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The Effect of Computer Simulation on Grade 11 Learners' Conceptualisation of Stoichiometric Chemistry

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ABSTRACT

This study, titled *The Effect of Computer Simulation on Grade 11 Learners' Conceptualisation of Stoichiometric Chemistry*, was carried out at a school in the Frances Baard District of the Northern Cape province of South Africa. Poor conceptualisation of stoichiometric chemistry by learners in Grades 10-12 in South Africa and, hence, their failure to apply the concepts to problem-solving in the same and other topics in chemistry, is a cause for concern. The study was conducted with the theoretical framework of activity theory. A mixed method design that consisted of a pre-test post-test experimental design, a questionnaire and interviews were used for the study. Two Grade 11 physical sciences classes which consisted of a control and experimental group were taught stoichiometric chemistry after the SCAT pre-test. The experimental group obtained an intervention comprising computer simulations during teaching, while the control group was taught using the lecture method. The ANOVA results showed that learners of the control and experimental groups were comparable in terms of prior knowledge of the topic of stoichiometric chemistry. The paired t-test showed that both groups improved their performance in stoichiometric chemistry. However, the ANCOVA results showed that the experimental group had a greater improvement in performance than the control group. The results of the SCAT post-test, observation of lessons, questionnaire and interviews showed that the experimental group conceptualised stoichiometric chemistry better than the control group. The quantitative and qualitative data was triangulated, and it also indicated that the experimental group conceptualised stoichiometric chemistry better than the control group. It is therefore suggested that using computer simulations for the teaching and learning of stoichiometric chemistry is a better method to improve its conceptualisation in the FET phase of schools in South Africa.

Keywords: stoichiometric chemistry, conceptualisation, activity theory, computer simulation, intervention

INTRODUCTION

Conceptualisation of stoichiometric chemistry is the foundation to understand the quantitative aspects of any of the topics in chemistry such as rate of reactions, chemical equilibrium, acids and bases, electrochemistry and organic chemistry (Jusniar et. al. 2019: 141; Malcolm et. al. 2018: 134; Ndlovu, 2017: 2-3). Stoichiometric chemistry deals with the study of the quantitative aspects of mass-mole relationships, chemical formulae and reactions. In chemistry, stoichiometric chemistry is a topic that is very difficult, and few learners/students like and succeed in learning it – most of them struggle to conceptualise it (Fang, Hart and Clarke, 2016: 182; Hanson, 2016:

2).Therefore, improving learners' learning and understanding of stoichiometric chemistry could possibly open doors to further studies for more students in the field of chemistry and other science-related careers (Agung and Schwartz, 2007: 4; Arya and Kumar, 2018: 2).

RATIONALE FOR THE STUDY

The National Senior Certificate examination in South Africa for Physical sciences paper 2 has questions based on application of stoichiometric chemistry concepts and the results of the examination showed that stoichiometric chemistry was performed poorly over the years. The diagnostic report recommends that learners need greater exposure in conceptualising stoichiometric chemistry for applying the concepts in the different questions where applicable (DBE, 2016, 2017; Ndlovu, 2017: 2). Malcolm *et al.* (2018: 135) argue that learners find it difficult to perform well in stoichiometric calculations, due to their lack of conceptual understanding of the mole concept, their failure to construct and balance chemical equations from a reaction given, lack of mathematical skills, and finding it difficult to interpret word problems into steps that they can proceed for problem solving in the quantitative aspects of a reaction. The ability to understand and use the mole ratio is at the heart of stoichiometry, but students lack this skill (Chandrasegaran *et al.,* 2009: 14).

Teachers need to assist learners to conceptualise stoichiometric chemistry through instruction in the classroom. However, studies conducted has reported that teachers find it difficult to teach the concepts effectively (Malcolm *et al.*, 2018: 135). The problem-solving strategies used in stoichiometry and its poor conceptualisation, have long been of concern to researchers around the world – at least since the early 1990s (Atwater and Alick, 1990: 157; Tigere, 2014: 12). Various researchers, such as Malcolm *et al.* (2018), Nkemakolam *et al.* (2018), Özmen (2008), and Rutten *et al.* (2012), all point out that using computer technology in education can help to deepen learners' understanding of scientific concepts. Develaki (2019: 10) reports that computer simulations can be incorporated into different kinds of teaching, thereby promoting students' understanding of science concepts, developing their inquiry skills and enhancing teacher education and their professional growth by recreating real-world perspectives, which, in normal classroom situations, would not be possible. In another study, by Liu (2005: 187), on making use of computer simulations, molecular animations helped students to connect chemical reactions to chemical equations when using symbols and signs. The use computer simulations to teach acids and bases, chemical bonding and chemical equilibrium also proved to have a positive effect on students' conceptualisation, achievement and also prevents misconceptions (Bayrak and Bayram, 2010: 234; Özmen, 2008: 435; Sarıçayır *et al.,* 2006: 134).

Though research has been done on the difficulties and problems learners experience learning stoichiometric chemistry and therefore performing poorly in the topic, a literature search using JSTOR, ERIC, SpringerLink, Worldwide Science, EBSCOhost and Google Scholar, on the study of teaching stoichiometric chemistry with computer simulations in Africa, did not yield any results. Therefore, considering the poor conceptualisation of stoichiometric chemistry by learners and its importance in the field of chemistry, this study seeks to determine whether using computer simulations can enhance the conceptualisation of stoichiometric chemistry.

The following null hypotheses were formulated to guide the empirical study.

$H_0$1 The learners in the control group and experimental group are not comparable in terms of their knowledge of stoichiometric chemistry.

$H_0$2 There is no significant difference between the pre-test and post-test mean scores of the Grade 11 learners in the control group.

$H_0$3 There is no significant difference between the mean pre-test and post-test scores of the of the Grade 11 learners in the experimental group.

$H_0$4 There is no significant difference between the mean post-test scores of learners in the control and experimental groups, after controlling for the effect of pre-test scores.

LITERATURE REVIEW

Stoichiometric chemistry is an important topic in chemistry that deals with the quantitative aspects of chemical change- which is the stoichiometry of a chemical reaction. (Malcolm *et al.*, 2018; Ndlovu, 2017: 2). Stoichiometric chemistry basically deals with the mole concept and its calculations with different quantities such as mass of substances, number of particles and volume. Mole is the basic unit of the amount of substance with the SI unit mol (Pekdağ and Azizoğlu, 2013: 118). Stoichiometric chemistry also involves problem solving in relation to the relationships between the number of moles of reactants and products in a chemical reaction (Hanson, 2016: 2; Okanlawon, 2010: 28). For solving problems in stoichiometry, the learner needs to do calculations on molar mass of compounds, write balanced chemical equations, apply the mole concept, determine empirical and molecular formula, use ratios in balanced equations of reactants and products, determine the limiting reagent, mass percentage and percentage yield (Gulacar, 2007: 4).

Stoichiometric chemistry is reported to be having abstract concepts and hence poorly conceptualised (Atwater and Alick, 1990: 157; BouJaoude and Barakat, 2000: 91; Bridges, 2015: 4; Fach *et al.*, 2007: 13; Schmidt, 1994: 191; Tigere, 2014: 12). As learners do not conceptualise the concepts behind stoichiometric problem-solving, they make use of algorithmic methods, and teachers even encourage them to do so. They may reach a correct answer by just memorising a formula, manipulating the formula and substituting values (Schmidt and Jignéus, 2003: 306). Researchers regard the poor conceptualisation of stoichiometric chemistry as one of the reasons that affects the interest of students in learning chemistry; researchers are also concerned that there has been a decline in the number of chemistry students at an advanced level all over the world (Broman *et al.*, 2011: 43; Fang *et al.*, 2016: 215; Malcolm *et al.*, 2018: 134).

As the traditional lecture method to teach abstract concepts does not always seem to be effective, researchers recommended using other instructional methods such as computer simulation to address the issues of learning and understanding of difficult concepts. Bailey (2007: 31) reports that students can achieve a better understanding of the relationship between the microscopic and macroscopic levels of the concepts of gases using computer animation. Udo and Etiubon (2011: 215) reports that chemistry teachers use computer simulation due to its high facilitative effect on student performance. Another study showed that the visual information provided by computer simulations helps learners to connect their understanding of chemical reactions to chemical equations (Liu, 2005: 187). Using computer-aided teaching for the topic of acids and bases had a positive effect on the achievement of students (Bayrak and Bayram, 2010: 235). Findings of the positive impact of using computer simulation to teach led Nkemakolam *et al.* (2018: 288), after conducting research on the use of computer simulation for teaching in Nigeria, to recommend that chemistry teachers should make use of computer simulation to improve students' achievement in chemistry.

Based on the reports of researchers such as Sari *et al.* (2018: 6) and Astutik and Prahani (2018: 410) that PhET simulations, when integrated in teaching and learning could enhance conceptualisation of the subject content, the same simulation was used to teach stoichiometric chemistry for the study.

THEORETICAL FRAMEWORK

For the conceptualisation of a topic such as stoichiometric chemistry, learners need to construct knowledge through activities. Hence, the study aimed to determine the effect of computer simulation on learners' conceptualisation of stoichiometric chemistry within the framework of activity theory. Activity theory helps in designing a constructivist learning environment in which learners construct their own knowledge and understanding (Singh and Yaduvanshi, 2015: 1). In the current study which consisted of an experimental group and control group, a simulation was used to teach stoichiometric chemistry to the experimental group while the control group were taught using traditional lecture method. During the lesson the experimental group learners were involved in activities based on the simulation to achieve an outcome while the control group learners involved in activities from the textbook. Hence, activity theory is appropriate as the theoretical framework for the study. Making use of visual representations can create a learning environment in which learners are able to interact with abstract concepts (Naidoo, 2017: 2). Therefore, the intentional design of the learning activities with simulations for the current study, done by interaction, can create conceptual understanding. By applying activity theory, the teacher, by using computer simulation, creates an environment that should be conducive for learners to reach their level of development.

According to the activity theory model, within the context of the study, the subject was the teachers teaching stoichiometric chemistry, the instruments were the simulations and the other teaching tools for stoichiometric chemistry, and the object or objective was the development of the various concepts in stoichiometric chemistry. In the context of the study, the tools used varied for each teacher teaching the learners. One teacher used computer simulation in addition to the whiteboard and textbook, while the second teacher used the textbook as the tool in addition to the whiteboard. The community in the activity system refers to the group of individuals who share a common objective to achieve. The communities in the study are the learners in the two classes (experimental group and control group), and their respective teachers. The subject belongs to a community that is governed by rules and divisions of roles (labour). During interaction, members of each community collaborated with each other to achieve the outcome of the activity system, which was the conceptualisation of stoichiometric chemistry (Naidoo, 2017: 4).

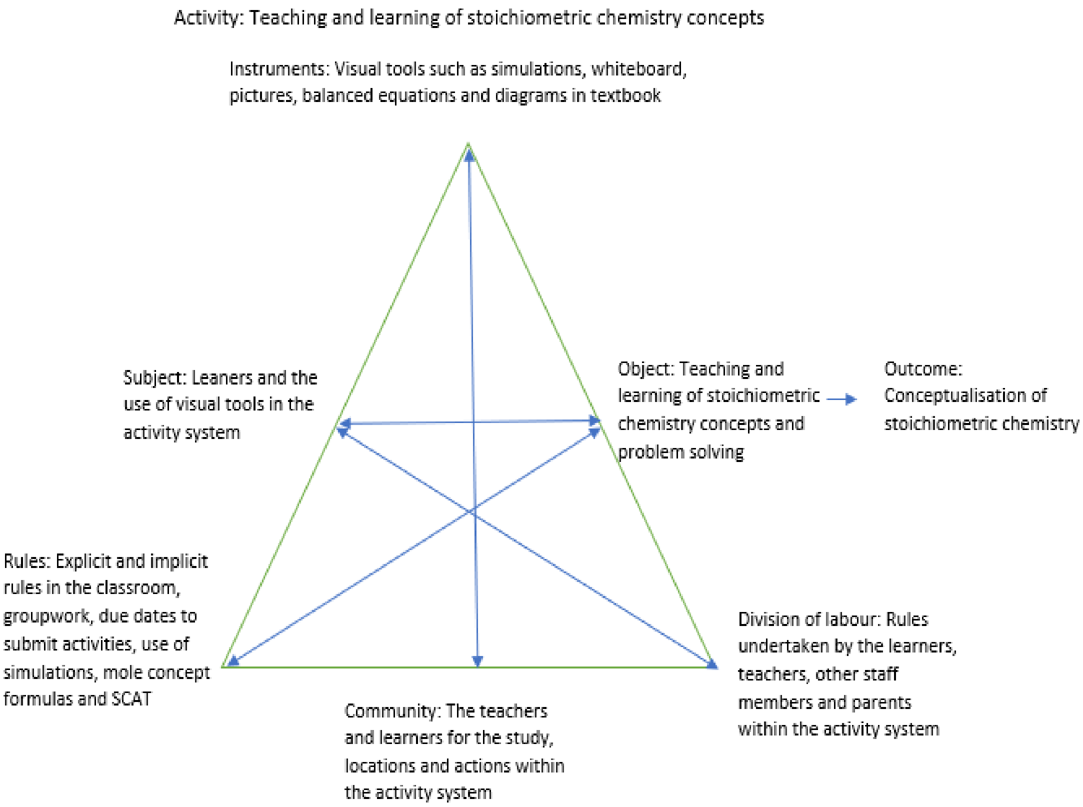


Figure 1. Adapted Activity theory model

Figure 1 emerged from this study which was adapted from the activity theory model of Engeström (Naidoo, 2017: 4). The activity system for the study is the act of teaching and learning stoichiometric chemistry with and without computer simulation. As the learners work and solve problems together within the activity system, they develop a new set of values and notions.

METHODOLOGY

Sequential experimental mixed methods design which is characterised by the collection and analysis of quantitative data in a first phase of research, followed by the collection and analysis of qualitative data in a second phase was used for the study (Subedi, 2016: 574). The explanatory sequential design is the most common and straightforward mixed methods design, whereby qualitative findings help to refine, explain and clarify the general picture presented by the quantitative results (Creswell and Creswell, 2017: 196; Maree, 2016: 316). The permission for the study was granted by the University of the Free state (Ethical clearance number UFS-HSD2018/1292) and the study formed part of the researcher's PhD project. By making use of purposive sampling learners in a school from the Frances Baard district in Kimberley, South Africa with two grade 11 classes taught by two different teachers were selected (Palinkas *et al.*, 2015: 535). The two Grade 11 classes as the sample were randomly assigned as control (CG) and experimental groups (EG).

PROCEDURE FOR DATA COLLECTION AND ANALYSIS

The control group was taught stoichiometric chemistry by making use of the lecture method while the experimental group was taught the same concepts by making use of PhET computer simulations. The quantitative data for the study was collected by pre-test post-test experimental design (Creswell and Creswell, 2018: 273; Leavy, 2017: 95). A validated Stoichiometric Chemistry Achievement Test (SCAT) for the pre-test and post-test was administered on the control and experimental groups. The SCAT consisted of two main questions with sub-questions. The questions were set from the learning area of quantitative aspects of chemical change in Grade 11, adapted from past question papers for Grade 11. The questions consisted of writing balanced equations, using balanced equations to determine the limiting and excess reactants, and calculating mass and volume of products formed.

After the pre-test, lessons in stoichiometric chemistry were conducted for both control and experimental group and it was observed using an observation schedule adapted from RTOP. RTOP is an instrument that was specially designed by the Evaluation Facilitation group of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) to measure reformed teaching, the idea of which is to prepare teachers to adopt a constructivist way of teaching (Kunnath, 2017: 76; MacIsaac and Falconer, 2002: 479). The observation schedule for the lesson observations of both the control and experimental groups consisted of five themes. The themes were structured to assess the degree to which the teaching took place by including aspects such as content knowledge of teacher, organisation and presentation of material, teacher- learner interaction, learner-learner interaction, opportunities for active learning with an emphasis on fundamental concepts and the incorporation of learner ideas into class trajectory. Hence the observation schedule helped to implement the study within the theoretical framework of activity theory.

For the qualitative data, self-administered questionnaire was distributed to all learners and interviews were conducted with selected learners in the study. The questionnaire required learners to complete a set of questions and to respond to related prompts after the post-test (Kabir, 2016: 208). The questionnaire consisted of 6 questions that investigated learners' understanding of stoichiometric chemistry, related calculations, and the method of teaching the lessons. Four of the six questions were based on the learners' conceptualisation of stoichiometric chemistry. The answers helped to understand whether the intervention in the experimental group had any impact on their conceptualisation. One question was based on the confidence level of the learners in stochiometric chemistry concepts. The last question was based on learners' experience of the lessons conducted in their respective groups and to determine whether the intervention with simulation helped the learners in better conceptualisation for problem solving of stoichiometric calculations.

Followed by the questionnaire, semi-structured one on one interviews with selected learners who scored the highest, middle and the lowest marks from both groups were conducted. The interview provided an elaborated in depth understanding of the learners' conceptualisation of stoichiometric chemistry and the teaching methods used for the lessons which helped to corroborate data that was gathered from the pre-test post-test and questionnaire. The interview consisted mainly of questions related to the learners' understanding of the quantitative aspects of chemical change, the importance of balancing a chemical equation for performing calculations in a chemical reaction, how well their respective lessons helped to conceptualise stoichiometric chemistry in Grade 11, and helped them to answer the post-test. The interview questions were sequenced logically and clarified during the interview where necessary. The interviews were audio recorded with the consent of the learners. This helped to explore and probe these topics and to collection in-depth, reliable and comparable qualitative data (Kabir, 2016: 212; Maree, 2016: 93).

