some degree of connection. "The experiences may occur in one or several class periods, throughout a curriculum, be reflected in the organization of a single course or an entire school or be encompassed in an out-of-school activity" (Honey et al., 2014: 2). Consequently, they define integration as "…working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines" (Honey et al., 2014: 52).

In the current study, we use Honey et al.'s definition, and thus we approach iSTEM in terms of the integration of all its components into a single curricular project that emphasizes concepts and their application from across the four disciplines (Roehrig, Moore, Wang and Park, 2012). Within this approach, the literature differentiates between multidisciplinary and interdisciplinary integration (Wang et al., 2011). The metaphor of chicken noodle soup versus tomato soup provided by Lederman and Niess (1997), is often used to explain the differences between these two forms of integration. The chicken noodle soup represents multidisciplinary integration, where each ingredient maintains its identity without a direct mixture in the totality of the integration. Multidisciplinarity starts from subject-based content and skills, and students are expected to form connections between the subjects that they have been taught in different classes (Wang et al., 2011). Tomato soup, on the other hand, represents interdisciplinary integration, where the boundaries between subjects are blurry. Interdisciplinarity starts from a problem that requires an understanding of the content and skills of multiple subjects (Wang et al., 2011). Vasquez, Sneider, and Comer (2013) add an additional level of increased integration by introducing the concept of transdisciplinary integration. Knowledge and skills from multiple disciplines are hereby applied to solve real-world problems. In the current study, we approach education in iSTEM as a transdisciplinary concept.

Educational Research in Integrated STEM

Removing barriers between disciplines is meant to increase students' conceptual understanding and achievements regarding STEM topics and increase recognition of the relevance of the subjects in relation to each other and to the context of real-world problems (Honey et al., 2014; Thibaut et al., 2018a). Integrated STEM education is a promising approach to attracting more qualified and motivated students in STEM fields by improving students' interest and learning in STEM. It has received increasing attention from educators and researchers over the past decade (Honey et al., 2014; Yang and Baldwin, 2020). Besides the possible positive effects of iSTEM education on the general student population, it has also been argued that iSTEM might be particularly beneficial to certain student populations. Cantrell, Pekca, and Ahmad (2006) for instance, showed that an integrated engineering curriculum diminished achievement gaps in typically low-achieving ethnic minority student groups. Newton et al. (2020) demonstrated that informal STEM learning in robotics and game design could influence computational thinking skills in African-American students living in an urban context. Other studies demonstrate that gender differences in performance might reduce when students follow iSTEM courses linked with real-world activities (Standish, Christensen, Knezek, Kjellstorm and Bredder, 2016). Hence, student characteristics that might have an effect on cognitive STEM outcomes might have a differential impact in an iSTEM educational approach. In the literature, such characteristics are well documented: previous research has indicated that gender, abstract reasoning ability and socioeconomic status (SES) might influence cognitive scores on STEM domains (e.g., Halpern et al., 2007; Deary, Strand, Smith and Fernandes, 2007; Yerdelen-Damar and Peşman, 2013).

To conclude, an iSTEM educational approach is promising for both the general student population and for a variety of students with different characteristics. In response, numerous new teaching materials, projects, and even complete study programs have been developed (e.g., Yang et al., 2021). Such a development entails the challenge to investigate empirical evidence to support the effective implementation of iSTEM education (Becker and Park, 2011). Indeed, the notion that learning becomes more meaningful and prolonged when students can make connections between STEM concepts has prompted research that aims to investigate the cognitive benefits of iSTEM education.

Becker and Park (2011) have synthesized research findings on the effects of integrated approaches among STEM subjects on students' cognitive performances. In their meta-analysis they described 28 studies reporting on effectiveness regarding students' learning in integrated STEM conditions. According to Becker and Park (2011), the small number of studies is due to the finding that many pieces of research are in the form of opinion papers without empirical data. Studies varied in the degree to which they addressed the integration of two or more STEM-subjects, the number of participants, and their age. A first gap in the current body of knowledge is the number of studies that integrated all components of STEM and reported on all associated cognitive outcomes. Only one study addressed the integration of all components, i.e., a study on the effect of integrated STEM on students with learning disabilities (Lam et al., 2008). Five studies discussed achievement scores after integration of S-T-E, and five studies reported on scores after the integration of S-T-M. Other studies integrated only two components. Regarding the measured achievement, only Lam et al. (2008), reported on the scores on all components, and just two studies measured the scores on S-T-E. No studies reported scores on questions addressing integrated STEM. A second concern is the low number of participants and the small scale of the interventions. Since the mean number of participants is 174.58 (min. = 21; max. = 1,053), it is difficult to draw far-reaching conclusions. A third shortage is that studies are limited in terms of time perspective. No longitudinal studies could be included, which has the implication that little is known about the long-term effect of iSTEM education.

Studies published after Becker and Park's (2011) meta-analysis encounter the same problems (i.e., a skewed focus on science at the expense of mathematics, no integration of all subjects, limited numbers of participants, and no studies from a long-term perspective) (English, 2016; Yildirim, 2016), and continue to be small in number. To conclude, long-term research with all STEM components integrated is very rare and, as a result, the effects of an iSTEM approach on cognitive performances is a crucial gap in the field. More empirical research on the educational effects of (integrated) STEM education is therefore needed (Honey et al., 2014). With our current long-term study, we respond to this challenge and to the need to fill the gaps in integrated STEM educational research. We focus explicitly on the effect of a large-scale intervention where all STEM components are integrated in the developed learning modules.

Design of the Intervention

The intervention, called STEM@School is a collaborative project between two universities (KU Leuven, University of Antwerp) and two educational umbrella organizations (GO!, Catholic Education Flanders) covering approximately 70% of all schools in Flanders. The KU Leuven developed the learning materials in collaboration with teacher design teams, and the University of Antwerp evaluated the project. The role of the two umbrella organizations was to support the participating schools in their implementation, and to monitor the content of the developed materials so that they cover all learning objectives and curriculum guidelines.

Five iSTEM learning modules were developed. Schools incorporated three of these modules into the curriculum in grade 9 (third year in secondary education; age: 13-15 years), and two in grade 10 (fourth year in secondary education; age: 14-16 years). The participating schools introduced an integrated STEM subject in which the learning modules were addressed. To implement these learning modules, 4 to 5 teaching hours a week were required for the duration of each of two semesters. The schools taught the integrated STEM subject partly within the teaching hours of the regular mathematics, physics and engineering classes (where the regular content was aligned with the curriculum of the integrated STEM subject), and partly within additional hours in the form of optional classes. More detailed information of the project and its implementation approach can be found in the project paper of STEM@School (Knipprath et al., 2018).

The learning modules consisted of challenges that were relevant in terms of societal and ecological problems, applying a transdisciplinary approach (Vasquez et al., 2013). Students address these challenges by applying knowledge and skills across disciplines, hereby making connections between principles and concepts. Problem-solving in an integrated STEM context also requires inquiry and design competences on the part of the students (Thibaut et al., 2018a). These characteristics constituted the core of the iSTEM intervention and were the foundation of all learning modules.