The analysis of the quantitative section of the pre-test post-test design used statistical analysis with SPSS 24.0. Both descriptive and inferential analysis of the quantitative data obtained from the pre-test and post-test was done. The lesson observation schedule was analysed according to each criterion and the findings are provided in **Table 8**. The test response analysis was used to assess the depth of content knowledge gained by learners, and whether conceptual and or procedural knowledge was acquired and thereby, they could understand the level of conceptualisation of the content taught (Sapire, Shalem, Wilson-Thompson and Paulsen, 2016: 4–6). The answers for each question in the pre-test and post-test by learners that were selected to be interviewed were analysed. The analysis was done to identify the correctness and errors the learners made in the pre-test and how they answered the same question in the post- test, after the intervention. Therefore, analysis was done to compare performance on the pre-test and post-test and to determine whether any improvement in performance was due to an improvement in conceptualisation of stoichiometric chemistry concepts.

Thematic analysis of the open-ended questions in the questionnaire and the semi structured interview was also done. The same procedure was used for the thematic analysis of the questionnaire and the interview and is given below.

- Step 1: Familiarising with the responses written by the participants by reading through it several times and reflecting on its overall meaning. The recordings of the interview were transcribed and the same step was followed.
- Step 2: Taking the text data from the responses in the questionnaire and interview, segmenting the sentences into categories and labelling the categories with a term. This step is called coding.
- Step 3: Generating a description and themes from codes. In this step, codes from the previous step were used to generate themes. These themes appeared as major findings in qualitative analysis. An inductive approach to data coding and analysis was predominantly used (Braun and Clarke, 2012:57). It is a bottom-up approach, where the content of the data collected derives the codes, which closely match the content.
- Step 4: Representing the description and themes by making use of visuals, figures or tables as adjuncts to the discussion. This step involved the final analysis step of writing and reporting.

The research instruments described above and their aim are summarised in the **Table 1**.

Table 1. Summary of research instruments

Phase	Instrument	Aim
1. Quantitative data collection	Pre-test and post-test	Numerical data
2. Qualitative data collection	Observation schedule, questionnaire, structured interview	Textual data
3. Quantitative data analysis	Descriptive and inferential analysis of pre-test post-test	Meaningful measures of quantitative data
4. Qualitative data analysis	Lesson observation analysis of both groups, pre-test post-test response analysis, thematic analysis of questionnaire and interviews of the same learners	Qualitative explanation of results

Table 2. ANOVA results of the pre-test

	ANOVA- Pre-test						
	Mean scores	**SD**	**Sum of squares**	**df**	**Mean square**	**F**	**Sig.**
Control group	23.87	21.179					
Experimental group	19.63	15.521					
Between groups			5498.667	10	549.867	1.391	.257
Within groups			7508.800	19	395.200		
Total			13007.467	29			

Table 3. Means and SD for pre-test and post-test of control group

SCAT	Mean	N	SD
Pre-test	23.87	30	21.179
Post-test	41.20	30	28.924

Table 4. Paired samples t-test for control group

	Paired difference						
	Mean	**SD**	**95% confidence interval of the difference**		**t**	**df**	**Sig. (2-tailed)**
			Lower	**Upper**			
Pre-test-Post-test	-17.33	21.485	-25.536	-9.311	-4.419	29	.000

RESULTS OF THE PRE-TEST AND POST-TEST OF CONTROL AND EXPERIMENTAL GROUP

The means, modes, medians and standard deviation for the pre-test were calculated. ANOVA was used to determine whether the learners in the two groups were comparable in terms of their knowledge of the topic of stoichiometric chemistry. It was found that there was no significant difference in the pre-test scores at $p < 0.05$ level for the two groups [$F(10, 19) = 1.391$, $p = .257 > 0.05$]. The null hypothesis ($H_0 1$) which stated that the learners in the control group and experimental group are not comparable in terms of their knowledge of stoichiometric chemistry is, thus, rejected. The probability is that the two groups were comparable in terms of their knowledge of the topic of stoichiometric chemistry. **Table 2** represents the ANOVA results of the pre-test.

Paired t-Test

The paired sample t-test was conducted to find out if there was a significant difference between the mean scores of the pre-test and post-test of the control group and experimental group. Means and standard deviation (SD) for the pre-test and post-test of the control group were calculated (see **Table 3**). It was observed that the control group had improved from the pre-test to (Mean = 23.87, Standard Deviation = 21.179) to the post-test (Mean = 41.20, Standard Deviation = 28.924).

From **Table 4**, it can be observed that there is a significant difference between the pre-test and post-test scores of the control group ($t(29) = -4.419$, $p < 0.05$, Sig. (2-tailed) = .000). As the p value is < 0.05, the probability is, thus, greater that there is some significant difference between the pre-test and post-test mean scores of the control group. The null hypothesis ($H_0 2$) is, thus, rejected.

Means and standard deviation (SD) for the pre-test and post-test of the experimental group were calculated (see **Table 5**). It was observed that the experimental group had improved from the pre-test (Mean = 19.63, Standard Deviation = 15.521) to the post-test (Mean = 52.94, Standard Deviation = 20.66).

Table 5. Means and SD for pre-test and post-test for experimental group

SCAT	Mean	N	SD
Pre-test	19.63	32	15.521
Post-test	52.94	32	20.666

Table 6. Paired samples t-test for experimental group

	Paired difference						
	Mean	SD	95% confidence interval of the difference		t	df	Sig. (2-tailed)
			Lower	Upper			
Pre-test-Post-test	-33.313	19.633	-40.391	-26.234	-9.598	31	.000

Table 7. ANCOVA summary of achievement by control group and experimental group

Tests of between subject effects						
Dependent variable: Post-test						
Source	**Type III sum of squares**	**Df**	**Mean square**	**F**	**Sig.**	**Partial Eta squared**
Corrected model	15141.473	2	7570.736	18.237	.000	.382
Intercept	22332.658	1	22532.658	54.279	.000	.479
Pre-test	13008.277	1	13008.277	31.336	.000	.347
Group	3491.589	1	3491.589	8.411	.005	.125
Error	24492.398	59	415.125			
Total	178100.000	62				
Corrected Total	39633.871	61				

a. R Squared =.382 (Adjusted R squared = .361)

The results in **Table 6** showed that there is a significant difference between the pre-test and post-test scores of the experimental group ($t (31) = -9.598$, $p < 0.05$, Sig. (2-tailed) = .000 (p value < 0.05)), and, hence, the null hypothesis $H_0$3, which stated that there is no significant difference between the mean pre-test and post-test scores of the experimental group, is rejected.

ANCOVA

ANCOVA (Analysis of Covariance) was used to find out whether there is any significant difference between the group means of the SCAT administered for the two groups. The lecture teaching method for the control group and the use of computer simulations for the intervention with the experimental group were the independent variables for the one-way ANCOVA. The post-test scores were the dependent variables and the pre-test scores were used as the covariate to control for individual difference.

The result of the ANCOVA is that there is a significant effect of the covariate, which is the pre-test, as $F (1,61) = 31.336$, $p < 0.05$, Sig. value = .000. Moreover, the result shows that the instructional method had a significant effect (Group), as $F (1,61) = 8.411$, $p < 0.05$, Sig. value = .005 (p value < 0.0). The ANCOVA results show that there is a statistically significant difference between the mean post-test scores of learners in the control and experimental groups. Therefore, the null hypothesis ($H_0$4), which states that there is no significant difference between the mean post-test scores of learners in the control and experimental groups, after controlling for the effect of pre-test scores, is rejected.

PRACTICAL SIGNIFICANCE AND EFFECT SIZE

The effect size using Cohen's *d* was calculated to assist in drawing conclusions on the practical significance. For the study, Cohen's *d* was determined by calculating the mean difference between the post-test scores of the two groups, and then dividing the result by the pooled SD, using the formula given below.

$$\text{Cohen's } d = (M_2 - M_1) / SD_{pooled}$$

where

$$SD_{pooled} = \sqrt{((SD_1^2 + SD_2^2)/2)}.$$

If the Cohen's $d = 0.2$, it represents a small effect, $d = 0.5$, represents medium effect and $d = 0.8$ represents a large effect.

The Cohen's *d* was calculated as 0,46 and hence, it can be understood that the intervention for the experimental group had a medium effect and the statistical difference found between the mean post-test scores of learners in the experimental group and control group was meaningful.

DESCRIPTIVE STATISTICS

Graphical comparison of the means of the pre-test post-test results were conducted and is given below. CG represents control group and EG represents experimental group.

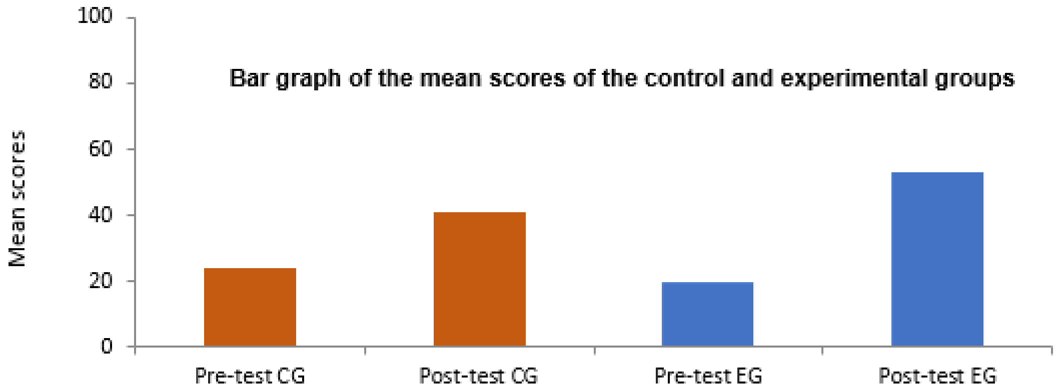


Figure 2. Bar graphs of means of the pre-test and post-test scores of the control group and experimental group

The graphical representation shows that the post-test scores for both CG and EG were greater than their respective pre-test scores. However, the mean post test score of the EG was greater than that of the CG.

RESULTS OF THE LESSON OBSERVATION

A summary of the analysis of the lesson observation conducted with the observation schedule of both control and experimental group under the different themes is presented in **Table 8**.

Table 8. Findings from lesson observation

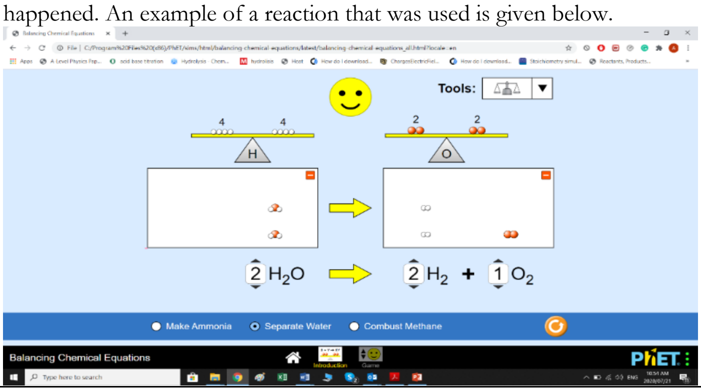
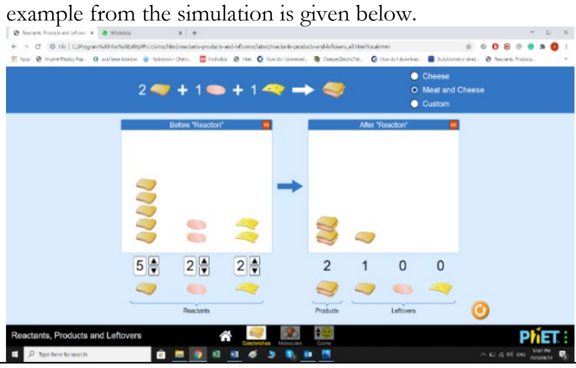
Themes	Control group	Experimental group
1. Lesson design and implementation-	For the control group, the teacher used the traditional lecture method for teaching the concepts in stoichiometric chemistry. Checking on prior knowledge was not done for all lessons. The lessons provided minimum opportunity for learners to gain active exploration experience and to interact with the teacher for problem-solving. During the lessons, the teacher wrote chemical equations on the board and asked the learners to balance the equations by manipulating the coefficients of the formula of each substance in the reaction. Steps were provided for learners to follow to perform mole ratio calculations.	For the experimental group, in all lessons the learners had the opportunity to apply their prior knowledge. Teacher–learner and learner–learner interactions were evident, and the learners could actively explore the concepts by using PhET simulations and engage in discussions, The lessons demonstrated the model for activity theory. This could have helped the experimental group to develop meaning of the content. With the PhET simulations, the learners could view the microscopic representation of each molecule in the reaction, and they could answer to the questions of the teacher. Hence it could be interpreted that representations helped them to recall their understanding of atoms and molecules and visualise each molecule and any change that happened. An example of a reaction that was used is given below. 

Table 8. Findings from lesson observation (continued)

Themes	Control group	Experimental group
2. Content knowledge of teacher, organisation and presentation of material-	For the lessons the teacher used the whiteboard and textbook as media. The lessons were observed to be mostly presented by delivering factual information. For example, the concept of using ratios to calculate the limiting reagent, amount of product formed, and leftovers, was presented by explaining how to do the calculation following certain steps.	In the experimental group, the PhET simulations, whiteboard and textbook were used as media while teaching. Except for one lesson the teacher linked the concept with real-life experiences, to achieve better conceptualisation. Real life example of making sandwich was used to teach the application of mole ratio in stoichiometric chemistry calculations. A screen shot of a real life example from the simulation is given below. 
3. Learner participation in the lesson-	The teacher used the whiteboard to explain the concepts in all lessons, and asked learners to read important points in the textbook. The learners were recalling/summarising facts and using algorithmic methods for doing the activities.	Except for one lesson, the teacher used the PhET simulations to conduct lessons based on calculations of limiting reactant, products and leftovers. It was observed that learners could view the reactants and products at the microscopic level and the leftovers of the reaction. Therefore, it could be interpreted that the molecular representation from the simulations allowed the learners to engage in critical evaluation of the content.
4. Classroom culture: learner–learner interaction-involvement of learners in communicating ideas in a variety of ways.	A few of the learners discussed in pairs and helped each other to balance equations and work on other problem-solving activities. The teacher mainly issued instructions to the learners and emphasized using the steps given to do the activities.	From the observation it was understood that the simulation gave the learners the opportunity to manipulate the game-based activities to determine the products and leftovers, and then to discuss their answers. In this way, the lessons with simulations opened doors for inquiry-based learning for problem-solving, which is likely to improve learners' ability to construct their own knowledge.
5. Classroom culture: teacher–learner interaction-	The teacher explained the various concepts to the learners, and followed up the explanation by assigning activities they had to complete. This was followed by corrections on the board by explaining the concept and the steps to follow for the complex stoichiometric calculations	In the experimental group the learners it was observed that learners had regular interaction with the teacher while they completed the activity through games to determine the products and leftovers. It was also observed that the teacher waited for the learners to provide answers for the games and, during explanations, learners were given the opportunity to engage in meaningful conversation to clear up confusion that they experienced and which caused them to make mistakes in calculations. Even though the lessons were controlled by the teacher, the learners had the freedom to interact with the teacher and to determine how the teacher could help with learning.

RESULTS OF THE TEST RESPONSE ANALYSIS OF PRE-TEST & POST-TEST

From the analysis of the responses to questions in the pre-test by the 12 interviewee learners of control and experimental groups, it was found that learners equally had challenges to balance equations. The other challenges included writing correct formulae of reactants and products, use of multiples of the actual coefficients in balanced equations, balancing by making the total number of molecules the same on both sides of the equation. Limiting reagent is a new concept in Grade 11 and, hence, neither group knew the definition for limiting reagent and its calculation. Learners in both groups could apply the mole-concept formula, which they had learned in Grade10, but could not use it for further calculations to find the number of moles when mass was given, and vice versa. Learners could not correctly apply the ratios in balanced equations to perform calculations.

The test response analysis of the post-test showed that more learners in the experimental group than the control group improved their performance and it could be interpreted that the improvement was due to learners understanding of the different concepts after the lesson. After the lessons both groups had improved in balancing equations. As mentioned above the limiting reagent and its calculations were a new topic in Grade 11, however, after the lessons there was an improvement in their understanding regarding the concept. The microscopic representations of the different reactions and the activities in the form of games in the simulations that were used for teaching and learning in the experimental group could have helped the learners to rearrange their initial understanding about the concepts in stoichiometric chemistry, thereby improving their conceptual understanding It was also observed that the learners in the control group used algorithms to do calculations, for instance, selecting a formula and substituting the data that was available.