An example of one of the learning modules is the challenge of the optimization of traffic flow through a green wave (i.e., the coordination of traffic lights to allow continuous traffic flow). Students had to design and program a car in such a way that it could drive through a green wave without exceeding a safe speed limit. To succeed in this challenge, they had to use knowledge and skills from all STEM disciplines, such as acceleration (science), building the car with appropriate materials (technology), programming the car (engineering), and functions (mathematics). Obviously, this division is to some extent artificial, as these domains are interdependent. For instance, mathematics is already embedded in the physical concept of acceleration (Becker and Park, 2011), and some authors consider engineering as a subset of technology (Williams, 2011). Nevertheless, all modules could be considered as challenges which incorporated themes from the different STEM domains.

Current Study

Given the need for long-term educational research regarding iSTEM education, we aimed to evaluate the effectiveness of a large-scale two-year intervention in which students had to respond to relevant challenges by making use of knowledge and skills from different STEM domains. To respond to challenges posed in previous integrated STEM educational research, we incorporated all four domains in the intervention, and investigated the cognitive effects on physics' knowledge, physics' application, mathematics' knowledge, mathematics' application, technological concepts, and integrated physics and mathematics. We put forward two research questions:

Research question 1. What is the impact of an iSTEM curriculum on cognitive performances regarding physics (both knowledge and application), mathematics (both knowledge and application), technological concepts, and integrated physics and mathematics after one and two years?

Research question 2. What is the differential effectiveness of the iSTEM curriculum regarding student characteristics (i.e., gender, SES and abstract reasoning)?

METHOD

Participants and Procedure

The schools in this study were part of STEM@School and volunteered to take part in this longitudinal study. Thirty schools involving 612 grade 9 students implemented the experimental condition of the iSTEM education program. To assemble a representative control group, all Flemish schools (i.e., schools serving the Dutch-speaking community of Belgium) were listed, and an inventory of relevant characteristics was created, such as the number of students, study track options, and membership of educational umbrella organizations. Subsequently, for each experimental school, three matching schools were selected at random and invited to participate in the project. Control schools were invited through a letter, and if no response was received, school administrators were called by a researcher as a follow-up. Nine control schools took part in the project, involving 247 students in the control condition of a traditional education program, with separate physics, engineering, and mathematics courses.

The students in this study were taking classes in one of the following three study tracks: 1. Science and Mathematics, 2. Engineering, and 3. Latin and Mathematics. The total number of participants and the division over condition and study track can be found in **Table 1**.

Table 1. Number of participants (absolute and relative) divided over condition and study track

	Experimental condition	Control condition	Total	%
Science & mathematics	396	169	565	66%
Engineering	201	47	248	29%
Latin & mathematics	15	31	46	5%
Total	**612**	**247**	**859**	100%
%	71%	29%	100%	100%

The participants totalled 859 (66% boys and 34% girls) grade 9 students with a mean age of 13.86 years (*SD* = .54) at the start of the study. We followed a quasi-experimental longitudinal design over two years. Three measurement moments were undertaken in both the experimental and control conditions: (1) before the start of grade 9, (2) at the end of grade 9, and (3) at the end of grade 10 (**Figure 1**).

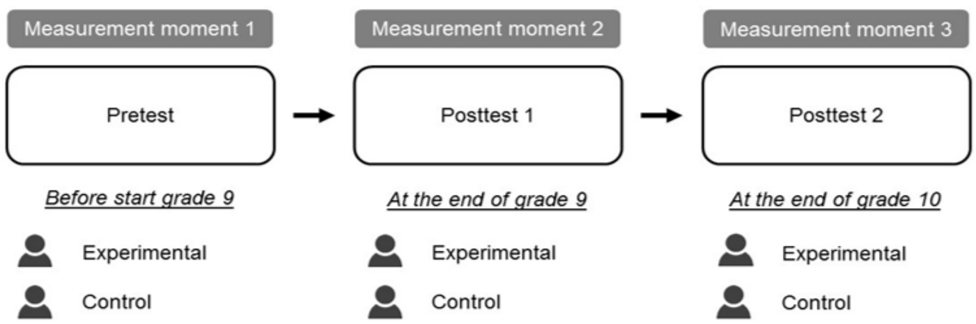

Figure 1. Measurement moments before start of grade 9, after the end of grade 9, and after the end of grade 10

While in total 859 unique participants were involved in the study, some of them were missing at different measurement moments. This could be due to schools dropping out of the project over time, or the failure of schools to administer surveys to students on a measurement moment, and because of the illness of individual students on a particular measurement moment. No selective attrition was observed, as Little's MCAR test showed that the data were missing completely at random. **Table 2** provides an overview of the number of recorded responses of students over the three measurement moments.

Table 2. Number of recorded responses over measurement moments

	Time 1	Time 2	Time 3
Experimental	556	443	302
Control	238	208	138
Total	**794**	**651**	**440**

Students were allotted a unique code to guarantee their anonymity and to allow the researchers both to connect different questionnaires and tests within measurement moments, and to link questionnaires and tests across time. At the first measurement moment, students filled in an online questionnaire to provide demographic information and completed a test measuring abstract reasoning ability. Online multiple-choice tests were administered, measuring cognitive outcomes with regard to STEM concepts. Cognitive outcomes were re-assessed at the second and third measurement moments, with tests that were adapted to the expected level at the end of grades 9 and 10 respectively. Students completed the online questionnaires and tests during normal school hours under supervision of the schools' contact person of [name project]. Students and their parents were provided with information about the aim of the study, and with a passive informed consent procedure. This procedure was approved by an institutional ethical committee.

Instruments

Demographic information

Information regarding age, gender, and the SES of participants was obtained from the self-report of students on an online questionnaire. SES was determined by language spoken at home, country of birth of respondents and both parents (Tate, 1997), both parents' education, and both parents' occupational status[1] (Bornstein and Bradley, 2003). We performed exploratory factor analysis with varimax rotation on the above-mentioned variables, which led to two underlying variables: (1) origin and (2) occupation and education. The weighted sum of the factor scores on these two variables led to a total SES score for each student.

Abstract reasoning ability

We gathered information on abstract reasoning ability as a proxy for general and non-verbal intelligence (Conway, Cowan, Bunting, Therriault and Minkoff, 2002; Raven, Court and Raven, 1977). The test consisted of 40 items and involved inductive reasoning about spatial features and relationships. Every item consisted of a series of figures with one inconsistent figure.

Cognitive outcomes regarding STEM concepts

Six instruments were developed to measure cognitive performance with regard to physics, mathematics and technological concepts: (1) physics knowledge, (2) physics application, (3) mathematics knowledge, (4) mathematics application, (5) technological concepts, and (6) integrated physics and mathematics (IPM). Adapted instruments for these outcomes were developed to respond to the expected level at each measurement moment, i.e., the start and end of the ninth grade, and the end of the tenth grade. Instruments were constructed based on the curriculum for physics, mathematics, and technological concepts of the ninth and tenth grades by pedagogical and subject-matter experts. In the case of integrated physics and mathematics, no items were developed for measurement moment 1, as students at the beginning of grade 9 were not yet familiar with curricular mathematics and physics concepts that lend themselves to be integrated in an overarching question. Information about the number of items per instrument, and an example item for each of the six measured outcomes, can be found in **Appendix A**. To reduce the burden on students and to make it possible to administer these tests during school hours, only eight items of each instrument were selected at random by the online software and presented to the students.