RESULTS OF THE QUALITATIVE SECTION OF QUESTIONNAIRE AND INTERVIEWS

The interview assisted in an in depth and detailed understanding of how well the learners improved in conceptualisation of the concepts and how the teaching methods assisted in the conceptualisation. From the data analysis of the questionnaire and interview, it could be interpreted that some learners in both control and experimental groups, even after the lessons, faced challenges in applying their understanding of stoichiometric chemistry. Most responses in both questionnaire and interview by the control group showed that deep learning did not take place and they only gained factual knowledge to solve stoichiometric calculations However, the data analysis of the responses from the questionnaire and interviews showed that the lessons of the experimental group resulted in an improvement in the learners' conceptualisation of stoichiometric chemistry.

In response to questions about the teaching method, more learners in the experimental group responded that using simulations helped them to visualise the balancing of equations and to do calculations based on amount of reactants, products, limiting reagents and leftovers. Therefore, it can be interpreted that the activities in the simulations, which involved visual representations in the form of games, helped learners to construct their own knowledge. It was evident in responses to the questionnaire and in the interviews that learners in the experimental group had an improvement in conceptual and procedural knowledge about the importance of balancing equations, limiting reagents and its calculations. This conceptualisation helped the experimental group learners to explain how the calculation to determine the limiting reagent could be performed, and how they could apply it in calculations – they were better than the control group learners at explaining this. It was evident from the responses of the control group that these learners still had this misconception. The responses from the learners in experimental group showed that they gained problem solving skills in stoichiometric chemistry calculations better than the control group learners.

DISCUSSION OF RESULTS

After analysing the data, the findings from the quantitative and qualitative methods were compared and contrasted by triangulation. The two forms of data were combined by integration, which is called connecting the quantitative results to qualitative data (Creswell and Creswell, 2018: 222). This is the point of integration in an explanatory sequential design. For the study, the quantitative results from the pre-test and post-test were triangulated with the qualitative test response analysis, interviews and the questionnaire. This helped to integrate the findings of the qualitative data and the quantitative results and enhanced the trustworthiness of the research findings (Creswell and Creswell, 2018: 223). For this study, the test response analysis, interviews and the questionnaire helped to clarify, interpret and explain the results, performance and conceptualisation of the learners, as gleaned from the post-test. The quantitative data explained whether the performance of learners changed (improved) after the intervention. Thus, the qualitative data provided greater depth and insight into the quantitative results. It explained how the data from the qualitative method informed the quantitative data.

While the quantitative analysis focused on the performance of learners in stoichiometric chemistry, the qualitative analysis focused on the conceptualisation of stoichiometric chemistry. The results that emerged from the quantitative analysis of the pre-test post-test design guided the whole research process and were complemented by the qualitative analysis of the test response analysis, questionnaire and interview. **Figure 3** shows the essence of the way triangulation that was facilitated for the study.

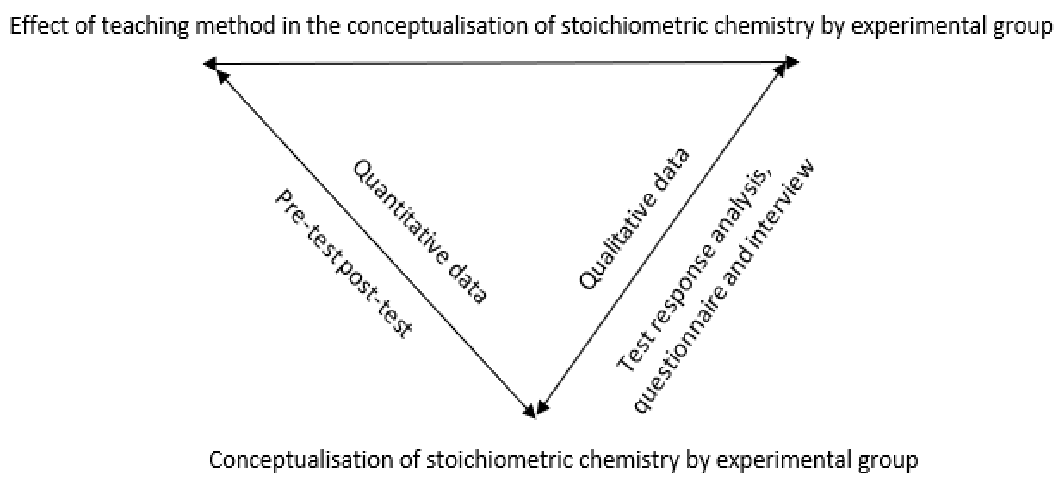


Figure 3. Triangulation of quantitative and qualitative results

The quantitative data analysis of the pre-test and post-test inductively found that both control and experimental groups improved in their performance of stoichiometric chemistry. Further analysis found that the performance improvement of the experimental group was greater than the control group. The qualitative test response analysis of the answers of the post-test supported this finding.

An inductive approach was also used for the analysis of the questionnaire and interview responses. The analysis of the qualitative questionnaire section and the interviews found that some of the learners in the control group were not satisfied with the lecture method to explain the concepts. However, most of the learners in the control group appeared satisfied with the algorithmic methods taught by the teacher for performing calculations. The teacher's use of algorithmic methods for problem solving was also noticeable during the lesson observation. It could then be interpreted that in the post-test, these learners followed the algorithmic steps to perform calculations and could not complete the calculations successfully. This interpretation is in line with researchers who has reported that the use of algorithmic methods without conceptualisation can be unsuccessful for problem solving. The interpretation concurs with their views that if conceptualisation does not occur, using algorithmic steps may fail to help a learner perform complex calculations correctly, because it comes down to applying steps without reflection and understanding.

From the findings of the interviews and questionnaire for the experimental group, it is clear that learners could interact with each other during discussions while being taught with the simulation. Moreover, the visual microscopic representations in the simulations helped many of the learners to understand the chemical reactions better. The visual representations helped them also to remember and understand what had been taught and helped them to perform better in the post-test. The rational for the study and literature review had also pointed out the positive impact of using molecular animations and visual representation with simulations for the better understanding of the different topics in chemistry. A major finding of the quantitative analysis is that the performance of experimental group learners in the post-test was better than that of learners in the control group. The interview and questionnaire analysis supports the above finding as the learners in the experimental group were better at explaining the importance of balancing equations, determining the limiting reagent, and explaining how ratios could be used to determine the limiting reagent and the amount of products formed. This finding further explains that experimental group learners had a better conceptualisation than the control group learners which resulted in a better performance in the post-test. Thus, the qualitative data that had been collected and analysed integrated with the quantitative data that had been collected and analysed, helped to develop a deeper understanding of the data and to gain a more complete picture of the study.

CONCLUSION

For further studies in chemistry, conceptualising stoichiometric chemistry plays an important role. The aim of this study, namely, to determine the effect of computer simulations on the conceptualisation of stoichiometric chemistry within theoretical framework of activity theory, was achieved. According to the activity theory model the use of visual tools which was mainly the PhET simulations, engaged the learners in activities based on chemical reactions. The interaction with simulated activities also helped the learners to construct their own knowledge thereby improving their conceptualisation of stoichiometric chemistry. From the analysis of the experimental design, questionnaire and interviews it can be concluded that there was greater improvement in learners' conceptualisation of stoichiometric chemistry in the experimental group than was the case for learners in the control group. Therefore, the study recommends the use of computer simulations for the teaching and learning of stoichiometric chemistry, as it is likely to improve its conceptualisation in the FET phase of schools in South Africa. The study further recommends a change in the teaching methods used by teachers and to integrate computer simulation to teach various concepts. Teachers may use a blended approach by making use of simulation in combination with other teaching methods, such as direct instruction, problem-solving and inductive or deductive reasoning.

The study has implications for physical sciences learners and teachers, physical sciences subject advisors, the Department of Basic Education, undergraduate chemistry students and chemistry lecturers at tertiary institutions. The study contributes to the improvement of learners' conceptualisation of stoichiometric chemistry and improved learner participation in the learning process, which makes learning science fun. Doing so might reduce the number of learners who discontinue learning physical sciences in Grades 10, 11 and 12 in South Africa due to their poor understanding and conceptualisation of stoichiometric chemistry and, hence, chemistry. Therefore, the study might contribute to producing more chemistry professionals for the chemical industry, to promote the economic growth and development of the country.

A limitation of the study was that instruments for the quantitative data collection used were not constructed to provide evidence of whether conceptualisation of the concepts took place. A well-designed quantitative questionnaire may have provided more evidence of the conceptualisation of stoichiometric chemistry. The topic of stoichiometric chemistry was dealt with at the school close to the June examinations. Hence, the teacher had to conclude the lessons and expose learners to minimum practise in solving problems using computer simulations at different difficulty levels. This could have affected the slow learners in relation to conceptualisation of the topic. Other than the guidance given by the researcher, the teacher involved in the teaching of stoichiometric chemistry using computer simulation as a tool was not given formal training by professionals on using computer simulation to teach. Formal training could have had an effect on the teacher, who may have explored simulation deeply, and used innovative ways to expose learners to the different difficulty levels of the games, while conducting the lessons. The study can be extended to a larger sample size, involving more learners doing physical sciences in the province or country, with a quantitative questionnaire to collect data. This could assist to generalise findings.

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Examination of STEAM-based Digital Learning Applications in Music Education

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ABSTRACT

STEAM is an interdisciplinary educational approach. Based on the idea that different disciplines can meet on a common ground, the STEAM approach aims to give students the habit of working together, to provide rich learning experiences and to focus on real-world problems. This study investigates STEAM-based digital learning applications used in music education, their contents and age group suitability. For this purpose, the method of the research is the narrative review study. In this context, we analyzed the Chrome Music Lab, Scratch Music, Groove Pizza, earSketch, UPISketch and iMuSciCA applications. Studies have proved that digital-based STEAM applications used in music education increase students' creativity, improve their music learning, and increase their interest in the lesson because they offer fun learning. With the development of technology, it has become necessary to adapt the methods and techniques used in music education to the age. By integrating art education, which has an important place in STEAM education, with other disciplines, music lessons can be effective and more permanent. The study shows that the more effective use of related applications by music teachers will contribute to music education and it is important in this regard.

Keywords: STEAM education, digital learning, music education

INTRODUCTION

The digitalization trend that continues unabated today affects learning approaches and environments. With the development of technological tools, terms such as web-based education and online education have emerged (Lin et al., 2017). The collection of these terms under a single title has brought the digital learning approach to the agenda. Especially with the global epidemic in recent years, the digital learning approach has gained more importance, and it has become inevitable to use digital learning in order to respond to the needs of new generations who have behavioral and perceptual differences and to improve their educational environment (Ünlü, 2019; Kocaman Karaoğlu et al., 2020). In addition, the idea of how this tendency can be used effectively for the development, benefit and welfare of societies has also been a matter of curiosity (Fukuyama, 2018).

Digital learning is a complex phenomenon associated with many things, and although there are different interpretations in the literature, it is generally defined as an unplanned and implicit process with the help of smartphones, tablets, computers and similar technological devices. In addition, digital learning often takes place unconsciously, without predetermined goals regarding learning outcomes (Sousa and Rocha, 2019).

Digital learning is also widely used in STEAM education. STEAM education is an interdisciplinary educational approach in which more than one of the fields of science, technology, engineering, art and mathematics are used together. In the literature review, studies show that digital learning, combined with STEAM education, has positive effects on students' interests and motivations (McDonald, 2016; Hawkins et al., 2019; Starkey, 2012). In a study investigating the effects of digital game-based STEM applications on students' interest in STEM fields and their scientific creativity, it was stated that positive results were obtained in terms of variables in the measurements performed before and after the application (Sarıçam, 2019). In another study, it was seen that socioscientific subject-based online STEM education carried out within the scope of digital learning supported students to transform their knowledge into skills and to use their achievements for different courses in an interdisciplinary way (Uyanık, 2021). Valko et al. (2020) stated that STEM applications used only in lessons are not sufficient for effective learning, the connection between digital learning and expected results should be deeply understood and this situation should be integrated into the learning process.

In the face of new teaching conditions and rapid development of technology, computer assisted music education serves as an important method in modern music teaching (Zhou, 2020). Gouzouasis and Bakan (2011) examined the potential impact of creative, digital technologies on music pedagogy in the 21st century. They stated that in the last decade digital technologies have fundamentally changed how to make, share, teach and learn music, and that digital music games and apps are an unprecedented revolution in social music making. In addition, they emphasized the need for music educators to be up-to-date on emerging trends in order to adapt their students to the era. Nart (2016), on the other hand, emphasized that digital learning applications in music education are important in terms of effective and efficient education process, and as a reflection of this, educators should closely follow the technological developments in their fields.

Music education, which is included in art education, is a versatile science that creates positive effects on students' cognitive, affective and social development and can interact with different disciplines.

Statement of the Problem

There are studies showing the importance and positive effects of STEAM education in art education (Liao, 2016; Jeon and Lee, 2014; Guyotte et al., 2015; Andreotti and Frans, 2019; Phanichraksaphong and Tsai, 2021; Morton at al., 2017). Hasanova (2021), drawing attention to the importance of aesthetic education in the full development of young generations, emphasized the invaluable contribution of music education in this direction. For this reason, music education emerges as an indispensable phenomenon in education systems. As these studies show, enriching music education with different approaches in a way that adapts to the era will further increase its effectiveness. An example of this is a study in which students are provided with an environment where they can rearrange their music within the scope of digitalization in learning environments, and positive results were obtained in their attitudes towards learning (Engelman et al., 2016). Especially with the Covid-19 epidemic, the difficulties experienced in different areas globally have deeply affected the education world. Hernandez (2021) conducted a study on how the Covid-19 epidemic affected computer-assisted teaching in Texas middle school choir classrooms. According to the results of the survey conducted before and after March 2020, he concluded that computer-assisted teaching in choir classes increased after March 2020. However, it is an undeniable fact that developed societies in the field of technology have overcome this process more easily. In this process, the importance of digitalization in education has once again come to the fore. For the stated reasons, it is important to introduce STEAM-based digital music applications to music educators and individuals who are interested in the field.

Research Question

In this research, we tried to introduce STEAM-based digital learning applications in music education. The aim is to ensure that music teachers create awareness of these applications in students by enriching their lessons and strengthening the bond of music science with different disciplines.

In this context, we seek answers for the following questions:

1. What are STEAM-based digital learning applications used in international music education?
2. What is the content of STEAM-based digital learning applications used in international music education?
3. For which age groups are these STEAM-based digital learning applications used in international music education suitable?

RESEARCH METHODOLOGY

In this research, literature review was conducted in order to present examples of STEAM-based music education digital learning applications and a narrative review was carried out in this direction. Narrative review is used for the purpose of making a general evaluation by organizing the studies found after the literature review on the subject (Çepni, 2018a; Snyder, 2019). Narrative review method, also known as unsystematic narrative review, is a summary of published studies on the subject under investigation (Green et al., 2006). In this context, we have compiled the tools obtained by examining the studies carried out in the databases with the keywords "STEAM", "Music Education" and "Digital Applications".

RESEARCH RESULTS

In this section, STEAM-based digital learning applications in music education are presented and evaluated under sub-headings.

Math, Science and Music Website

Mika Shino, director of the International Jazz Program at the Thelonious Monk Institute, has argued that music can be used successfully with mathematics and science. For this purpose, in 2016, Herbie Hancock Can Institute launched a website application to enable teachers to access music-based education programs to improve their STEM skills and perceptions (Huang, 2020). The program addresses the growing need for students to acquire skills, gain knowledge and learn to think creatively in science, technology, engineering, mathematics and music. The Institute collaborates with math, science, music and education experts at leading universities and the private sector to develop a wealth of free engaging curricula, games, apps, and other interactive online components. The Math, Science and Music website serves as an exciting and engaging repository of free, interactive tools for learning STEM subjects through music to prepare students for a world where technological skills are a necessary and important part of life. It is a platform with free applications that appeal to students of all age groups, from kindergarten to university (MathSciencesMusic, 2022 October 2).

Applications on the math, science and music website are listed below:

1. Chrome Music Lab

Aiding the transition from iconic technology to recording technology and standard notation, the Chrome Music Lab app is Google's hub for providing music-related experiments and activities, and is particularly useful in virtual and simultaneous teaching environments (Griffin, 2021). Chrome Music Lab is a website launched in 2016 that makes learning music more accessible through fun and hands-on experimentation. This digital learning platform, which consists of hands-on experiments including visualizers, can be used as a source of entertainment by immersing the student in an imaginary world, as well as a tool for teaching music to beginners (Garg, 2013). Many music teachers use the Chrome Music Lab app as a tool to combine dance and instruments with music to explore its connections to science, math, art and more (Chrome Music Lab, 2022 October 2). Especially music educators all over North America benefit from this practice to stimulate students' musical curiosity through visual interaction (Kosasih, 2021).

In the Chrome Music Lab, students can be asked to create their own rhythms, and inquiry skills based on mathematical concepts in rhythm can be developed. In addition, students gain by exploring mathematical concepts such as pattern, one-to-one equivalence, ratio and proportion, spatial thinking of fractions, row-column representation through music (Mishra, 2021).

The names and figures of the activities in the Chrome Music Lab application are given in **Table 1**. There are 14 activities in the Chrome Music Lab digital learning platform. The Kandinsky activity interprets the movements of the user as pitch, texture and rhythm. On the other hand, The Song Maker activity uses iconic notation as a piano roll showing students the relationship of pitches on a diatonic scale. By adding notes (boxes) to the grid, students can play their compositions and create melodies by revising them when necessary (Clauhs, 2021).

Table 1. Activities in the Chrome music lab app (Chrome Music Lab, 2022 October 2)

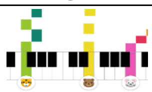
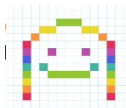
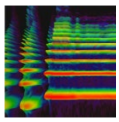
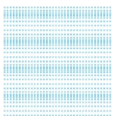
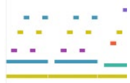
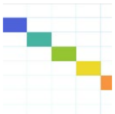
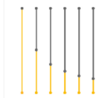
Name of the activity	Figure	Name of the activity	Figure
Shared Piano		Song Maker	
Rhythm		Spectrogram	
Sound Waves		Kandinsky	

Table 1. Activities in the Chrome music lab app (Chrome Music Lab, 2022 October 2) (continued)

Name of the activity	Figure	Name of the activity	Figure
Harmonics		Arpeggios	
Voice Spinner		Piano Roll	
Melody Maker		Chords	
Oscillators		Strings	

2. Scratch Music

Coding education has an important place in the STEAM approach. Educators in many countries of the world provide coding training in STEAM approaches. (Çepni, 2018b). Launched in the United States in 2013, Project Tynker is a creative computing platform where students organize games and apps through coding (Tynker Review, 2022). Another project is the Code Club Project for children aged 9-13 in England. This project was developed to enable children to follow computer technologies throughout their lives (Code Club, 2022 December 7). In addition to the exemplary studies, there are also STEAM-based music education applications with the help of coding.

Scratch is a programming environment designed and developed at the Lifelong Kindergarten Group at the MIT Media Lab. First launched in 2007, Scratch 1.0 is a native runtime application for Mac and Windows. Since 2013, Scratch 2.0 version has been coded to run in the web browser in Adobe's Flash environment. With the deprecation of Flash as a supported web environment, the new version 3.0 of Scratch has been reprogrammed using JavaScript and the Web Audio API. This version was made available for free to all users in January 2019 (Payne and Ruthmann, 2019). In addition, Scratch offers users different language options. Scratch allows users produce meaningful projects such as animated stories and games with the help of coding. One of the main aims of this program is to support learning through peer collaboration (Maloney et al., 2010).

While there are numerous studies examining Scratch in the context of children's creating games and coding interactive environments in general, little is known about its creative sound or its music-specific functionality. Music and sound are an important part of children's lives, but their ability to easily create music in coding environments is limited by the deep knowledge needed in music theory and computation to easily realize musical ideas (Payne and Ruthmann, 2019). This application, which all age groups starting from primary school age can use, teaches students the concepts of mathematical and computation, and provides them with 21st century skills as well as creative thinking, reasoning and working in collaboration (Resnick et al., 2009).

Scratch is a great environment to explore and create music. Scratch makes the first steps of creating music easy and accessible. Unlike many music programming languages, it provides instant audio feedback to the student with a single block of code that can be clicked and activated at any point. Often other music encoding programs require more complex structures to play a sound, such as starting a new instrument, finding and loading a sample, and turning on the sound output before producing a result (Payne and Ruthmann, 2019). To write a script that makes things happen from scratch, you should use code blocks. Scripts are associated with the stage background or individual animated characters. A new project starts with a blank background and a Cat sprite named Sprite 1 (Brown and Ruthmann, 2020). The sample usage of Scratch application is given in **Figure 1** (Scratch, 2022 December 2).

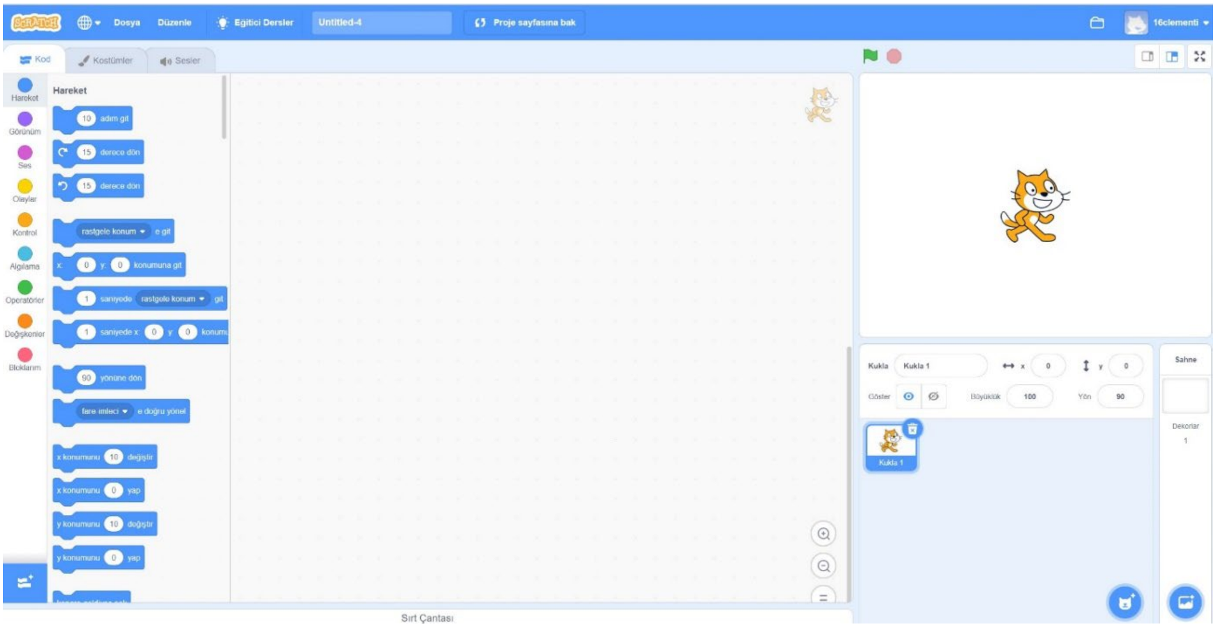


Figure 1. An example of scratch application

3. Groove Pizza

The starting point of Groove Pizza application coincides with Ethan Hein's Master's thesis written in 2013. Then, the first web prototype was created in collaboration with Adam November in 2015. Currently Groove Pizza is a comprehensive application reaching 1.5 million users in 216 countries (Groove Pizza, 2022 October 2).

Groove Pizza is a widely used web application that allows users to program drum rhythm patterns on a circular grid for creative music making and learning. This visualization scheme supports the creation of fun rhythm patterns using mathematical concepts such as shapes, angles and patterns. In this application, the symmetrical patterns in the visual field correspond to those in the auditory field (Holland et al., 2019). It's also a fun tool for creating music using math concepts like shapes, angles, and patterns.

When students program the drums in pop and dance idioms, they can embody rhythmic abstracts through direct multi-sensory experience. Groove Pizza has some unusual features designed to support intuitive rhythmic exploration. Rhythms appear as geometric shapes that can be applied directly. For example, users can change patterns rhythmically by rotating the corresponding shapes on the circle (Holland et al., 2019). The sample usage of Groove Pizza application is given in **Figure 2** (Groove Pizza, 2022 October 2).

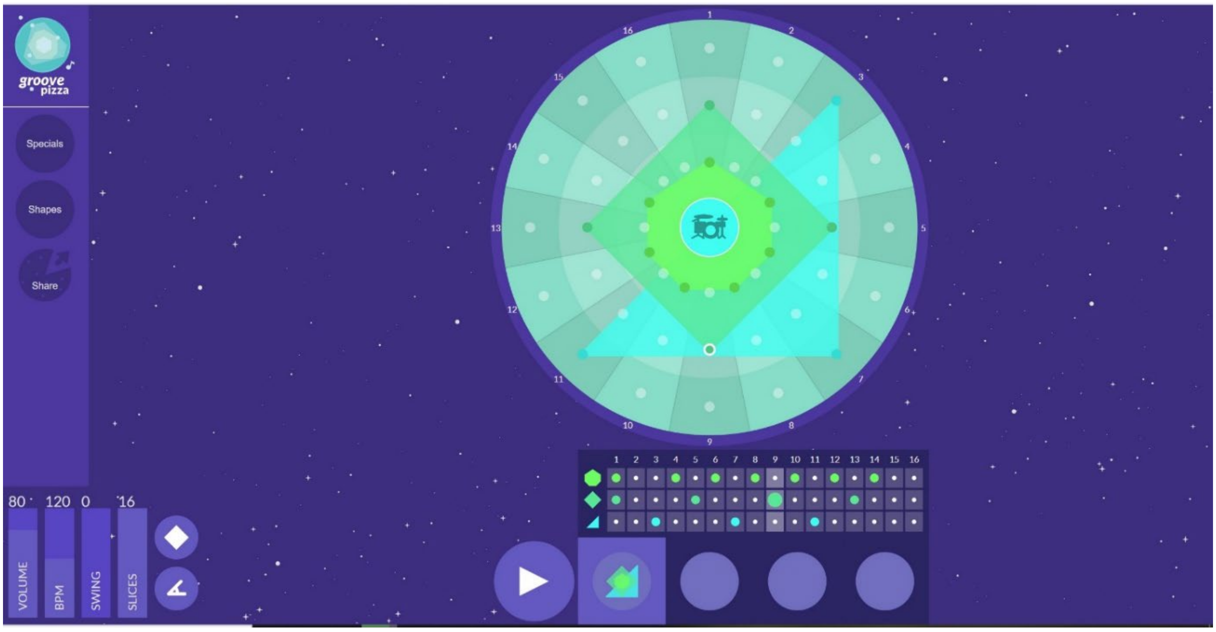


Figure 2. An example of groove pizza application

earSketch

earSketch is a free program that offers students a collaborative and authentic learning environment that introduces students to programming through music remixing in commonly used programming languages such as Python and JavaScript. Since the development of EarSketch began in 2011, more than 10000 users have been reached for use in many schools, summer camps, academic courses and other educational programs from primary schools to university (Mahadevan at al., 2015). The purpose of EarSketch is to offer users the opportunity to create music with the help of coding in a digital learning environment (Engelmen et al., 2017). EarSketch consists of an integrated curriculum, software toolset, audio loop library and social media website. The software toolset enables students to create music by manipulating loops, creating beats, and applying effects with Python code. On the other hand, the social media Web site allows students to upload their music and source codes, view other students' work, and create musical remixes derived from students' codes (Magerko et al., 2016). McKlin et al. (2018, February) stated that the EarSketch program attracted students' attention by providing the opportunity to start coding and creating music quickly in an environment perceived as authentic.

The user can access the application for free. The application consists of 4 main parts. These sections are 'Content Manager', 'Digital Audio Workstation', 'Code Editor' and 'Curriculum'. You can access the sound browser by selecting sounds in the content manager just below the EarSketch logo. You can search for sounds by artist, genre, and instrument. The sound collection menu will also have suggestions for sounds suitable for the music you want to create, or sounds used by others looking for similar sounds. You can create your music by performing the coding process in the code editor section. In the Digital Audio Workstation section, you can listen to the music you have encoded. Explanation and explanation video about the use of the application can be found under the Curriculum. The sample usage of earSketch application Figure 3 (EarSketch, 2022 October 2).

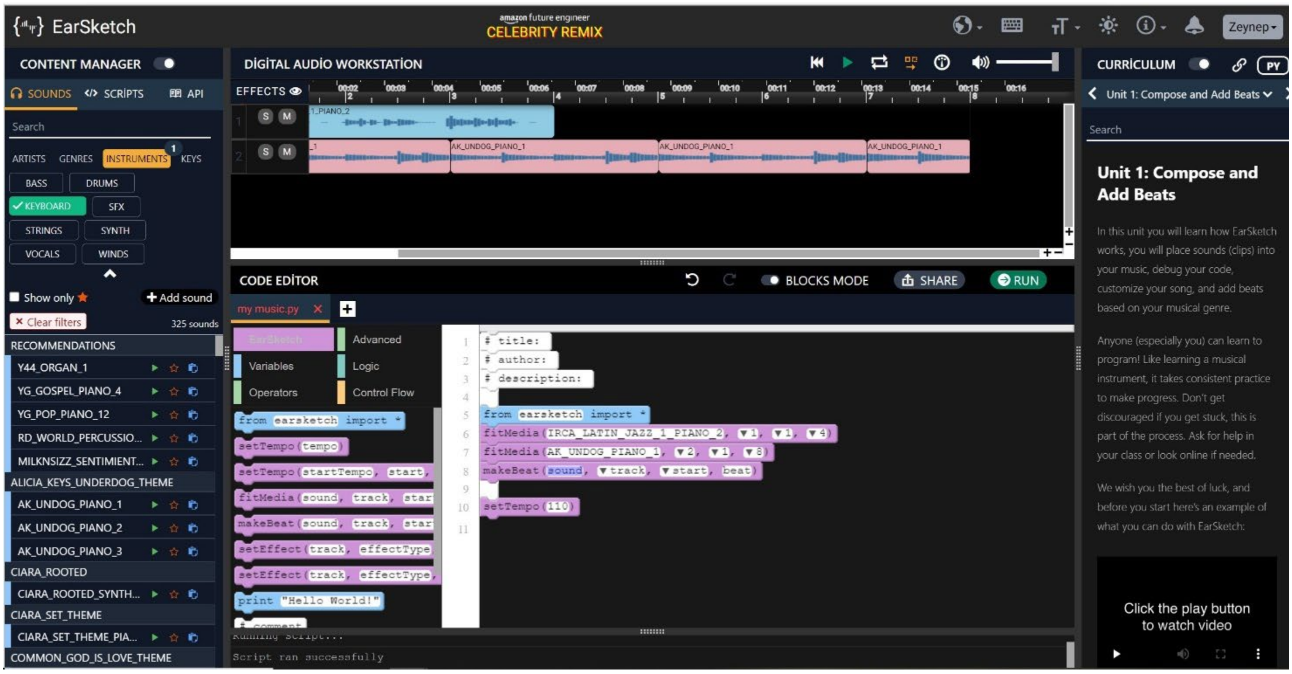


Figure 3. An example of earSketch application

iMuSciCA

Within iMuSciCA, combining Science, Technology, Engineering, Arts and Mathematics (STEAM) in a unified pedagogical framework enables students to directly identify the connections between abstract concepts and real-world elements. iMuSciCA is a European-funded project that provides a web-based work environment with several educational tools to connect science, math, technology and music. It includes instructions and suggestions for teachers to develop lesson plans to encourage creativity in learning and enable deeper learning (Katsouros et al., 2018).

The main purpose of the iMuSciCA project is to explore the phenomena and scientific rules of physics, geometry, mathematics and technology disciplines through musical activities, to examine them from different perspectives, and to develop curriculum topics that contribute to innovative interdisciplinary approaches. iMuSciCA Workbench is the main web platform where the user can perform STEAM related activities according to the iMuSciCA pedagogical framework. It provides tools categorized by different STEAM areas in music, science

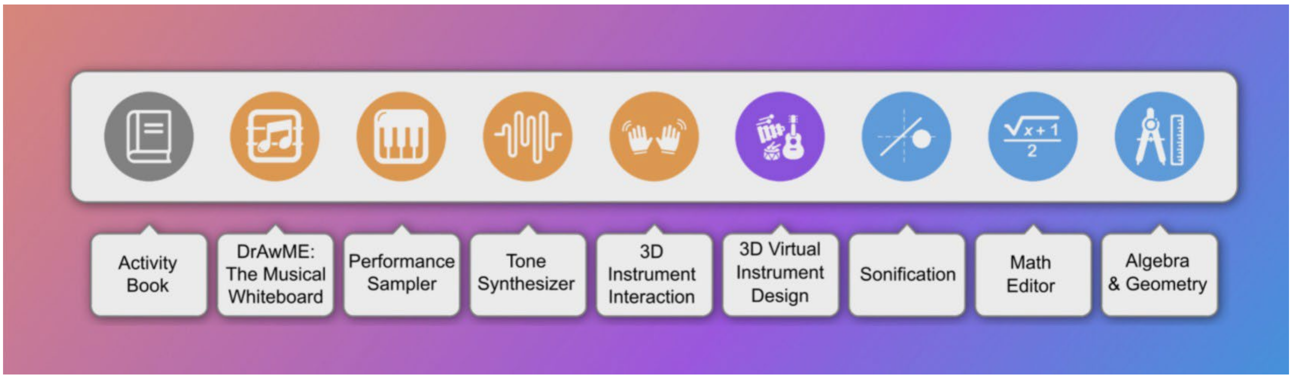


Figure 4. iMuSciCa workbench

and math, engineering and technology. These tools are Physical Model-based Sound Synthesis, Activity Enviroments, Music Tools, Visualization, Metronome, Sound Recorder and Clipboard. (Kritsis, 2019).

The iMuSciCA project directly addresses current needs in education and learning for new pedagogical methodologies and innovative educational technology tools, by providing students and teachers with opportunities for collaboration, co-creation, in order to support active, exploratory, individualized and engaging learning. As a STEAM-focused project, iMuSciCA has designed a suite of software tools and services to teach/learn STEAM, built on new enabling technologies integrated into a platform that will provide interactive music activities. iMuSciCA aims to support secondary school students in the mastery of core academic content in STEM subjects (Physics, Geometry, Mathematics and Technology) as well as supporting the development of creativity and deeper learning skills by participating in music activities (iMuSciCA, 2022 October 2). The Workbench of iMuSciCA website is given **Figure 4** (iMuSciCA Workbench, 2022 December 2).