[1] Typically, information about the family's economic situation is also used to calculate a measure for SES (Bornstein and Bradley, 2003). However, as we questioned students with an age range of 13-15, the current study did not include economic questions (Bradley and Corwyn, 2002).

The psychometric qualities of the tests for physics knowledge, physics application, mathematics knowledge, mathematics application, technological concepts, and integrated physics and mathematics were investigated, using latent trait models under Item Response Theory (IRT; Rizopoulos, 2006). A detailed description of the IRT analyses can be found in **Appendix B**. After the psychometric qualities of the instrument were investigated, a factor score for each student was calculated. This procedure was repeated for every cognitive test instrument for each of the three measurement moments. Due to poor psychometric qualities of the physics knowledge test at measurement moment 3, no individual scores were available for that scale.

Plan of Analysis

First, we investigated the intercorrelations among the dependent variables of the study which are shown in **Table 3**. Given that the correlations were between .01 (no linear relationship) and .42 (a small linear relationship), we conducted separate univariate analyses for all six cognitive outcomes.

Table 3. Intercorrelations among the dependent variables of the study

Variables	1.	2.	3.	4.	5.	6.
1. Physics knowledge						
2. Physics application	.11***					
3. Mathematics knowledge	.11***	.24***				
4. Mathematics application	.21***	.20***	.42***			
5. Technological concepts	-.03	-.01	.06*	.11***		
6. Integrated physics and mathematics	.10***	.06	.09**	.18**	.09***	

Note. The scores on the variables are aggregated IRT scores over time.
*p<.05. **p<.01. ***p<.001.

Subsequently, we constructed mixed models which allowed us to investigate the general and differential effects of the iSTEM intervention. We conducted multilevel analysis employing JMP software (John's Macintosh Project) version JMP pro 13. Linear mixed models in JMP make use of all data (and not only complete cases), thereby also including information of cases with missing values.

This study used a three-level model where measurement moments at level 1 were nested within students at level 2, which in turn were nested within schools at level 3. Multilevel modelling allows data to be clustered in groups (e.g., multiple measurement moments of one student, multiple students in one class group, multiple class groups in one school, etc.), and to have a hierarchical structure (e.g., students are part of a class group, and class groups are in turn part of a school). As students are measured three times, and their results are not independent. 'Student ID' was thus included as a random factor. Also, students learn together in a school, which could cause the outcomes of students within the same school to be more highly correlated than the outcomes of students between schools. Therefore, school was also included as a random factor. For all six investigated outcomes, we inspected whether a model with a fixed slope (random intercept model) fitted better to the data than a model with a random slope (random intercept and random slope model) (Raudenbush and Bryk, 2002). A multivariate likelihood-ratio test (2log (likelihood random slope)–2 log (likelihood random intercept)) revealed that the random slope model fitted better than the restricted (i.e., fixed slope) model in the case of physics application and mathematics knowledge. To examine agreement among students and agreement among schools we computed intra-cluster correlation coefficients (ICC).

With regard to the fixed effects, we included six main effects to control for their direct influence on the cognitive outcomes. Besides condition (0 = control condition, 1 = experimental condition), and measurement moment (1 = time 1, 2 = time 2, 3 = time 3), we also controlled for gender (1 = male, 2 = female), abstract reasoning and SES, as previous research indicated that these variables might influence cognitive scores on STEM domains (Halpern et al., 2007; Deary, Strand, Smith and Fernandes, 2007; Yerdelen-Damar and Peşman, 2013). Scores for abstract reasoning abilities and SES were standardized. It was also important to control for study (1= focus on science and mathematics, 2 = focus on engineering, 3 = focus on Latin and mathematics) as this variable was not homogenous in our sample.

To investigate the general intervention effects over time (see research question 1), we added the interaction between condition and measurement moment in the model. Differential intervention effects (see research question 2) for students with specific characteristics (i.e., gender, SES and abstract reasoning) were investigated by adding three-way interactions to the model.

Table 4. Multilevel analysis of the effects of condition (0 = control, 1 = experimental), time (1 = time 1, 2 = time 2, 3 = time 3, study track (1 = science and mathematics, 2 = engineering, 3 = Latin and mathematics), gender (1 = male, 2 = female), abstract reasoning, and SES on cognitive outcomes

Fixed effects	Phys. know.		Phys. app.		Math. know.		Math. app.		Techn.		IPM	
	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Intercept	-0.01	0.08	0.07	0.09	-0.20	0.13	0.03	0.12	-0.06	0.08	0.02	0.08
Main effects												
Condition [0]	-0.05	0.05	-0.06	0.06	-0.09	0.12	-0.20*	0.09	-0.15**	0.05	-0.10	0.05
Time [1]	0.02	0.03	-0.02	0.03	-0.01	0.04	-0.07	0.04	-0.09**	0.03		
Time [2]			-0.05	0.04	-0.08	0.04	-0.06	0.04	-0.06	0.03	-0.03	0.03
Study track [1]	0.00	0.08	-0.15	0.09	0.17	0.11	0.07	0.11	0.15*	0.08	0.03	0.08
Study track [2]	0.03	0.09	-0.19*	0.10	0.27	0.15	0.19	0.13	0.12	0.08	0.15	0.09
Gender [1]	0.02	0.04	0.18***	0.04	0.09	0.05	-0.01	0.05	0.03	0.04	-0.02	0.04
Abstract reasoning	0.01	0.02	0.09***	0.02	0.08**	0.03	-0.00*	0.03	-0.03	0.02	0.03	0.02
SES	0.02	0.02	0.04*	0.02	0.04	0.02	0.04	0.02	-0.00	0.02	0.00	0.02
Two-way interaction												
Condition [0]×time [1]	0.20	0.16	-0.11	0.15	0.65***	0.19	0.23	0.19	0.30*	0.14		
Condition [0]×time [2]			-0.08	0.15	0.64**	0.19	0.74***	0.20	0.45**	0.16	0.21	0.13
Three-way interactions												
Con. [0]×time [1]×study track [1]	-0.31	0.18	0.31	0.17	-0.65**	0.21	0.02	0.21	-0.10	0.16		
Con. [0]×time [2]×study track [1]			0.14	0.18	-0.29	0.22	-0.57*	0.23	-0.30	0.19	-0.29*	0.15
Con. [0]×time [1]×study track [2]	0.21	0.28	0.78**	0.24	-0.56	0.31	0.05	0.31	-0.27	0.22		
Con. [0]×time [2]×study track [2]			0.29	0.25	-0.97**	0.32	-1.49***	0.34	-0.13	0.26	-0.43*	0.20
Con. [0]×time [1]×gender [1]	0.04	0.17	-0.36*	0.14	-0.22	0.18	-0.06	0.18	0.12	0.13		
Con. [0]×time [2]×gender [1]			-0.11	0.16	0.02	0.20	0.13	0.21	-0.02	0.16	0.20	0.12
Con. [0]×time [1]×abs. reas.	0.08	0.08	-0.03	0.07	0.14	0.08	0.22*	0.08	0.01	0.06		
Con. [0]×time [2]×abs. reas.			-0.03	0.08	0.20*	0.09	0.09	0.09	0.03	0.07	0.01	0.06
Con. [0]×time [1]×SES	-0.06	0.06	-0.13*	0.06	-0.09	0.08	-0.04	0.08	0.02	0.06		
Con. [0]×time [2]×SES			-0.06	0.08	0.09	0.10	-0.01	0.10	-0.02	0.08	0.01	0.06
Random effects												
ICC student	.02*		.13***		0.23**		0.09		.01		.11	
ICC school	.02**		.02		0.16***		0.07**		.01		.04*	

Note. *p<.05; **p<.01; ***p<.001. Non-reference categories are specified between brackets.