At iMuSciCA, the 3D design and printing of musical instruments is accomplished through a web-based workbench that integrates advanced core enabling technologies, including body-tracking sensors for motion recognition, interactive pens and tablets, as well as sound creation and manipulation tools (Kaliakatsos-Papakostas et al., 2020). There are 8 tools in the iMuSciCA application. You can design 3D virtual instruments with The Musical Whiteboard. In this environment, the user can load pre-designed multichord, xylophone, guitar and membrane instruments. Thus, with The Musical Whiteboard, you can hear how the sound changes by adjusting various parameters such as length or chord tension of the sound produced from the instrument (Katsouros et al., 2018). The Performance Sampler, on the other hand, is designed for the user to load up to four recorded waveforms and create a composition from these recorded tracks (Kritsis et al., 2019).

In the 3D Virtual Instrument Design tool, when users open the application, they see a standard-tuned acoustic guitar, but they have the opportunity to change parameters such as the structure of the material of the string, its thickness and tension. In this way, they experience how the sound obtained from the guitar changes under which factors (Andreotti & Frans, 2019). 3D musical instruments are a workbench where you can simulate and analyze sound developed according to acoustic principles derived from physics and mathematics. You can also accurately experience harmonic ratios as a result of the physical properties of sounds (Stergiopoulos, 2021 May).

UPISketch

UPISketch is a software designed by Iannis Xenakis in collaboration with the European University of Cyprus to create drawing-based sound compositions. With the invention of UPIC by Xenakis in 1977, it was the first time that musical ideas drawn by a computer were realized as sonic. The idea of explaining the development of sound parameters using today's technology and creating a musical form in line with graphical curves led to the birth of UPISketch software. (Bourotte and Kanach, 2019). UPISketch is designed to be open access, simple and intuitive, enabling the realization of cross-platform audio applications. Thanks to this program, the user can design sound movements by defining melodic lines without the need for solfeggio knowledge, as in a musical score. Thus, it can be easily used by children as a pedagogical tool (UPISketch, 2022 December 2). In addition, the application integrates mathematics and music under the same roof, allowing users to produce mathematically supported musical elements. Thus, the UPISketch program represents an important STEAM example that can create connections between music, technology and mathematics for children. The sample usage of UPISketch application is given **Figure 5** (UPISketch, 2022 December 2).

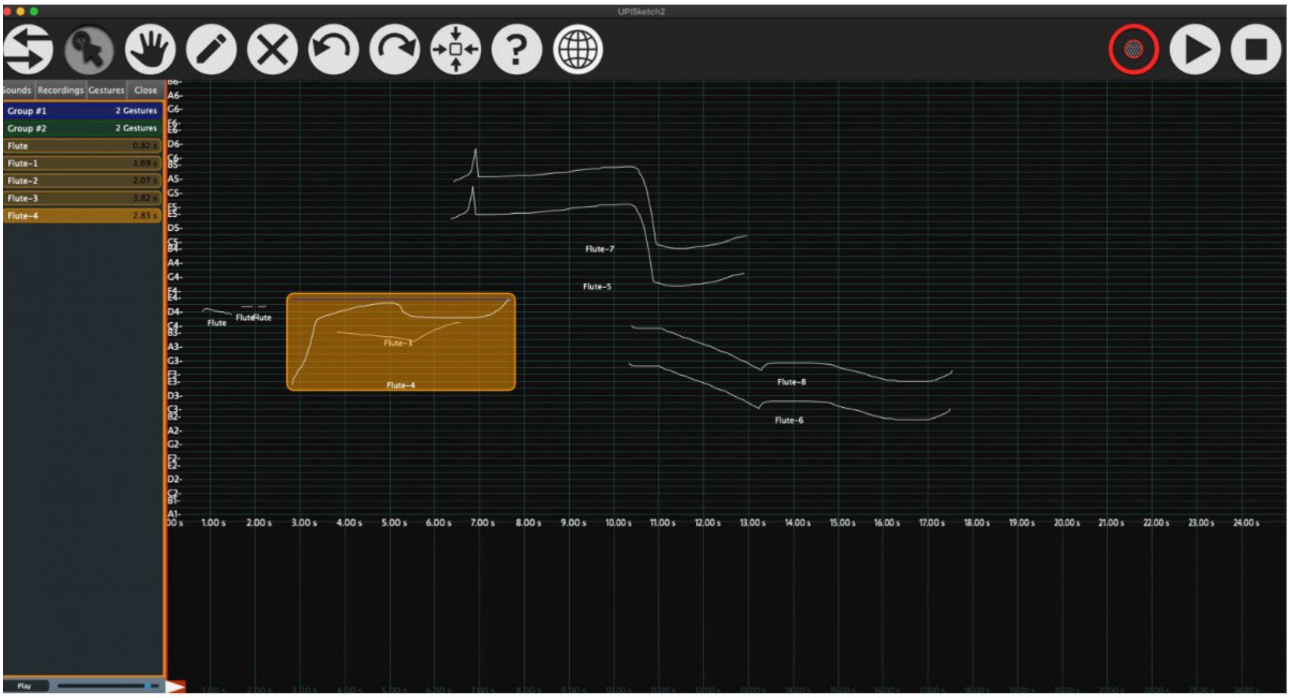


Figure 5. An example of UPISketch application

DISCUSSION AND CONCLUSION

In line with the researches carried out about these applications, the importance of the music discipline within the STEAM approach is clear. Studies have proved that digital learning environments developed with this understanding provide positive contributions to students. Wanzer et al. (2020) conducted a meta-analysis of 13 studies published between 2012-2018 to examine whether the EarSketch learning environment and curriculum support students' motivation in informatics in their future careers. Experts stated that EarSketch is a computer education program and curriculum that can help students continue to pursue informatics in the future and support the STEM approach (Wanzer et al., 2020).

Harris and Carroll (2020, July) stated in their study that web-based music applications used in music education have positive contributions to classroom teachers' music teaching and self-efficacy beliefs.

With 38 primary school teachers working in Indonesia, Julia et al. (2020) carried out music design applications with the Scratch program in order to improve the technology-based music education skills of the teachers. At the end of the research, it was concluded that the teachers could easily implement the relevant program and thus enrich their music teaching environment by improving their technological skills.

In a postgraduate study conducted in Turkey, the effects of Scratch programming and Makey Makey electronic card on the development of primary school students in reading and writing notes in music lessons were investigated. In this 12-week study, it was observed that students' reading and writing skills improved at all grade levels (Özkandemir, 2019).

Based on the findings obtained in this research, we can conclude that STEAM-based digital music education applications are designed within universities or developed within the scope of a project. Although the relevant programs are designed for all ages, they are mostly aimed at primary and secondary school students. In addition, these programs are often carried out within the framework of mathematics, technology and music disciplines. STEAM-based digital music education programs are designed to develop students' creativity and have features that students can easily access and implement.

The results obtained in this study show that these programs are at the forefront of producing music through coding and that they are actively used in international music education. Based on our experience, it is important to have different language options so that STEAM-based digital music education applications can be used more actively around the world. In particular, we think that these applications will be useful in developing computational thinking skills in children. In addition, we believe that music teachers will realize effective learning by enriching the course content by learning these applications.

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Digital Research Skills in Secondary Science Education: A Guiding Framework and University Teachers' Perception

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ABSTRACT

This study focuses on the perceived gap between the required and actual level of *digital research skills* (DRS) of students entering tertiary science education. By combining existing frameworks for research skills and digital literacy skills, a guiding framework of DRS was constructed. The DRS framework incorporates seven categories and is evaluated using an exploratory qualitative study employing semi-structured interviews with university teachers (N = 15). The level of DRS at the start of university science education and university teachers' perceptions of first-year students' level of DRS have been investigated. The results show that the skills of writing a research paper using digital tools, using proper resources, and analysing, transforming, and visualising data were generally found to be wanting.

Keywords: research skills, digital literacy skills, secondary science education, university teachers' perceptions, digital research skills

INTRODUCTION

In preparing students for academic education in STEM subjects, secondary education has the goal of providing a certain initial level of academic skills. Apart from the obvious STEM domain content, these skills include, among others, research skills (RS) and digital literacy skills (DLS). To give just one example, one of the most important research skills for STEM students is constructing a graph out of a dataset. A recent study in science education shows that pre-university physics students are generally able to construct suitable graphs on paper, 67% of which meet all scientific conventions (Pols et al., 2021). However, when students are confronted with constructing similar graphs by digital means, the results are insufficient (Sadikin et al., 2021).

First-year university students are confronted with an environment that often draws upon RS and DLS, and there have been consistent reports that they are lacking the necessary skills. To mention a few examples, Julien and Barker (2009) noticed that students are unaware of how search engines identify potentially relevant sources. Hyytinen et al. (2017) found that many beginning students in higher education still struggled with how to use their sources. Wollscheid's (2021) data show a lack of adequate scientific writing skills among starting students. First-year university students also have been reported to have difficulties related to adapting, interpreting and evaluating outcomes during data processing and working with statistics (Oakleaf and Owen, 2010). Akuegwu and Uche (2019) found that reading, presentation, communication and information-gathering skills of freshman STEM students were adequate, whereas especially data analysis was found wanting.

Other research confirmed this problematic level of skills such as information-seeking and using ICT among students in secondary education (Julien and Barker, 2009; Meelissen et al., 2014; Smith et al., 2013; Walraven et al., 2008). In the past decades several authors advocated integration of DLS in undergraduate and secondary education (Pratolo and Solikhati, 2021; Voogt et al., 2013; Udeogalanya, 2022).

In many countries, the learning objectives for secondary education are prescribed in terms of the subject aims, core knowledge and skill areas. However, even when secondary education syllabi do give some guidelines on the development of RS and DLS, concrete demands concerning the level of these skills are often lacking (Maddens et al., 2021; Thijs et al., 2014; Voogt et al., 2013). These levels are therefore not easily measured or assessed. As a consequence of this situation, several university science programs offer compulsory modules for first-year students, teaching them RS and DLS (Curtis et al., 2017). It is recently found that students' digital literacy positively affects learning outcomes in science subjects (Akhyar et al., 2021; Latip et al., 2022)

Despite the importance of DLS and RS for academic success (Briggs et al., 2012; Hurwitz and Schmitt, 2020; Oostdam et al., 2007), only a few scientific studies have addressed the development of these skills in secondary education and the way this affects the ensuing transition to science undergraduate education. Most studies in this field have focused on students' characteristics (Maddens et al., 2021; Smith and White, 2015), general transition factors (Leese, 2010), teaching and testing approaches (Mumba et al., 2002) or a mismatch of STEM syllabi (De Meester et al., 2020).

In this study we synthesized a framework for the combination of DLS and RS, which we label *Digital Research Skills* (DRS). The main aim of this study is to evaluate how proficient science university teachers judge their starting students to be in DRS. The following research question will be addressed: For which digital research skills (DRS) do university teachers perceive a gap between the final level of secondary education and the required entry level for science studies?

The two sub-questions are:

1. Which DRS do university teachers consider important for starting science students?
2. What are university teachers' perceptions about starting science students' level of DRS?

In the next section, we describe a framework for DRS based on existing RS and DLS frameworks. To answer the sub-questions, we then use this DRS framework as a basis for interviewing university teachers on their perceptions about the level of DRS among first-year science students.

THEORETICAL FRAMEWORK

In this section we aim to combine existing frameworks for RS and DLS into a framework that covers DRS.

Existing Frameworks for RS

Fischer et. al, defined *research skills* (RS) as a set of "skills and abilities to understand how scientific knowledge is generated in different scientific disciplines, to evaluate the validity of science-related claims, to assess the relevance of new scientific concepts, methods, and findings, and to generate new knowledge using these concepts and methods" (Fischer et al., 2014: 29). Significant consensus on RS is found in literature, resulting in the introduction of several similar frameworks for RS. For example, for upper secondary education, Fischer et al. (2014) and Opitz (2017) deconstruct research skills into eight scientific activities in which students have to be able to engage, from problem identification, to drawing conclusions and communicating. Similarly, Stokking et al. (2004) mapped secondary school examination requirements to RS in 10 steps. The inquiry-based learning framework developed by Pedaste et al. (2015) is another example of such an approach. Furthermore, different versions of the Research Skills Development (RSD) framework (Willison and O'Regan, 2007) have been developed for students in higher education (van Laar et al., 2017) and undergraduate students (Willison and Buisman-Pijlman, 2016). This RSD framework (not to be confused with our acronym DRS for digital research skills) aims to conceptualise research skills using levels of autonomy and identifies six research skills.

In the present study, the latter framework presented by Willison (2018) is adopted, because: (1) it covers most of what has been mentioned in the other frameworks for RS; (2) it is comprehensive, (3) quite recent, and (4) suitable for the target group.

A comparison of this RSD framework with the other known RS frameworks is given in **Table 1**.

Table 1. Research skills, steps or stages described in literature compared with the RSD framework of Willison

Research skill (Willison, 2018; Willison and Buisman-Pijlman, 2016; Willison and O'Regan, 2007)	**General description** (Willison, 2018, p. 2; Willison and Buisman-Pijlman, 2016, p. 66; Willison and O'Regan, 2007, pp. 402–403)	**Similar skill(s) in research stages or steps described in the literature**
Embark and clarify	Students respond to or initiate direction, clarify and consider ethical, cultural, social and team (ECST) issues.	1. Recognise the problem. 2. Identify and define the problem. 3. Formulate a problem hypothesis, deduce consequences and define basic terms and variables. (Allison et al., 2016, p. 17,18) 1. Problem identification, 2. Questioning, 3. Hypothesis generation. (Fischer et al., 2014, pp. 33–35; Maddens et al., 2021, p. 494; Opitz et al., 2017, p. 79) 1. Identify and formulate a problem using subject-specific concepts. 2. Formulate the research question(s), hypotheses and expectations (if any). (Stokking et al., 2004, p. 99) 1.Questioning. 2. Hypothesis generation. (Pedaste et al., 2015, p. 54)
Find and generate	Students find information and generate data/ideas using appropriate methodology.	6. Conduct experiment. (Allison et al., 2016, p. 18) 5. Evidence generation. (Fischer et al., 2014, pp. 33–35; Maddens et al., 2021, p. 494; Opitz et al., 2017, p. 79) 4. Gather and select information/data. 5. Assess the value and utility of the data. (Stokking et al., 2004, p. 99) 4. Experimentation. (Pedaste et al., 2015, p. 54)
Evaluate and reflect	Students determine the credibility of sources, information, data and ideas, and make their own research processes visible.	4. Select experimental variables. (Allison et al., 2016, p. 18) 4. Construction and redesign of artefacts. 6. Evidence evaluation. (Fischer et al., 2014, pp. 33–35; Maddens et al., 2021, p. 494; Opitz et al., 2017, p. 79) 8. Evaluate the research. (Stokking et al., 2004, p. 99) 7. Reflection. (Pedaste et al., 2015, p. 54)
Organise and manage	Students organise information and data to reveal patterns/themes, managing teams and processes.	5. Construct experimental plan. 7. Reduce raw data to allow examination of effect thought to exist. (Allison et al., 2016, p. 18) 3. Make and monitor the research plan: research design and time schedule. (Stokking et al., 2004, p. 99) 3. Exploration (Pedaste et al., 2015, p. 54)
Analyse and synthesise	Students analyse information/data critically and synthesise new knowledge to produce coherent individual/team understandings.	8. Test for significance. (Allison et al., 2016, p. 18) 7. Drawing conclusions. (Fischer et al., 2014, pp. 33–35; Maddens et al., 2021, p. 494; Opitz et al., 2017, p. 79) 6. Analyse the data. 7. Draw conclusions. (Stokking et al., 2004, p. 99) 5. Data interpretation (Pedaste et al., 2015, p. 54)
Communicate and apply	Students apply their understanding and discuss, listen, write, perform, respond to feedback and present processes, knowledge and implications of research.	8. Communicating and scrutinising. (Fischer et al., 2014, pp. 33–35; Maddens et al., 2021, p. 494; Opitz et al., 2017, p. 79) 9. Develop and substantiate a personal point of view. 10. Report (describe) and present (communicate) the research. (Stokking et al., 2004, p. 99) 6. Communication (Pedaste et al., 2015, p. 54)

A Framework for DRS

In contrast to the consensus on RS, there appears to be no consensus about what exactly the concept of digital literacy in education entails (Pangrazio et al., 2020). The different definitions of digital literacy (scientific and reference frameworks) mainly address skills and knowledge (Voogt et al., 2019). In order to work towards a framework for both RS and DLS, we have studied publications on DLS from the past ten years that were related to or assessed in secondary education.

We considered six frameworks for digital literacy in the 21st century aimed specifically at students over 12: learning literacies for the digital age (LLiDA) with a broad audience, described by Beetham et al. (2009); the Digital Competence Assessment (DCA) by Calvani et al. (2008, 2010), the international computer and information literacy study (ICILS) by Fraillon et al. (2013, 2014, 2020), digital literacy (DL), by Eshet-Alkalai (2012, 2002; Eshet-Alkalai and Chajut, 2009); the European digital competence framework for citizens (DigComp) by Carretero et al. (2017), Ferrari (2013) and Vuorikari et al. (2016, 2019); and the technology & engineering literacy framework (TEL) by the National Assessment Governing Board (2018).