RESULTS

Mixed models were constructed for each cognitive outcome, containing the main effects of condition, time, study, gender, abstract reasoning ability, and SES, the interaction effect of condition x time, and three-way interactions of condition x time with the other predictors. The results, including intra-cluster correlation coefficients (ICC) of the two levels (students and school) are summarized in **Table 4**. Employing dummy coding, the last category was used as a reference category each time.

Inspection of the ICC indicated that the correlation between scores of the same student (that were not explained by the model) was 2% for physics knowledge, 13% for physics application, and 23% for mathematics knowledge. Correlation between schools was 2% for physics knowledge, 16% for mathematics knowledge, 7% for mathematics application, and 4% for integrated physics and mathematics. Note that 'student ID' is nested in 'school', so that the correlations of scores with regard to the same student entail correlations within the same school. For instance, no extra ICC for students was found for physics knowledge (2%), as the ICC of school was already 2%.

General Intervention Effects

We examined to what extent cognitive performances in terms of physics (knowledge and application), mathematics (knowledge and application), technological concepts, and integrated physics and mathematics questions are impacted by the iSTEM intervention (research question 1). More specifically, we investigated whether or not students in the experimental schools would perform better on STEM concepts than students in the control schools. Additionally, we also investigated whether or not students in the experimental condition would perform better after two years than after one year, in comparison to the control group, by examining the scores in the two different conditions over time.

The univariate analyses for the six cognitive outcomes are presented together in **Table 4**. The interaction between condition and time, indicating the effect of the iSTEM intervention, is displayed underneath the 'two-way interaction' header. This interaction was significant for mathematics (knowledge and application), and

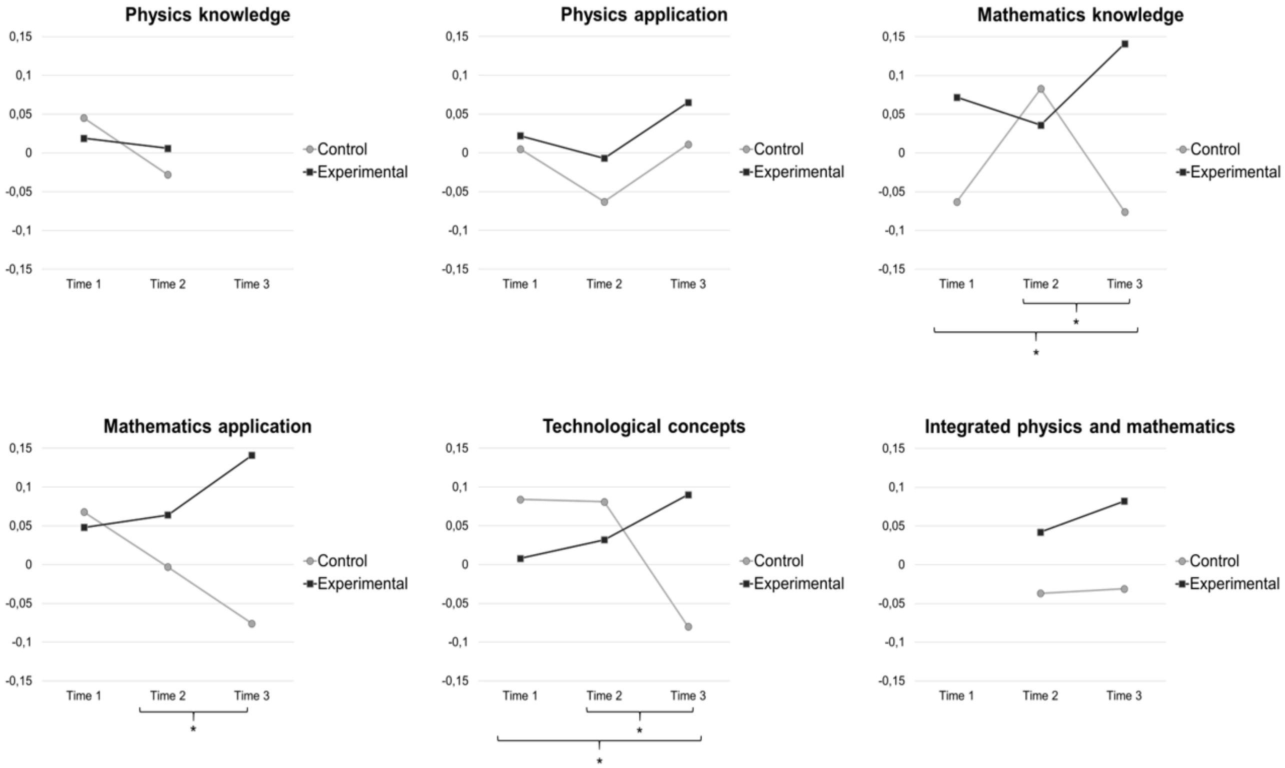

Figure 2. IRT scores on physics (knowledge and application), mathematics (knowledge and application), technological concepts and integrated physics and mathematics in control and experimental conditions on pre-test (= Time 1), post-test 1 (= Time 2), and post-test 2 (= Time 3).

Note. Significant interactions between condition and time are indicated with an asterisk.

technological concepts. No significant interaction was found for physics (knowledge and application) and integrated physics and mathematics. This finding indicates that iSTEM education mainly has an effect on cognitive performances in terms of mathematics and technological concepts.

A closer inspection of the interaction effect between condition and time for all cognitive outcomes can be found in **Figure 2**. The scores on the six outcomes are graphically displayed for control and experimental conditions across the three measurement moments. Note that these are IRT scores at a particular time-point, which means that this gives information about the relative scores of students on this time-point, but not about general progress over time.

In the case of physics knowledge, physics application and integrated physics and mathematics, no significant differences were found between the control and experimental condition over time. For mathematics knowledge, mathematics application and technological concepts, significant interactions were found. After two years, students in the experimental condition scored significantly higher on mathematics knowledge than did students in the control condition. The same result was found for technological concepts. However, both for mathematics knowledge and technological concepts, no significant difference between conditions could be found after one year. This finding indicates that the difference between the control and the experimental condition would become more pronounced after two years of iSTEM. For three of the six outcomes (mathematics knowledge, mathematics application and technological concepts), a difference was found between the scores after the first year compared to the scores after the second year. In addition, from this perspective, students in the experimental condition performed better than students in the control condition.

Differential Intervention Effects

Besides the general intervention effects, we also examined the differential cognitive effects of an iSTEM curriculum with regard to students with specific characteristics (research question 2). More specifically, we investigated whether the effects of the iSTEM intervention differed for boys or girls, students with different SES, and students with different levels of abstract reasoning ability.