In **Table 2**, we have compared these frameworks for DLS with the RSD framework presented by Willison (2018). The third column in **Table 2** gives the corresponding categories of our DRS framework. The ability to browse, search, filter and use advanced search methods for various purposes from DLS overlaps with RSD skill 1 'embark and clarify' in **Table 1**. We therefore defined the combination of these research and digital literacy skills as 'browse, search and filter information', the first digital research skills (DRS) category in the third column of **Table 2**.

DLS such as accessing and selecting information, the ability to construct knowledge and use digital resources are connected to research skill 2 'find and generate' of the RSD framework. This combination forms the second DRS category: 'gather, measure and collect digital content/data' in **Table 2**.

The ability to evaluate information for timeliness and accuracy, and developing strategies to check the credibility of sources overlaps with skill 3 'evaluate and reflect' of the RSD framework. In a similar way, category 4 'structure, manage and protect digital content/data' and category 5 'analyse, transform and visualise content/data digitally' found their way in **Table 2**.

Table 2. Matching of research skills and digital literacy skills to identify corresponding digital research skills (DRS)

Research skill (RSD)	Similar digital literacy skills in other frameworks	Corresponding digital research skill
1. Embark and clarify	• Browse, search and filter data, information and digital content (DigComp) • Use advanced search techniques with digital and network tools and media resources (TEL)	Browse, search and filter information
2. Find and generate	• Access information (ICILS) • The ability to construct knowledge by nonlinear navigation (DL) • Select digital and network tools and media resources (TEL) • Use digital tools and resources (TEL)	Gather, measure and collect digital content/data
3. Evaluate and reflect	• Evaluate information (ICILS, DigComp) • The ability to consume information critically and sort out false and biased information (DL) • Search media and digital resources on a community or world issue and evaluate the timeliness and accuracy of the information (TEL) • Evaluate the credibility of the source (TEL) • Justify choices based on the tools' efficiency and effectiveness for a given purpose (TEL)	Determine the accuracy and validity of sources/methods
4. Organise and manage	• Manage information and digital content (ICILS, DigComp) • Safety, privacy and security (ICILS, DigComp, TEL) • Netiquette, copyright and licenses (DigComp) • Knowledge about many different ICT tools (TEL) • Responsible and ethical behaviour (TEL)	Structure, manage and protect digital content/data
5. Analyse and synthesise	• Transform and create information (ICILS) • Integrate and re-elaborate digital content (DigComp) • Creatively use digital technology (DigComp) • The ability to process and evaluate large volumes of information in real time (DL) • Use digital tools to collect, analyse, and display data in order to design and conduct complicated investigations (TEL) • Conduct a simulation of a system using a digital model (TEL)	Analyse, transform and visualise content/data digitally
6. Communicate and apply	• Develop digital content (DigComp) • Manipulate pre-existing digital texts and formats (DL) • The ability to create authentic, meaningful written and artwork (DL) • Explain rationale for the design and justify conclusions based on observed patterns in the data (TEL)	Write a research paper using digital tools
7. Communicate and apply	• Share and interact with information through digital technologies (ICILS, DigComp) • Develop digital content (DigComp) • The ability to communicate effectively in online communication platforms (DL)	Share and present content/data

Skill 6 'communication and apply' of the original RSD framework is defined as "Discuss, listen, write, present and perform the processes, understandings and applications of the research…" (Willison and Buisman-Pijlman, 2016: 67). Research projects in secondary education, however, often entail writing a report as well as giving a presentation. For the purpose of this study RSD skill 6 was therefore subdivided into two DRS categories: 'Write a research paper using digital tools' (category 6) and 'Share and present content/data' (category 7).

METHOD

In order the answer the sub-questions, we conducted an exploratory qualitative study to clarify what DRS are required at the start of higher science education in the Netherlands.

Context

To start academic STEM studies in the Netherlands, only a valid pre-university diploma with one or more compulsory subjects such as chemistry and physics is required. No further specification or prior knowledge in the field of RS and DLS is required to obtain this diploma. The required entrance level of these skills is also unspecified at many Dutch universities.

Every secondary education subject has a nationally-established syllabus which contains a description of learning goals. In the syllabi for physics and chemistry, DRS are mentioned three times in the domain of 'skills'.

> A8.1: Acquiring and selecting information from written, oral and audio-visual sources, partly with the help of ICT:
>
> - Extract data from graphs, tables, drawings, simulations, schemes and diagrams;
> - Look up quantities, units, symbols, formulas and data in suitable tables. (CvTE, 2021a: 13, 2021b: 9)
>
> A8.2: Analysing, displaying and structuring information, data and measurement results in graphs, drawings, diagrams, diagrams and tables, partly with the help of ICT. (CvTE, 2021a: 13, 2021b: 9)
>
> A11.2: Using the computer to model and visualize phenomena and processes, and to process data. (CvTE, 2021a: 15)

Only the third specification, which relates only to pre-university physics, requires that the required skills must be fully performed on the computer. The syllabus for mathematics states that pre-university students are able to use ICT for, among other things, modelling, algebraizing and investigating geometric properties of objects. However, ICT refers here to a rudimentary graphic calculator (CvTE, 2021c: 6).

Participants

This qualitative study was based on semi-structured interviews with 15 academic science teachers (**Table 3**), selected based on the following criteria: they teach first-year chemistry and/or physics students and/or supervise or teach these students when the students are doing a research project. Out of a total of 30 candidates approached, 15 responded. Participants provided written informed consent, which was repeated orally at the start of the interview. The academics were men and women in different age categories (30-67 year) from eight comprehensive and two technical universities in the Netherlands.

Table 3. Pseudonymized name and function of interviewees (*N* = 15)

	Function	Pseudonymized name
1	Coordinator and lecturer Physics practical	Ed
2	Full professor, program director and lecturer Chemical Science and Engineering	Ethan
3	Lecturer Physics practical	Dean
4	Coordinator and Lecturer Physics practical	Kevin
5	Supervisor Educational Chemistry	Esther
6	Lecturer academic skills Technical Natural Sciences	Emmy
7	Lecturer Science Education and Communication	Alycia
8	Lecturer Molecular Life Sciences	Noah
9	Lecturer academic skills Pharmacy	Nadir
10	Lecturer Introduction Scientific Research	Aimee
11	Full professor, program director and lecturer in Life, Science and Technology	Simon
12	Lecturer Chemistry Practical	Rachid
13	Full professor and lecturer of Mechanical Engineering	Kyano
14	Program director and associate professor of Engineering Physics	Nigel
15	Coordinator and lecturer Chemistry practical	Michael

Procedure

All interviews were conducted and recorded in an online platform. In order to determine academics' views on DRS, the interview consisted of six basic questions.

1. In which course or courses are you involved and what is your role in this?
2. Can you name some DRS that you think first-year students should be able to apply while conducting research?
3. To what extent are you satisfied with the degree to which students have mastered the DRS?
4. If you were allowed to include one thing in secondary education in the field of DRS, what would you like to add to the program in pre-university education?

The interview ended with two closed-ended questions.

5. How satisfied are you with the degree to which first-year students apply digital skills in applications such as Word, Excel, PowerPoint? Can you grade this from 1 to 10, where 1 = least and 10 = most?
6. How important do you think it is that first-year students have mastered digital skills in applications? Can you grade this from 1 to 10, where 1 = least and 10 = most?

During the first part of the interview follow-up questions were used, such as: Can you give an example? How should they be able to do this? Does this apply to most students? The participants were not introduced to our DRS framework before the interview, in order to leave the approach of the subject entirely to the interviewee. No questions were framed around specific DRS. Note that question 5 addresses no specific science applications, such as Python, Origin, or LateX. Only the basic applications that all students in secondary education are likely to encounter have been included in the questions. All questions were presented in Dutch. The quotes have been translated into English.

Data Analysis

All recordings were transcribed and pseudonymised. Potentially interesting quotes from the participants were selected and coded using the categories in the DRS framework in **Table 2**. The DRS framework outlined in **Table 2** above has been employed as an axial coding scheme. Similar self-contained quotes were grouped together per category in the framework. Each quote was also coded as reflecting either a positive or negative perception by the interviewee. We organized the data in a bar chart, indicating the number of quotes per category and subdividing the bars to include positive and negative quotes. Duplicate coding was done on 50 of the 223 quotes; Cohen's kappa was found to be 0.88 for determining whether a quote was positive or negative and 0.81 for assigning the codes to the seven categories of the DRS framework, indicating good to near-perfect interrater reliability for both coding processes.

Quantitative data were obtained from the last two interview questions. The scales on the interviewees' ratings of importance or satisfaction with the degree to which their students have mastered digital skills in applications such as Word, Excel, and PowerPoint were averaged and organized in a diagram.

RESULTS

This section outlines the main findings of the interviews.

Important Digital Research Skills

Following transcription and coding, 223 quotes with examples in the field of DRS were identified. The quotes were coded according to the framework in **Table 2**. **Table 4** gives some examples for each category of the DRS framework.

The most frequently mentioned examples (76) belong to category 6: writing a research paper using digital tools; 60 quotes concern category 5: analysing, transforming and visualising content/data digitally; 41 quotes concern category 2: gathering, measuring and collecting digital content/data; 21 quotes concern category 1: Browse, search and filter information and 14 quotes concern category 7: Share and present content/data. Categories 3 (7 quotes) and 4 (4 quotes) were least mentioned. Eight quotes contain examples in more than one category.

Quotes with examples such as being able to use search engines, assessing and selecting sources for reliability and transform data into a graph were mentioned by 13 of the 15 interviewees. Examples associated with writing a research paper were mentioned by all interviewees, included details such as using calculating functions, a functional type of chart with correct labelling of axes, display of measurement points and use of a caption.

Table 4. Examples of skills related to proposed DRS categories mentioned by interviewees (N = 15)

DRS categories	Examples mentioned by interviewees*
1. Browse, search and filter information	• Using search engines and databases (n = 4) • Filtering information (n = 4) • Using advanced search techniques by combining keywords with operators (n = 3)
2. Gather, measure and collect digital content/data	• Maintaining a resource list and refer to sources (n = 8) • Selecting scientific literature (n = 5) • Knowledge and use of digital/online environments to (automatically) acquire data (n = 2) • Avoiding plagiarism using quoting and paraphrasing (n = 1)
3. Determine the accuracy and validity of sources/methods	• Comparing and assessing digital sources/information (n = 2) • Digital visualisation of the search strategy (n = 1) • Evaluation of information/data for timeliness and accuracy (n = 1) • Checking the credibility of sources (n = 1)
4. Structure, manage and protect digital content/data	• Drawing a research setup (n = 2) • Storing data in a safe and orderly way (n = 1) • Developing a research plan, using a structural procedure (n = 1)
5. Analyse, transform and visualise content/data digitally	• Using application software to enter calculation functions (n = 11) • Plotting a graph using a functional type of chart with axis labels and/or a legend (n = 8) • Using error bars, a curve-fit and/or trendlines (n = 3) • Processing multiple datasets (n = 2) • Using a curve-fit or fitting a model to the data (n = 1) • Programming a script or model to process and analyse data (n = 1)
6. Write a research paper using digital tools	• Inserting figures, graphs and tables using references and captions (n = 5) • Processing and formatting content using a digital application (n = 4) • Using styles, headings and subheadings (n = 2) • Using automatic numbering (n = 2)
7. Share and present content/data	• Using application software or an online tool for displaying and formatting content (n = 2) • Collaborating and presenting in a digital/online environment (n = 1) • Using a slide master and/or a digital template (n = 1) • Reduction of text and graphic design of content (n = 1)

* We paraphrased these quotes for the sake of brevity.

Perceptions of Students' Level of Digital Research Skills

In **Figure 1**, the total number of quotes on the students' level of proficiency is displayed, divided into positive and negative quotes. A positive quote means that the interviewee was mostly satisfied with the extent to which students applied the corresponding skill. A negative quote means the interviewee was generally not satisfied.

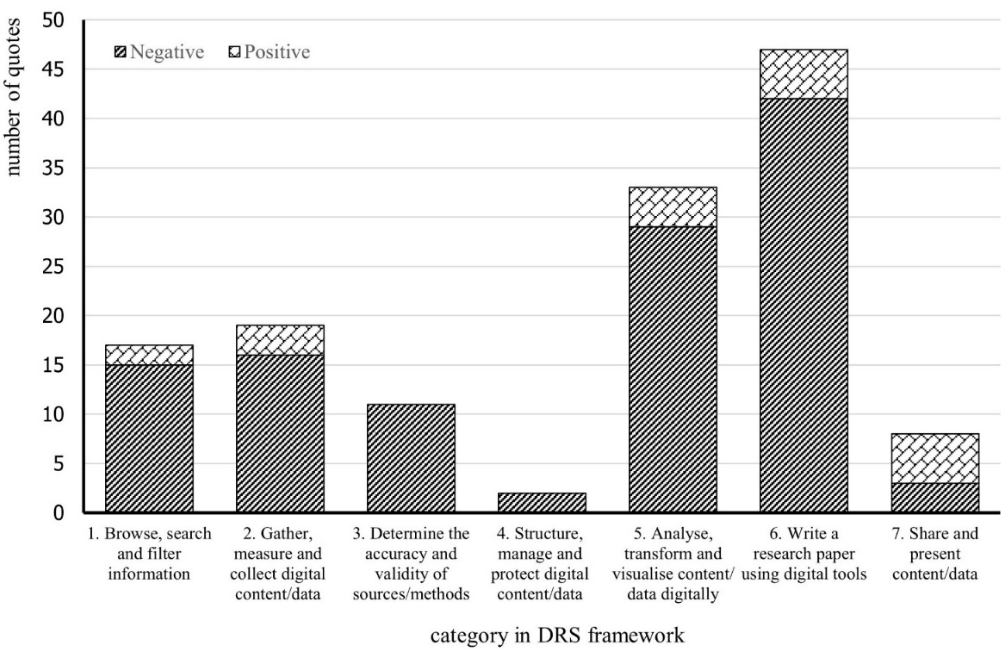

Figure 1. Frequency of positive and negative interview quotes per category of our DRS framework (N = 15)

It is striking that most quotes (106 out of 125), in response to the third interview question were negative. The negative quotes mainly indicate a lack of skill in: writing a research paper using digital skills; analysing, transforming and visualising content/data; and gathering, measuring and collecting digital content/data. Dean (Lecturer Physics practical) said:

> They have very little familiarity with more advanced packages. Really, just the digital skills of making a report neat. How do I actually just draw a research setup? What am I going to use? What exactly can I measure?

The positive quotes mainly related to skills such as sharing and presenting content/data and also writing a research paper using digital tools.

We now give examples of quotes as presented in **Figure 1**, starting with the largest group, where the numbers in parentheses mean: (number of quotes/number of interviewees mentioning the quotes).

Category 6: Write a research paper using digital tools (42 negative quotes; 5 positive quotes)

The majority of the negative quotes in this category are related to big differences in skill level between the students (11/8). Kevin (Coordinator and Lecturer Physics practical) said:

> There are students who come from a pre-university school with a lot of practicals and research report experience, but there are also students who have actually done zero practicals, because the teachers think it is a waste of time, so that is just very diverse what comes in.

Other quotes refer to lack of skill in using captions and references (10/8), line of reasoning in a paper (10/6) and text formatting (8/5). Michael (Coordinator and lecturer Chemistry practical) said:

> I see, which is a very common mistake, that students just put pictures in there. So you see the results section and then you see two images without a proper caption. And then, if you're lucky, there will be a few more lines of text underneath and that's it. That is really something I see very often.

The positive quotes (5/3) related to general skills in writing a paper.

Category 5: Analyse, transform and visualise content/data digitally (29 negative quotes; 4 positive quotes).

In addition to the lack of adding an explanation in the caption (14/8), a significant number of the negative quotes in this category are related to students' lack of digital skills to process data (8/5). Michael (Coordinator and lecturer Chemistry practical) said:

> 30 to 40 percent of the students can handle it just fine and others have never done it. So if you look in their lab journal on the first few experiments, they have a hand-drawn graph, while you really said, well, try doing it in Excel, but then they say yes, they have no idea how it should be.

Other quotes refer adding a correct axis label (8/8) and adding a trendline instead of connecting the measure points (7/7). The positive quotes were about visualizing content/data in general (4/3).

Category 2: Gather, measure and collect digital content/data (16 negative quotes; 3 positive quotes)

Three interviewees noticed that there is a lot of difference in the level of skill with which students select scientific literature. They were surprised that most first-year students are not yet able to do this, so they have to be trained to do it. Aimee (Lecturer Introduction Scientific Research) said:

> What I often notice is that they have trouble citing sources properly, because very often they cite an article they have found in PubMed as a link to PubMed. I keep encountering that, even in the third year. The difference between a journal and a database is not yet completely clear to them.

Other quotes mentioned that students use too few references (6/5), the quality of used reference does not suffice (8/4) or that they use non-evaluable links (2/2).

Category 1: Browse, search and filter information (15 negative quotes; 2 positive quotes)

The majority of the negative quotes in this category are related to first-year students' insufficiency to search for information on the Internet (11/6). Nigel (Program director and associate professor of Engineering Physics) said:

> The average student taking final exams is not very good at looking for very specific information. If you're talking about: "Look for an article that is about topic x or about application y", then that is quite disappointing.

Not every teacher expected students to be familiar with these skills.

Category 3: Determine the accuracy and validity of sources/methods (11 negative quotes; 0 positive quotes) and Category 4: Structure, manage and protect digital content/data (2 negative quotes; 0 positive quotes)

Only four interviewees gave quotes related to students' skills at determining the accuracy and validity of sources/methods, category 3 of the DRS framework. The majority of the negative quotes in this category are related to students' insufficient ability to assess sources for reliability (9/4), that they should take more time during this step. Dean (Lecturer Physics practical):

> What they are just not used to is to properly review sources. So the moment you don't train them and before we trained them, they came up with a lot of Wikipedia, that you think: yes guys, gosh. I mean, you've already written a research paper in secondary education.

There were not many quotes about students' ability to determine the accuracy and validity of sources/methods, category 3, and to structure, manage, and protect content/data, category 4. Moreover, all were negative.

Category 7: Share and present content/data (3 negative quotes; 5 positive quotes)

As can be seen in **Figure 1**, students' ability to share and present content/date was the only skill with more positive than negative quotes. The positive quotes concerned presentation skills, such as oral proficiency and designing a poster or slide show (5/4).

Ratings of Importance and Satisfaction

Figure 2 gives the distribution of the ratings from the two closed-ended interview questions. The interviewees rated the students' ability to apply digital skills in software applications such as Word, Excel and PowerPoint with an average grade of 7.4 (SD = 1,1). This indicates that they were sufficiently satisfied with the students' ability. When asked about the importance of these skills, the interviewees rated their importance at an average of 7.6 (SD = 1,8).

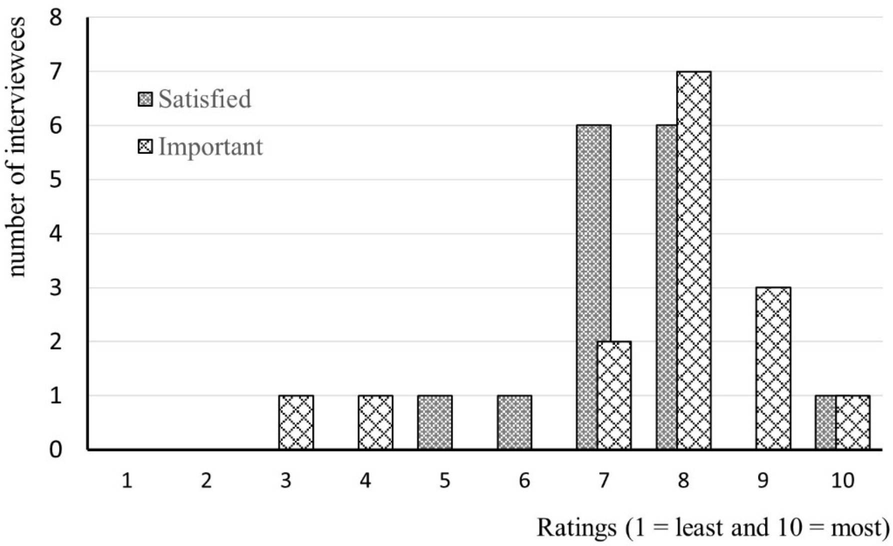

Figure 2. Frequency distribution of the ratings of importance of students' ability and satisfaction with their ability to apply digital skills in software applications (N = 15). 1 = least satisfied/important and 10 = most satisfied/important

Suggestions Offered

Each of the 15 interviewees was also asked what they would like to add to the secondary education curriculum in the field of DRS. In answering this question, six interviewees did not mention a research skill, but a digital skill: being able to work with a word processor, a program to process data, or a search engine.

Six of the 15 interviewees would want students in pre-university education to be able to process data better, which is related to category 5 of our DRS framework. Three interviewees explicitly mentioned working with Excel and 3 interviewees wanted students to be able to program. Nigel (Program director and associate professor of Engineering Physics) said:

> I actually don't understand why they use Coach in high school and not just very simple programming language with Python scripts. If you can do Python, then every company will say, "oh nice that you can program in Python".

Four out of 15 interviewees wanted students in pre-university education to learn to write a coherent story better, which is related to category 6 of our DRS framework. Four of the 15 interviewees also stated that they want students to be able to assess the quality of sources, which is related to category 3 of the DRS framework.

In addition, two interviewees mentioned points that were partly related to DRS. They wanted students to be able to combine the knowledge and skills from several subjects, so that there is a connection between them when formulating sentences in a report.

CONCLUSION

By structuring and comparing both RS and DLS in pre-university education, we formulated seven categories in a framework for DRS: (1) Browse, search and filter information; (2) Gather, measure and collect digital content/data; (3) Determine the accuracy and validity of sources/methods; (4) Structure, manage and protect digital content/data; (5) Analyse, transform and visualise content/data digitally; (6) Write a research paper using digital tools and (7) Share and present content/data.

Our research question was: For which digital research skills (DRS) do university teachers perceive a gap between the final level of secondary education and the required entry level for science studies?

Starting with the sub-questions:

SQ 1. Which DRS do university teachers consider important for starting science students?

The 15 interviewed academic science teachers and professors generally agreed on the importance of writing skills using digital tools. These skills include the ability to format text, using styles and headings, subscripts and superscripts or to edit formulas, the ability to use captions when inserting figures and graphs, their references and explanatory notes in the text and the ability to write and construct a paper that has a logical structure. All of them also valued skills with charts, axis labels, error bars and trendlines, and the ability to program a script to analyse data. Most of them mentioned the use of search engines, maintaining a source list, and assessing and selecting sources for reliability and credibility.

SQ 2. What are university teacher perceptions about the level of DRS of starting science students?

The university teachers' perceptions about students' DRS proficiency were mostly negative, with the exception of skills in elementary software applications such as Word and PowerPoint. The primary problem concerned the writing of a research paper using digital tools. Students lack the ability to structure a paper and lack skills in referencing, use of captions and formatting. Despite the fact that students are able to draw adequate graphs on paper (Pols et al., 2021), displaying graphs digitally remains difficult. Similar to Sadikin et al.'s (2021) findings, many students were found to have insufficient experience with using spreadsheets, e.g., in processing data, axis labelling, drawing of a trendline, etc. However, consistent with the results of earlier studies (Hyytinen et al., 2017; Rakedzon and Baram-Tsabari, 2017; Salisbury and Karasmanis, 2011), the interviewees note big differences between individual students in this respect. Furthermore, students are reported to demonstrate difficulties browsing, searching and filtering information, consistent with Walraven et al.'s (2008) and Julien and Barker's (2009) observations. In contrast, the interviewees were mostly satisfied with students' level of sharing and presenting content/data.

All but one interviewee experienced a gap from secondary to university science education and suggested adding DRS or both DRS and DLS to the secondary science education curriculum. Three interviewees even mentioned explicitly that students should be able to program in Python and draw graphs in Excel when starting science studies.

In answering the main research question, our results showed that there is indeed a gap in DRS between the final level of secondary education and the required entry level for science studies. The perceived gap is most pronounced in digitally analysing, transforming and visualising content/data and in writing a research paper using digital tools.

DISCUSSION

Limitations

The sample of interviewed university teachers was exclusively from Dutch universities and thus solely reflects the situation in the Netherlands. However, the general literature cited in the introduction showed that the issues addressed are encountered in other countries as well (Akuegwu and Uche, 2019; Care et al., 2018; Wollscheid et al., 2021). The sample size was relatively small and there is a possible availability bias because the interviews were on a voluntary basis. The interviewees have not been informed about the DRS framework. It is to be expected that the quotes would have been of a different nature if the interviewees would have been informed on the framework beforehand. However, the fact that the framework was not mentioned does give the interviewee more freedom in approaching the subject.

The two closed-ended questions during the interview (questions 5 and 6) essentially were about digital skills rather than DRS. Also in this case, openness of the interview was preferred over completeness of the concepts. The fact that certain aspects of DRS were not mentioned spontaneously is in itself an indicator of the perceived importance of these aspects. Specific software used in science studies (e.g., modelling and probe software) was not mentioned in the questions. We focused on the more elementary software all students in secondary education are likely to encounter.

The university teachers were, however, consistent about the gap in DRS; further research with broader samples in different countries could confirm our result.

Our proposed framework for DRS was also based on the most-cited works in the field and the existing frameworks showed considerable overlap, so that we expect to have arrived at a universally applicable framework for DRS.

Implications

Students appear to be especially lacking in skill on data processing and writing a research paper. More attention for these skills in secondary science education could help to bridge this gap. This could be reflected in the learning goals in the syllabi of science subjects in secondary education, for example, by simply rephrasing 'partly with the help of ICT' to 'with the help of ICT', or by adding the skill of drawing a trend line with the help of ICT and being able to digitally process and format different parts of one's research in a research paper.

Future research

Our study provides a step towards identifying national and international digital research skill levels to bridge the gap from pre-university to academic science education. An important next step will be to analyse to what extent pre-university students actually apply skills from the DRS framework, such as the use of resources, citing, paraphrasing and the extent to which graphs, axis labels and captions are used or the extent to which students use the formula editor, sub/superscripts, styles and headings in research assignments. Our proposed framework could serve as a guiding instrument in this regard. In this way, concrete steps can be formulated for pre-university teachers and students to bridge the gap in DRS when making the transition to academic science study.

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An Exploration of Impostor Syndrome in STEM and STEM Self-Efficacy in Adolescent Learners from a Teacher's Perspective

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ABSTRACT

Over the years, there has been a surge in the demand for a proficient STEM (Science, Technology, Engineering, and Math) workforce to occupy the proliferating STEM job vacancies worldwide. The STEM workforce must be expanded in order to fill this gap. However, the reputation of STEM learning as being arduous has proven to be a deterrent to students' interest in the pursuit of STEM careers. In an expounding qualitative study, three STEM teachers were interviewed for the purpose of examining STEM Impostor Syndrome (IS) and STEM Self-Efficacy (S-SE) from a teacher's perspective. Findings suggest that teachers are sentient of the manifestation of STEM IS among students. Teachers noted that STEM IS poses a significant challenge for their interactions with students in the classroom, and also suggested that STEM IS is inversely proportional to S-SE.

Keywords: self-efficacy, STEM, STEM learners, impostor syndrome, career

INTRODUCTION

Careers and jobs in STEM (Science, Technology, Engineering and Math) are rapidly expanding around the globe, so it is imperative that countries across the world produce a competitive STEM workforce to help support that industry (WEF, 2020). However, the reputation of STEM subjects as being academically difficult discourages students from the pursuit of STEM degrees (Funk and Parker, 2018), creating a situation which requires an increasing demand for a competent STEM labor force; a demand that has been met by an inadequate supply (Jang 2016; Wang and Degol, 2016). The mismatch between supply and demand makes it crucial to discern the factors that serve as obstacles to learners' interest and pursuit of STEM careers (Blotnicky et al., 2018). Although individuals with STEM undergraduate degrees are generally paid a higher salary than those with non-STEM degrees, there is still a relatively low interest in STEM courses and careers, therefore leaving educators puzzled (Kennedy et al., 2021). To add some clarity to this issue, in the current study we sought out teachers' perspectives on the prevalence of STEM Impostor Syndrome (IS) in the classroom, and asked what implications, if any, are there for working with students who show signs of STEM IS. Teachers are often in a unique position to observe and interact with their students on a regular basis and may be more likely to notice when a student is struggling with these issues. Their perceptions of this relationship are important as they might notice indicators of IS and SE such as perfectionism, self-doubt, anxiety, and self-deprecation. A teacher who is aware of the relationship between IS and SE can use this knowledge to respond to their students in a supportive way. If IS and SE are related, and a teacher notices that a student is experiencing IS, they can provide cues or strategies to help the student increase their sense of self-efficacy (SE) and overcome their negative thoughts and feelings.

The term IS was introduced by Clance and Imes (1978) in reference to the inability to internalize success due to one's conviction that they are not intelligent enough to have accomplished a particular task, and so their success is unwarranted. SE on the other hand, is a person's belief in their ability to perform a task to the expected degree (Bandura, 1977). Our study focused exclusively on STEM self-efficacy (S-SE) beliefs since these beliefs differ by domain. Individuals' SE beliefs relate to their perceptions about their capabilities in specific settings. A person's level of SE, in this case SE in STEM, may contribute to their decision to pursue STEM subjects and a STEM career, and if S-SE is low, it is likely to trigger impostor fears. This implies that individuals who question their abilities in the implementation of their goals would prefer to avoid a field that makes them think they do not belong. The possible connection between an individual's career choices and/ or interest, is supported by the Social Cognitive Career Theory (Lent et al., 1994), which will be discussed further in the literature review.

Persons with IS tend to disparage their success and attribute it to external factors such as luck, an educator's leniency, hard work, among others while also magnifying their failures and viewing them as proof of their inadequacy and unintelligence (Wiener, 2008). The features of IS include the inability to internalize academic success, belief of their own intellectual disingenuousness, fear of being exposed as a failure, and the attribution of any successful academic performance to external factors and never their own ability (Clance and Imes, 1978). STEM IS as referenced in this study is the presence of IS in STEM subjects.

According to extant research on the subject, STEM IS could be common among early adolescent learners (Caselman et al., 2006; Collins et al., 2020). The study of STEM IS in early adolescents as well as how it may possibly be triggered by IS is imperative because of the cognitive vulnerability at that young age. If low S-SE contributes to the occurrence of STEM IS, this could support the idea that educators, through the teaching strategies they use, could reduce IS by increasing S-SE, hopefully increasing the number of students who believe they are skilled enough to pursue STEM degrees and ultimately join the workforce.

Although most previous studies on IS have involved graduate students and professionals, we chose to delve into IS in early adolescents as this, according to Social Cognitive Career Theory (Lent et al., 1994), may be where the self-perception of IS first manifests. Also, due to the domain-specificity of SE, we focused on the phenomenon in STEM only. Adolescence is a period of psychosocial development from the beginning of puberty to adulthood (10-19 years old). The uncertainty of the cognitive, psychological, and temperamental changes can create a very sensitive and precarious developmental stage for young adolescents because they are neither children nor adults (Hamburg and Takinishi, 1989). Blakemore (2019) described the period of adolescence as an especially vulnerable time in development where people are especially susceptible to mental health problems such as anxiety and depression. It was noted that an unhealthy mentality that begins in adolescence can often persist into adulthood. IS, as a mental state (Clance and Imes, 1978), tends to breed anxiety that stems from self-doubt, while serving as a gridlock that stifles students' academic and social progress (Schock, 2019). The manifestation of IS in adolescents, therefore, could create situations that negatively impact students' progress, especially in STEM domains.

As stated, majority of previous studies have measured the relationship between IS and SE in graduate students and professionals (Tao and Gloria, 2019), and to our knowledge there are hardly any published studies on the ways in which S-SE and STEM IS hinder adolescent STEM career interest. Comprehension of the connection between the two psychological constructs is essential due to its potential to suggest an indirect solution to the pernicious mental health phenomenon that is STEM IS among lower secondary school students. According to Schunk and Meece (2006), students' academic choices, performance and participation are influenced by what they believe about their ability to perform the task successfully. The self-doubt that self-imposed impostors grapple with could possibly be likened to low SE, and the discovery of a negative relationship between STEM IS and S-SE could indicate that in order to increase S-SE, and potentially positively impact the STEM workforce, educators could focus on countering IS in early adolescent learners. Our study sought to explore the manifestation of STEM IS in learning, as well as the ways in which this concept is as a result of an individual's S-SE. The next chapter provides an overview of foundational literature as well as operational definitions of these self-perceptions.

LITERATURE REVIEW

Impostor Syndrome and STEM Self-Efficacy

The aim of this study was to give an in-depth investigation into the manifestation of STEM IS and S-SE in the classroom based on teachers' interaction with their students. A person convinces themselves they are an impostor when they do not believe they deserve the academic accomplishments they have, and they choose to credit external factors for their success rather than it being as a result of their own intelligence and capabilities (Clance, 1985). IS is a mental state (Clance and Imes, 1978) whereas S-SE is a self-belief, however, both have known associations with academic outcomes (e.g., Thompson et al., 1998; Kolo et al., 2017). That being said, the ways in which the two concepts are connected is not fully understood, and not much research has explicitly and specifically studied how IS and S-SE are associated, nor has there been an examination of if and how teachers perceive these constructs in their classroom. A critical investigation of these concepts can help with the comprehension of the ways in which S-SE contributes to the prevalence of STEM IS from a teachers' perspective while exploring the implications for classroom instruction.

Impostor Syndrome in Adolescents

Due to the scarcity of studies that center on the phenomenon of IS in early adolescents and the potential impact IS might have on stifling academic progress, this study focused on the manifestation of IS and SE in this demographic. Although majority of research about IS has focused on young adults and adults, possibly due to the superior cognitive ability of adults to self-examine, adolescents have been said to be cognitively developed enough to be introspective (Winters et al., 2021; Blakemore, 2012). In their breakthrough study of the Impostor Phenomenon, Clance and Imes (1978) posited that during the developmental period of adolescence, they struggle with the internalization of their self-perception. This is an indication of the presence of IS at that age, considering the inability to internalize one's concept or views about themselves is one major hallmark of IS. Caselman, Self, and Self (2006) in their study of 14–18-year-old adolescents found evidence of IS and also that it occurs at a similar rate as adults. Over the years, there have been very few studies of IS in adolescents. Nevertheless, those that do exist suggest that some form of IS is present in that age group. For instance, Stahl et al. (1980) in their research revealed that 55% of African American high school girls attributed their academic success to external factors, and not as a result of their own competence or intellectual capacity. High-achieving Asian high school students were also found to generally exhibit symptoms of IS, although these symptoms are said to be generated mostly due to their family educational values rather than because of the individual's self-confidence (Kang et al., 2021). While these studies provide evidence that IS is present in adolescents, they all fail to explore the academic implications from the perspective of a teacher.