The interaction between condition, time, and specific student characteristics, indicating the differential effect of the iSTEM intervention, is displayed in **Table 4** underneath the 'three-way interaction' header. The relationship between condition and time differed according to the study track for mathematics (knowledge and application) and technological concepts. We found a remarkable result for the effect of gender on the physics application scores. In general, male students performed better on this subject than did female students. However, females in the experimental condition performed significantly better after two years than females in the control condition, while no difference was observed for males. Abstract reasoning ability might to a certain extent positively determine the scores with regard to cognitive outcomes (i.e., for physics application and mathematics knowledge), but in the case of mathematics knowledge and application, the condition determines the impact of this relationship. For students in the experimental condition, the impact of abstract reasoning ability on mathematics (knowledge and application) was larger than for students in the control condition. With regard to the SES of students, a three-way interaction between condition and time was found for physics application. The relationship between SES and scores on physics application was stronger for students in the control condition. Students with higher SES have an advantage over students with lower SES when it comes to their scores on physics application, but this advantage was more pronounced in the control condition than in the experimental condition. Otherwise stated, the impact of SES was lower for students in the experimental condition of integrated STEM.

DISCUSSION

The aim of this study was to investigate the effect of an iSTEM curriculum on students' cognitive performances regarding physics (both knowledge and application), mathematics (both knowledge and application), technological concepts, and integrated physics and mathematics. We answered two research questions: (1) what is the impact of an iSTEM curriculum on cognitive performances after one and two years, and (2) what is the differential effectiveness of an iSTEM curriculum with regard to student characteristics?

General Intervention Effects

Aligned with previous research (e.g., Becker and Park, 2011), our study highlights the potential of an iSTEM education approach on diverse cognitive outcomes. However, some differences were found regarding the domains on which the intervention of an integrated approach had an impact. Becker and Park (2011), Honey et al. (2014), and English (2016) pointed out that the positive impact of iSTEM education differed for science (i.e., physics) and mathematics, with less evidence of a positive effect on mathematics' outcomes. Our results contrasted with these findings from previous research, as we found a positive impact of iSTEM on mathematics (both for knowledge and application), but not for physics.

Students in the experimental condition scored significantly better on mathematics than students in the control condition after two years of the intervention. For students in the experimental condition, the relevance of mathematics might have become clearer and less abstract throughout the learning modules, leading to an improved understanding of mathematical concepts and applications (Fitzmaurice, O'Meara and Johnson, 2021). While outcomes on both mathematics knowledge and mathematics application could be considered as medium effects according to Cohen (1988), the largest effect was found for mathematics application. An explanation for this finding might be that students in the iSTEM condition are more familiar with applying concepts of one subdomain to another. In this way, the ability to apply STEM concepts might be facilitated.

In this study, we did not find an intervention effect in terms of physics knowledge or application. That we did not these find these effects does not necessarily suggest that such an intervention could not have benefits regarding cognitive physics' outcomes. A possible explanation for the absence of positive effects with regard to physics knowledge might be that no data were collected on the third measurement moment due to the poor psychometric qualities of the test. Consequently, we could only analyze the difference between the first and the second measurement moment with regard to the two conditions. The fact that we did not find significant differences between the two conditions with regard to these two measurement moments might not be surprising, as no significant results were found for the other cognitive outcomes of this study either. Only when the third measurement moment (i.e., after two years of iSTEM education) was taken into account, were significant differences between experimental and control condition found. Presumably, this might also be the case for the outcomes regarding physics knowledge. However, this does not explain why we did not find an effect in terms of physics application. Given the larger effects with regard to mathematics application compared with mathematics knowledge, and given the findings from previous studies (e.g., Becker and Park, 2011), we might have expected an apparent effect on physics application as well.

The contrasting findings with those of previous research (i.e., effect on physics versus mathematics) might potentially be a consequence of differences in the operationalization of the intervention. The number and the degree of integration of the different components of STEM might, for example, be decisive factors. Also, interventions could differ in their emphasis on particular concepts or topics. It has been reported by English (2016) and Yildirim (2016) that a skewed focus on science at the expense of mathematics, and no integration of all subjects, is a common limitation within iSTEM education research. As little research exists involving the integration of all STEM components, further empirical research on the effects of iSTEM education needs to be conducted to extend the findings of the current study.

Analogous to the results with regard to mathematics knowledge, a positive effect of iSTEM education was found in terms of the results regarding technological concepts. Students in the experimental condition scored higher than students in the control condition after the third measurement moment (i.e., after two years of iSTEM education), both when compared to the first and the second measurement moments. The effect size of iSTEM on technological concepts was small (Cohen, 1988), in contrast to the effect sizes of mathematical outcomes, which were medium. This result indicates that further growth might be possible, by more explicitly addressing the technological concepts within the learning modules of the intervention. With regard to integrated physics and mathematics, no significant results were found. This result is remarkable, as the curriculum explicitly focused on the integration of the STEM domains. This finding demonstrates that it is not because connections between STEM domains are emphasized in the curriculum, students' own ability to integrate knowledge and skills necessarily improves. Thus far, the intervention of an integrated STEM curriculum appears to only effect cognitive outcomes regarding separate domains.

But the impact of an iSTEM educational approach might go beyond the cognitive outcomes measured in this study. Irrespective of the effects on the measured cognitive outcomes, the iSTEM approach could motivate students to see real-world applications and the relevance of the different STEM fields, even though students' performance did not increase in this study (Becker and Park, 2011).

To summarize, a positive impact of an iSTEM approach was found with regard to mathematics (knowledge and application) and technological concepts. Our findings indicate that the positive impact of iSTEM education is not limited to science but could also positively influence cognitive scores in other domains. From this perspective, it is important for future initiatives to explicitly incorporate all STEM domains in teaching materials, and not only select two pragmatic combinations such as physics and technology. As already mentioned, no differences were found between conditions after one year of iSTEM. This stresses the importance of a long-term iSTEM approach and has implications for the design of new integrated STEM programs. Long-term approaches with iSTEM incorporated in the standard curriculum are better suited to increase students' cognitive performance than short-term interventions.

Differential Intervention Effects

Our results showed an interesting positive impact on the performance of females with regard to 'physics application' (while no changes were found for the performances of males). As the lower physics scores of females is a well-known concern in the literature (Halpern et al., 2007), this might be an extra argument for the implementation of an integrated approach to STEM. Also, integration with more STEM domains (e.g., biology) or arts (so called 'STEAM') might have extra positive effects for girls. Previous research shows that girls tend to be more interested in biology than in physics (Baram-Tsabari and Yarden, 2008), and that STEM activities are more appealing to girls when also arts are involved (Boyle, 2021).

Scores on physics application differed for students with lower SES, when the integrated STEM condition was compared with the traditional approach. The negative impact of low SES (Yerdelen-Damar and Peşman, 2013) was smaller for students in the experimental condition of iSTEM. From this perspective, iSTEM education might create more equity.

For students in the experimental condition, the impact of abstract reasoning ability on mathematics (knowledge and application) was larger than for students in the control condition. This finding implies that, with regard to mathematics, an iSTEM approach favors those who already have more cognitive capabilities. The challenging nature of the learning modules might provide an explanation for this finding. When designing an integrated STEM intervention, educators should bear in mind that the impact of the intervention could vary with reasoning ability.

Limitations and Directions for Future Research

While our study has several strengths, such as its scale and longitudinal design, the explicit focus on iSTEM (the inclusion of all STEM domains), and the inclusion of multiple cognitive outcomes, limitations should also be acknowledged. First, we compared experimental schools with control schools, but it could not be guaranteed that the experimental schools implemented the iSTEM intervention in an impeccable way (O'Donnell, 2008), and that students in the control condition had no STEM initiatives whatsoever in their schools. It is more plausible that the experimental schools varied in the extent to which they implemented the intervention as intended, and that the control schools varied in the degree to which they did not implement (other) STEM initiatives. Nevertheless, we could ensure that all experimental schools were familiar with the integrated approach and that they implemented the learning modules in their classes. Also, intervisions with experimental schools and educational umbrellas were regularly organized so that schools were guided through the process and could optimize their iSTEM approach. The control schools, on the other hand, were queried about their ongoing STEM initiatives during the study. Most control schools did provide STEM projects for their students. However, they were only small-scale (e.g., extra programming exercises) and did not follow an integrated approach. In conclusion, we could presume that the critical component of the intervention (i.e., an iSTEM approach) was not present in the control condition. Another component in which experimental and control schools could differ was the time-on-task. While iSTEM was taught in the regular hours for mathematics and physics, schools still had the autonomy to allocate optional hours to the iSTEM learning modules. This extra time-on-task could accordingly have led to improved cognitive performances on STEM domains. But control schools might also have optional hours in which students can opt for further deepening in mathematics or sciences. And even when time-on-task was different for experimental and control schools, we know from earlier research that variation in cognitive performance is not consistently explained by differences in instructional time: only 1 to 15 percent of the variance was explained by time-on-task (Karweit, 1984), and explained variance varied depending on the time-on-task estimation method (Kovanovic et al., 2015). Therefore, providing extra time is not a sufficient condition for learning to take place. Also, if time-on-task was a crucial factor, we could expect that all learning outcomes would benefit from extra learning time. However, this was not the case in the current study. Future research could measure different characteristics (e.g., degree of integration, presence of a design challenge, time-on-task, etc.) of STEM initiatives in experimental and control settings and determine the relationship with students' cognitive outcomes. In this way, a measure for implementation fidelity in the experimental setting could be provided, and a stricter oversight of the control condition could be attained.

A second limitation is that the role of the teacher was not included explicitly in this study. Variations in the implementation of the intervention could be mainly attributed to teacher characteristics and practices. Factors such as teachers' individual characteristics when accepting a new instructional approach, their attitudes towards an integrated approach with regard to STEM education, and their prior experiences could have an influence on the implementation of the learning modules (Thibaut et al., 2018b; Henderson and Dancy, 2007). Although teacher influence could be partially accounted for by controlling for the random effect of schools, we suggest that future research incorporates teacher characteristics when investigating the effect of iSTEM education. At the same time, further research is needed on ways of assisting teachers to implement iSTEM learning modules (Moore and Smith, 2014; Sevimli and Ünal, 2022).

Summarizing, research regarding educational interventions is complex due to its multifaceted nature, such as the impact of implementation fidelity, teachers' characteristics, and complex settings. This exploratory study provided a first insight into the effects of iSTEM on a wide range of cognitive outcomes and encourages future research to further investigate the crucial ingredients and the effective mechanisms associated with an iSTEM education.

CONCLUSION

This longitudinal study revealed that iSTEM education had positive effects on cognitive performance on mathematics knowledge and application, and technological concepts. Furthermore, the intervention had a positive impact on the performance of females on physics application, the negative impact of low SES was smaller in the case of physics application, and students with high abstract reasoning capabilities were favored when it came to mathematics knowledge and application. Our research shows the importance of a long-term integrated STEM educational approach and advocates the integration of all STEM domains in educational initiatives.

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REFERENCES

Baram-Tsabari, A. and Yarden, A. (2008). Girls' biology, boys' physics: Evidence from free-choice science learning settings. *Research in Science & Technological Education*, 26(1), 75-92. https://doi.org/10.1080/02635140701847538

Becker, K. and Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education*, 12(5/6), 23-27.

Bøe, M. V., Henriksen, E. K., Lyons, T. and Schreiner, C. (2011). Participation in science and technology: Young people's achievement-related choices in late-modern societies. *Studies in Science Education*, 47(1), 37-72. https://doi.org/10.1080/03057267.2011.549621

Bornstein, M. H. and Bradley, R. H. (2003.) *Socioeconomic status, parenting, and child development*. Mahwah, NJ: Lawrence Erlbaum Associates.

Boyle, J. (2021). Oceans of inspiration: A marine based STEAM project. *European Journal of STEM Education*, 6(1), 15-36. https://doi.org/10.20897/ejsteme/11356

Bradley, R. H. and Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology*, 53(1), 371-399. https://doi.org/10.1146/annurev.psych.53.100901.135233

Cantrell, P., Pekca, G. and Ahmad, I. (2006). The effects of engineering modules on student learning in middle school science classrooms. *Journal of Engineering Education*, 95(4), 301-309. https://doi.org/10.1002/j.2168-9830.2006.tb00905.x

Cohen, J. (1988). *Statistical power analysis for the behavioral science (2nd ed.)*. Hillsdale, NJ: Lawrence Erlbaum Associations.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J. and Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, 30(2), 163-183. https://doi.org/10.1016/S0160-2896(01)00096-4

Deary, I. J., Strand, S., Smith, P. and Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence*, 35(1), 13-21. https://doi.org/10.1016/j.intell.2006.02.001

De Loof, H., Boeve-de Pauw, J. and Van Petegem, P. (2022). Engaging Students with Integrated STEM Education: a Happy Marriage or a Failed Engagement?. *International Journal of Science and Mathematics Education*, 20(7), 1291-1313. https://doi.org/10.1007/s10763-021-10159-0

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, 3(1), 3. https://doi.org/10.1186/s40594-016-0036-1

Fitzmaurice, O., O'Meara, N. and Johnson, P. (2021). Highlighting the relevance of mathematics to secondary school students--Why and how. *European Journal of STEM Education*, 6(1), 7-19. https://doi.org/10.20897/ejsteme/10895

Halpern, D. F., Benbow, C. P., Geary, D. C., Gur, R. C., Hyde, J. S. and Gernsbacher, M. A. (2007). The science of sex differences in science and mathematics. *Psychological Science in the Public Interest: A Journal of the American Psychological Society*, 8(1), 1-51. https://doi.org/10.1111/j.1529-1006.2007.00032.x

Henderson, C. and Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Physics Education Research*, 3(2), 1-14. https://doi.org/10.1103/PhysRevSTPER.3.020102

Hermans, S., Gijsen, M., Mombaers, T. and Van Petegem, P. (2022). Gendered patterns in students' motivation profiles regarding iSTEM and STEM test scores: A cluster analysis. *International Journal of STEM Education*, 9(1), 1-17. https://doi.org/10.1186/s40594-022-00379-3

Hernandez, P. R., Bodin, R., Elliott, J. W., Ibrahim, B., Rambo-Hernandez, K. E., Chen, T. W. and de Miranda, M. A. (2014). Connecting the STEM dots: Measuring the effect of an integrated engineering design intervention. *International Journal of Technology and Design Education*, 24(1), 107-120. https://doi.org/10.1007/s10798-013-9241-0

Honey, M., Pearson, G. and Schweingruber, H. (2014). *STEM integration K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press.

Karweit, N. (1984). Time-on-task reconsidered: Synthesis of research on time and learning. *Educational Leadership*, 41(8), 32-35.

Keith, K. (2018). *Case study: Exploring the implementation of an integrated STEM curriculum program in elementary first grade classes* [Doctoral dissertation, Concordia University, Portland].

Kjærnsli, M. and Lie, S. (2011). Students' preference for science careers: International comparisons based on PISA 2006. *International Journal of Science Education*, 33(1), 121-144. https://doi.org/10.1080/09500693.2010.518642

Kovanovic, V., Gašević, D., Dawson, S., Joksimovic, S. and Baker, R. (2015). Does time-on-task estimation matter? Implications on validity of learning analytics findings. *Journal of Learning Analytics*, 2(3), 81-110. https://doi.org/10.18608/jla.2015.23.6

Lam, P. C., Doverspike, D., Zhao, J., Zhe, J. and Menzemer, C. (2008). An evaluation of a STEM program for middle school students on learning disability related IEPs. *Journal of STEM Education: Innovations and Research*, 9(1/2), 21-29.

Lederman, N. G. and Niess, M. L. (1997). Integrated, interdisciplinary, or thematic instruction? Is this a question or is it questionable semantics? *School Science and Mathematics*, 97(2), 57-58. https://doi.org/10.1111/j.1949-8594.1997.tb17342.x

Moore, T. J. and Smith, K. A. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education*, 15(1), 5-10.

National Academies of Science. (2007). *Rising above the gathering storm*. The Committee on Prospering in the Global Economy of the 21st Century. Washington, DC: The National Academies Press.

Newton, K. J., Leonard, J., Buss, A., Wright, C. G. and Barnes-Johnson, J. (2020). Informal STEM: Learning with robotics and game design in an urban context. *Journal of Research on Technology in Education*, 52(2), 129-147. https://doi.org/10.1080/15391523.2020.1713263

O'Donnell, C. L. (2008). Defining, conceptualizing, and measuring fidelity of implementation and its relationship to outcomes in K-12 curriculum intervention research. *Review of Educational Research*, 78(1), 33-84. https://doi.org/10.3102/0034654307313793

Raudenbush, S. W. and Bryk, A. S. (2002). *Hierarchical linear models: Applications and data analysis methods (2nd edition)*. Newbury Park, CA: SAGE.

Raven, J. C., Court, J. H. and Raven, J. (1977). *Raven's progressive matrices and vocabulary scales*. New York, NY: Psychological Corporation.

Rizopoulos, D. (2006). ltm: An R package for latent variable modeling and item response theory analyses. *Journal of Statistical Software*, 17(5), 1-25. https://doi.org/10.18637/jss.v017.i05

Roehrig, G. H., Moore, T. J., Wang, H.-H. and Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, 112(1), 31-44. https://doi.org/10.1111/j.1949-8594.2011.00112.x

Sanders, M. (2009). STEM, STEM education, STEMmania. *Technology Teacher*, 68(4), 20-26.

Sevimli, E. and Ünal, E. (2022). Is the STEM approach useful in teaching mathematics? Evaluating the views of mathematics teachers. *European Journal of STEM Education*, 7(1), 1-11. https://doi.org/10.20897/ejsteme/11775

Standish, N., Christensen, R., Knezek, G., Kjellstrom, W. and Bredder, E. (2016). The effects of an engineering design module on student learning in a middle school science classroom. *International Journal of Learning, Teaching and Educational Research*, 15(6) 156-174.

Tate, W. F. (1997). Race-ethnicity, SES, gender, and language proficiency trends in mathematics achievement: An update. *Journal for Research in Mathematics Education*, 28(6), 652-679. https://doi.org/10.2307/749636

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., … and Hellinckx, L. (2018a). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, 3(1), 1-12. https://doi.org/10.20897/ejsteme/85525

Thibaut, L., Knipprath, H., Dehaene, W. and Depaepe, F. (2018b). The influence of teachers' attitudes and school context on instructional practices in integrated STEM education. *Teaching and Teacher Education*, 71, 190-205. https://doi.org/10.1016/j.tate.2017.12.014

Vasquez, J., Sneider, C. and Comer, M. (2013). *STEM lesson essentials, grades 3-8: Integrating science, technology, engineering, and mathematics*. Portsmouth, NH: Heinemann.

Wang, H. H., Moore, T. J., Roehrig, G. H. and Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, 1(2), 1-13.

Williams, P. J. (2011). Engineering: Good for technology education. In M. J. de Vries (ed), *Position technology education in the curriculum: International technology education series* (pp. 87-99). New York, NY: Springer. https://doi.org/10.1007/978-94-6091-675-5_8

World Economic Forum. (2016). *The future of jobs employment, skills and workforce strategy for the fourth industrial revolution. Global challenge insight report*. Geneva: World Economic Forum.

World Economic Forum. (2020). *The future of jobs report 2020*. Geneva: World Economic Forum.

Yang, D. and Baldwin, S. J. (2020). Using technology to support student learning in an integrated STEM learning environment. *International Journal of Technology in Education and Science*, 4(1), 1-11. https://doi.org/10.46328/ijtes.v4i1.22

Yang, D., Baek, Y., Ching, Y. H., Swanson, S., Chittoori, B. and Wang, S. (2021). Infusing computational thinking in an integrated STEM curriculum: User reactions and lessons learned. *European Journal of STEM Education*, 6(1), 4-18. https://doi.org/10.20897/ejsteme/9560

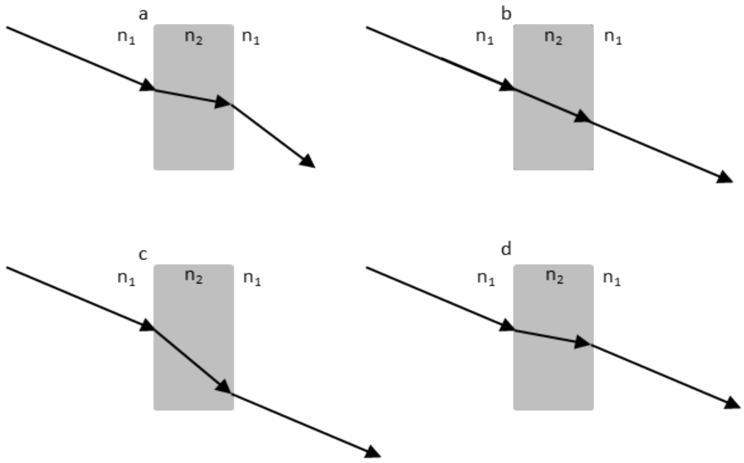
Yerdelen-Damar, S. and Peşman, H. (2013). Relations of gender and socioeconomic status to physics through metacognition and self-efficacy. *The Journal of Educational Research*, 106(4), 280-289. https://doi.org/10.1080/00220671.2012.692729

Yildirim, B. (2016). An analyses and meta-synthesis of research on STEM education. *Journal of Education and Practice*, 7(34), 23-33.

APPENDIX A

Physics Knowledge

A light beam passes through a plate. Which of the images below is correct when the refractive indices are n1<n2?



A) a
B) b
C) c
D) d

Physics Application

The spring constant of three identical massless springs is 0.200 N/cm. What is the stretching of the feathers when they are hung next to each other in order to carry a common load with a mass of 300 g?

A) 0.667 cm
B) 4.905 cm
C) 14.715 cm
D) 19.620 cm

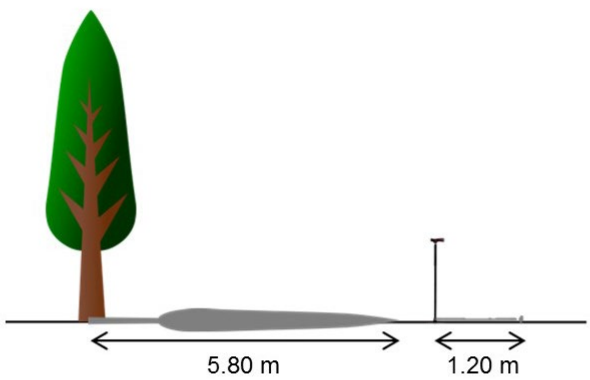
Mathematics Knowledge

The directional coefficient of the line through (a, 0) and (0, b) equals:

A) a/b
B) -a/b
C) b/a
D) -b/a

Mathematics Application

Peter would like to know the height of the tree. For this purpose, he can use grandma's walking stick, which is 1.0 m long. Given the illustration below, what is the height of the tree?



A) 6.8 m
B) 5.8 m
C) 4.8 m
D) 0.2 m

Technological Concepts

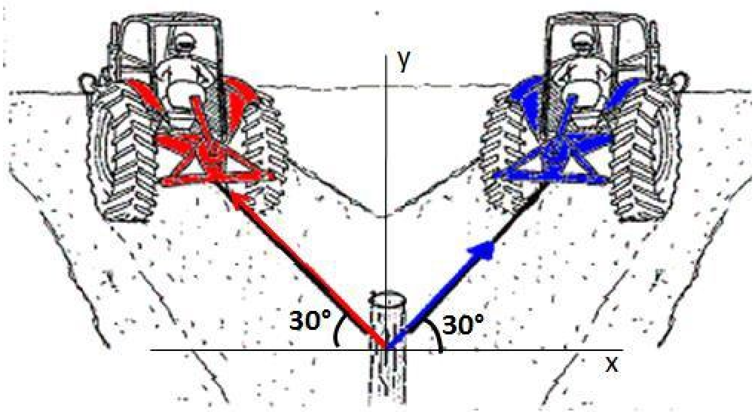
Given the program code below:

```
number i=0
number j=5
REPEAT AS LONG AS (i<3 and j+1<10) {
 PRINT (i, j)
 i=i+1
 j=j+1
 MEMORIZE i
 MEMORIZE j
}
PRINT (i, j)
```

what will be the printing output?

A) 0 5 1 6 2 7 3 8
B) 0 5 1 6 2 7 3 8 4 9 5 10
C) 0 5 1 6 2 7 3 8 4 9
D) 0 5 1 6 2 7 2 7

Integrated Physics and Mathematics



Two tractors are pulling a pole out of the ground. The red tractor uses a force of 5,000 N and the blue tractor uses a force of 2,500 N. What is the magnitude (in integers) of the total force that is applied on the pole in the direction of the y-axis?

A) 2500 N
B) 7500 N
C) 3590 N
D) 5590 N

APPENDIX B

The ltm-package of R (open source software for statistical computing) was employed, using latent trait models under IRT, which is fit for an analysis of multivariate dichotomous data (Rizopoulos, 2006). Difficulty (i.e., the ability required to guarantee a 50% probability of answering the item correctly) and discrimination of the items (i.e., an index of an item's capability to differentiate between students in different positions on the latent ability) were analyzed, and items with a discrimination value of less than 0.15 were removed from the item battery. Subsequently, IRT was re-performed with the remaining items. Thereafter, the model with the best fit for the data was identified by analysis of variance (ANOVA). The Rash model (i.e., all items have a discrimination index of 1 logit) was compared with the one-parameter logistic model (1-PL, i.e., the discrimination index are the same for all items, but can have a value other than 1) and with the two-parameter logistic model (2-PL, i.e., the discrimination index can vary over items). For each instrument, the model with the best fit, the initial number of items, the remaining number of items, and information regarding discrimination values (a) and difficulty (β) are presented.

Instruments Measurement Moment 1

In **Table B1**, the results of the IRT analyses of the pretest instruments (measurement moment 1) are shown. Analysis of variance (ANOVA) showed that for physics (knowledge and application) and mathematics (knowledge and application) the 2-PL model had the best fit for the data. The 1-PL model had the best fit for the data on technological concepts. All items from the mathematics tests (knowledge and application) were retained, as no item had low discrimination values (a<0.15). For the other instruments, one or more items were omitted.

Table B1. IRT analyses of instruments measurement moment 1

	Phys. know.	Phys. app.	Math. know.	Math. app.	Techn.	IPM
Model	2-PL	2-PL	2-PL	2-PL	1-PL	
# initial items	10	15	8	25	25	
# remaining items	9	14	8	25	18	
Min a	0.35	0.36	0.41	0.15	0.61	
Max a	1.33	1.72	1.24	1.62	0.61	/
Mean a	0.65	0.70	0.84	0.93	0.61	
Min β	-4.26	-1.94	-2.81	-2.00	-6.36	
Max β	-0.77	3.93	0.49	3.45	2.93	
Mean β	-1.88	0.30	-0.74	-0.67	2.93	

Instruments Measurement Moment 2

ANOVA showed that for all the instruments used in the first posttest (measurement moment 2) the 2-PL model had the best fit for the data (**Table B2**). For each instrument one or more items were omitted due to low discrimination values.

Table B2. IRT analyses of instruments measurement moment 2

	Phys. know.	Phys. app.	Math. know.	Math. app.	Techn.	IPM
Model	2-PL	2-PL	2-PL	2-PL	1-PL	2-PL
# initial items	29	22	10	31	25	14
# remaining items	22	15	9	29	20	9
Min a	0.19	0.20	0.24	0.29	0.18	0.18
Max a	1.87	2.02	1.37	2.38	2.31	17.91
Mean a	0.78	0.68	0.60	0.91	0.90	2.30
Min β	-2.82	-1.56	-2.30	-1.55	-1.47	-0.92
Max β	9.68	4.92	1.49	3.45	8.36	5.60
Mean β	0.73	1.09	-0.02	0.40	0.65	2.02

Instruments Measurement Moment 3

Table B3 shows the results of the IRT analyses of the second posttest (measurement moment 3). The 2-PL model best fitted the data of physics (application) and mathematics (knowledge and application), whereas the 1-PL model best fitted the data of technological concepts and integrated physics and mathematics questions. Of all 17 items in the physics knowledge test, only one item had a discrimination index of a>0.15, which was insufficient to perform further analysis. As a result, no reliable indicators of physics knowledge were collected in the second post-test of the study.

Table B3. IRT analyses of instruments measurement moment 3

	Phys. know.	Phys. app.	Math. know.	Math. app.	Techn.	IPM
Model		2-PL	2-PL	2-PL	1-PL	1-PL
# initial items	17	13	15	29	19	12
# remaining items	1	11	15	28	10	9
Min *a*		0.16	0.37	0.35	0.64	0.5
Max *a*		1.95	2.51	8.36	0.64	0.5
Mean *a*		0.64	1.45	1.77	0.64	0.5
Min *β*		-3.03	-1.73	-1.48	-1.07	0.83
Max *β*		8.39	3.76	5.06	1.90	3.54
Mean *β*		1.12	0.55	0.45	0.22	1.92

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