Importance of Self-Efficacy

SE has been identified as possibly the most imperative element of a student's self-belief system, in their engagement and perseverance in STEM learning (Concannon and Barrow, 2012). Brown et al. (2016) suggested that it is imperative to assess and comprehend an individual's SE in order to comprehend the factors necessary for the study of STEM as well as the sustenance of STEM learning.

According to Dweck (2016), Lent (2016) and Zimmerman (2013), mindset plays a role in how individuals perceive success or failure, and SE is influenced by one's interests, outcome expectations, and knowledge of self-regulatory behaviors. Individuals are more likely to feel confident in their ability to succeed when they are interested in the task, have a clear understanding of what the outcome will be, and have the necessary skills and strategies to regulate their behavior. Motivation is also a key component of this framework, as it is what drives individuals to pursue their goals and engage in self-regulatory behaviors. The authors also posit that motivation is influenced by SE, interests, and outcome expectations, as well as an individual's mindset. In spite of the role of interest in our self-regulatory behaviors, this study did not explore this concept. We only explored teachers' perceptions of the relationship between STEM IS and S-SE. Woolf et al. (2020) found that teachers who are aware of IS and its potential impact on student success are more likely to use supportive language and strategies that encourage student SE. They went on to highlight the importance of teachers' perceptions and responses to IS, as they can have a significant impact on students' academic progress. By providing support and strategies that help students overcome feelings of self-doubt and inadequacy, teachers can help students build a more positive self-image and achieve greater success in school and beyond.

Wigfield, Tonks and Klauda (2016) found a strong relationship between middle school students' S-SE and their persistence in STEM learning. They also found that students who reported higher levels of S-SE were more likely to persist in STEM learning, even when faced with challenges or setbacks. These findings reiterate the fact that students' STEM engagement and success can be encouraged and improved with the increase of their SE, which goes to show that SE is the major component of the decision to engage in STEM learning. Research by Mau and Li (2018) support these findings with their study which reported the STEM career goals of ninth graders being predicted by science SE. They, also found there to be a significant prediction of STEM career aspirations by math and science SE.

Differences Between Impostor Syndrome and Self-Efficacy

SE and IS are distinct constructs, but they also have some similarities that support the hypothesis that IS could impact S-SE. One difference is in their respective definitions. The concept of SE was introduced by Psychologist Albert Bandura in his Social Cognitive Theory, which explained the effect of environmental, cognitive, and behavioral factors on learning (Bandura, 1991). In this theory, Bandura described SE as an individual's belief in their own capability in effectively implementing the strategies required in achieving a goal. While SE is defined as a person's self-perception of their capabilities, and can be either positive or negative (Bandura, 1991), IS is a negative mental state only, where a person nullifies their accomplishments and /or success and attributes success to external factors such as luck (Clance and Imes, 1978). Both can be a byproduct of an individual's personality trait or as a result of other environmental factors. Research has found IS to be positively correlated with at least one of the Big Five Personality traits, namely Neuroticism, and these studies purported that the relationship is specifically derived from a particular facet of neuroticism, which is anxiety (Ross et al., 2001). Similarly, other findings indicate that SE is negatively linked with Consciousness and Neuroticism which are two of the Big Five Personality traits, and positively associated with Extroversion, also another of the Big Five traits (Abood et al., 2020). Just as an inefficacious person doubts their abilities with regards to the successful performance of tasks, an individual with IS is doubtful of their competence in performing a task. Therefore, following the attainment of their goals, they are unable to internalize this achievement and would rather attribute it to hard work and /or luck.

Relationship Between Impostor Syndrome and Self-Efficacy

The three dimensions of IS delineated by Clance and Imes (1978) are doubts about one's capabilities (SE), inability to internalize success (IS), and the attribution of one's accomplishments to chance (IS). This explanation of IS supports the claim that IS and SE are associated in some way. Tarieh (2021) in their assessment of the relationship between IS and SE found a negative relationship between the concepts, which means that the lower an individual's SE, the more likely they are to develop IS. Gottlieb et al. (2020) postulated that IS is likely to impact a person's SE as well as their potential success. Surprisingly, we found one study that discovered the concepts to be positively linked, with 91% of the self-efficacious students attributing their successful performance to other factors but not themselves (Yamini and Mandanizadeh, 2011). A positive connection indicates that the higher a person's level of S-SE the more likely they are to exhibit STEM IS. This finding may be an inaccurate report or an artifact of data collection because IS refers to a negative self-perception and SE is also concerned with self-belief. It seems more logical for any extant relationship between them to be the opposite (negative) since SE is considered a negative psychological state when it's low and a positive one when it's high, therefore when SE is low, there should be an increase in IS, thus indicating there is a negative relationship.

Proposed Study

The Social Cognitive Career Theory suggests that S-SE influences the career choices that students make. It is imperative that students are encouraged to be efficacious in their STEM capabilities because this is essential to their interest and perseverance in pursuing STEM careers. Teachers and students both can play an active role in increasing students' S-SE and reducing STEM IS. To this end, a qualitative study was conducted to illuminate the prevalence of STEM IS among adolescent learners through an exploration of STEM IS and S-SE from a teacher's perspective. The in-depth interviews will contribute to scarce literature on STEM IS and S-SE. Analysis was guided by the following research questions:

Research Questions

1. In what ways do teachers see IS manifest in the classroom?
   1a. What are the implications for their interactions with students?
2. How do teachers perceive the connection between STEM IS and S-SE?

METHODS

Qualitative

Participants

We reached out to K-12 teachers via email to request their inclusion in our study. They were recruited from Washington State University. Our participant from Guam was an elementary school science teacher with six years of experience teaching in public schools. Teacher from Central America taught first to fourth grade with three years of private school experience, while teacher from North America taught elementary school with ten years of private school experience. They each consented to participate in three separate 30-minute interview sessions conducted via Zoom within one week. All three identified as female. The diversity in our interview sample was a strength of this study.

Interview questions

Participants were asked questions in relation to their perceptions about the prevalence of STEM IS and S-SE among students in their STEM class. Examples of questions were *"In what ways do you perceive a connection between students' S-SE and STEM IS? In what ways do you think students' beliefs about their STEM capabilities is related to their future career interests? What role did your perceived S-SE as an early adolescent have in your decision to teach STEM in school?"*

Analysis

We employed an inductive approach in order to generate themes from the participants' responses. Memos were written during the interview discussions. Participants were not given access to the questions prior to conducting the interview but we ensured that they were cognizant of the concept of IS and SE in STEM. With participants' permission, all interviews were recorded for transcription purposes and deleted immediately after this was concluded. The coding process adopted the use of reflexive analysis which has been described as the method of thematic analysis involving the researcher's own interpretation and identification of specific patterns as well as the conceptualization of themes (Braun and Clarke, 2019).

Following each interview, the researcher worked on reflexively coding and thematically analyzing responses in order to determine the teacher's viewpoint regarding the prevalence of STEM IS, and the ways in which STEM IS and S-SE work together to influence the learner's self-perceptions and their career interests. During the reflexive coding process the researcher's positionality was acknowledged and considered. It should be noted that the researcher is a scholar who struggled with feelings of STEM IS and low S-SE as an adolescent. Specifically, she is a bilingual Educational Psychology master's student who grew up in Ghana, West Africa in a family with divorced parents. The researcher is currently an international student who as at the time this study was being conducted, had lived in the United States for seven months. It is imperative to state the researcher's positionality as an international student who experienced STEM IS as an adolescent, as this experience could have influenced the types of questions the teachers were asked, and may have swayed the discussion to generate more responses about the STEM IS prevalence.

RESULTS

Findings

Findings from interviews with a science teacher, a math teacher, and a general education teacher generated an in-depth understanding of the manifestation of STEM IS and S-SE in the classroom. These interviews allowed us to gain further insight into teachers' viewpoints regarding students' STEM IS, S-SE and STEM careers, as well as provide possible explanations for students' aversion to STEM subjects (Kopparla and Saini, 2022). Developed with the use of thematic analysis, the findings from this study are categorized into five distinctive themes (Braun and Clarke, 2006). They include the following: *Inversely proportional relationship, Intense cognitive effort requirement, STEM intelligence narrative, S-SE contributes to motivation, and S-SE influences career decision.*

Inversely proportional relationship

Information gathered from the interviews regarding teachers' perceptions about the topics showed that they perceive students' STEM IS to be impacted by their S-SE. The theme "inversely proportional relationship" was how the teachers described the ways in which students' beliefs about their STEM capabilities are affiliated with their own perception of their science or math intelligence. An inversely proportional relationship between STEM IS and S-SE indicates that the higher a student's S-SE, the less likely they are to harbor STEM IS. To put it another way, a learner's doubt about their STEM abilities can influence their self-perception about the role their intelligence played following a successful task completion. Specifically, one participant – a math teacher, stated that students may believe "if I can actually do this then I'm a science person. If not then it's not for me". They also elucidated that this thought pattern was not always the same among all students and provided examples of students who were confident in their cognitive ability to perform but yet doubted they were intelligent enough to be consistent. Another crucial finding from this math teacher was that "IS tends to be less when students actually have a firm understanding of the math topics we learn". This emphasized the inversely proportional ways in which teachers believe STEM IS and S-SE manifest together in STEM learning among adolescent learners.

Intense cognitive effort requirement

Findings from the interviews with teachers in some way echoed the sentiments expressed in the literature by Funk and Parker (2018), thereby shaping and reinforcing our problem statement regarding students' avoidance of

STEM fields due to their perceived difficulty. When asked about the reason for their students' aversion to STEM learning and engagement, they discussed how students dislike the "difficulty of math learning", as well as the "cognitive effort and dedication" that is required for the mastery of STEM subjects.

A particularly noteworthy discovery was made by the general education teacher who observed that students often developed a dislike for math or science based on the interests of the parent they identified with the most. These students, having witnessed their parents' struggles in these subjects, eventually resigned themselves to the belief that they were incapable of learning math or science. This knowledge further solidified their negative perception and contributed to their low SE in math or science, while also influencing their sense of belonging in the field. Feeling like they didn't belong became a significant characteristic of their experience, aligning with the concept of IS. In conclusion, the findings strongly suggest that adolescent learners' aversion to STEM subjects, particularly math and science, stems from the perceived difficulty in comprehending and mastering these subjects.

STEM intelligence narrative

The theme of the STEM intelligence narrative developed from discussions which reflected the idea about STEM learning and potential STEM careers as being suitable only for precocious learners who possess innate STEM capabilities. One math teacher disclosed that "the narrative about STEM influences STEM career interests". They elaborated on the narrative and/or misconception their students have about careers such as astronomical engineering, mathematician, scientist, as being attainable solely for those with "inherent 21st-century skills". Students with low S-SE do not show interest in STEM careers when they do not believe they possess the cognitive skills to excel in them. According to one teacher, students tend to show interest in STEM careers when they are in elementary school and wish to become an astronaut for instance, but that "interest begins to decline as they advance into higher grades and fail to develop mastery skills in the science and math subjects needed for those careers". The failure to develop the mastery experience needed for the sustenance of those STEM career goals and interests leads to a low S-SE and the eventual disinterest in a STEM career.

S-SE contributes to motivation

When asked about the differences they observed between students who exhibited a higher level of S-SE and students who were not efficacious in STEM learning, the common theme was "motivation". Speaking from their individual experiences with adolescent learners, they recalled those with a lower S-SE having a significant lack of motivation to engage with the "math, science, and technology-related subjects I taught in general education". Whereas students who possess confidence in their cognitive ability to perform well view learning tasks as "challenges", learners who have doubts about their cognitive abilities, view those tasks as "threats". An important finding was that those with low SE in STEM learning would always be more concerned with their grades and performance than the actual comprehension of the subjects. This is an implication that such learners with low S-SE were performance-oriented whereas those with a high S-SE were mastery-oriented.

S-SE influences career choice

Finally, as an overarching theme, teachers emphasized the role of learners' S-SE in their career choices. This discussion took the retrospective route with teachers reflecting on their own experiences and the ways in which their S-SE impacted their career choice. All teachers agreed that their S-SE in middle school and through higher education is the reason they chose to teach "math" and "science" subjects. One teacher for instance, established that their love for science was somewhat innate, but was also fortified by the encouragement from teachers in support of their ability to engage with the science topics taught in class. The only reason this teacher chose to teach Biology instead of study medicine as was the initial plan was because they were unable to handle the sight of blood; "teaching science was a close second and I'm glad I get to teach a subject I'm great at". "My mother was a math teacher, and I grew up loving math as well as having straight As in it" was the response from another one of the teachers we interviewed. Participants who mentioned having a high S-SE, confirmed that they never experienced any feelings of STEM IS possibly because they were thoroughly intrigued with the subject and their belongingness was confirmed by excellent academic performance. From an early age in elementary school, they knew their math performance was exemplary and thus their SE in the subject was high. They reported never struggling with IS in math learning, possibly due to their high SE in the subject as well as the influence from their mother who also taught math. This high SE in math served as a catalyst for their future participation in several math competitions. The choice to teach math was based on their love for tutoring others in a subject they perceived themselves to be cognitively equipped enough in to teach.

Teacher's interaction with students with STEM IS

Now, in response to the research question regarding teacher's interaction with students who exhibited signs of STEM IS, two out of three teachers recalled having a fairly more difficult time working with such students in comparison with students who show no signs of STEM IS. Although one teacher admitted to not taking any notice of STEM IS among their students, the other two spoke on their own teaching and learning experiences. According to one participant, "I had one student who hardly ever had good grades in my class, so much so that the few times she actually scored a high grade, she thought I was just being lenient because I felt sorry for her. I was never able to convince her otherwise". Another professed that students seem to retreat into their shells and become avoidant while class is in session. Activities that involve active interaction and learning with other students is met with resistance because students are embarrassed about being potentially unable to perform as well as their peers. According to one teacher, this fear stifles their "productivity and participation in class" while making it wearisome and taxing for the teacher to provide them with the obviously needed assistance. "The teacher can only do so much. It can get a bit frustrating. I noticed that some students are so firmly set in their negative perception of themselves that they stop trying".

DISCUSSION

STEM education is essential for the preparation of competent workers in order to fulfil the 21st-century demand for collaborative, communicative, and innovative critical thinkers who are to become experts in STEM fields (Widya et al., 2019). In recent times there has been a significant increase in the demand for workers that are proficient in science, math, technology, and engineering, but the supply has not been sufficient in meeting this demand (Jang 2016; Wang and Degol, 2016). The study of STEM IS is scarce, and its association with S-SE has yet to be meticulously explored and discussed among adolescent learners or with educators. The purpose and rationale of this study was to explore the manifestation, career and academic implications of STEM IS from a teacher's perspective. This will be helpful in providing further insight into possible reasons for the sparse supply of a competitive STEM workforce to meet the escalating demand (Jang 2016; Wang and Degol, 2016). In the current study we substantially focused on the connection between STEM IS and S-SE and also discussed the concepts of STEM IS and S-SE with teachers to gain insight into if and how these conceptions manifest in the classroom.

Presence of STEM Impostor Syndrome

The first goal of this study was to assess the prevalence of STEM IS among adolescent learners. As previous analogous studies on IS in adolescents (Chayer and Bouffard, 2010; Tarieh, 2021) have stated, although it may be with less intensity, early adolescents are prone to Impostorism. To our knowledge, hardly any studies have identified the presence of STEM IS among early adolescents in school.

The findings identified the prevalence of STEM IS in adolescent learners based on teacher's reports. This is in support of our primary research question which sought to explore the manifestation of STEM IS among adolescents. The results suggest that adolescent learners who have doubts about their competence in their successful performance of STEM tasks (Bandura, 1977) tend to also harbor uncertainties regarding the significant role of their own intelligence in accomplishing those tasks. This finding is in accordance with similar studies (Tarieh, 2021) that described in their assessment of the relationship between IS and SE a negative relationship between STEM IS and S-SE. This suggests that the lower an individual's SE, the more likely they are to develop IS.

Interviews with teachers

Discussions with the K-12 STEM teachers afforded us the opportunity to explore STEM IS from a teacher's perspective, while also giving us insight into the ways in which it manifests in their respective classrooms. In response to our first qualitative research question, teachers' perceptions of the ways in which STEM IS has evinced among students in their classroom was discussed. Findings suggest that students with low S-SE tend to avoid participating in group assignments or activities because of the fear of being discovered as unintelligent. This finding supports another which found that individuals struggling with IS in a field or subject have such beliefs of inadequacy that they tend to avoid situations of perceived failure (Enget et al., 2020). As mentioned at the beginning of this study, individuals with IS struggle with the anxiety of being exposed as intellectually disingenuous – a significant characteristic of the seemingly innocuous and almost trivial IS. Teachers reflected on their career choices as being unequivocally influenced by self-perceptions regarding their STEM capabilities as well as their belongingness in the field.

With regards to our question about the connection between STEM IS and S-SE, our finding suggests that teachers perceive that STEM IS and S-SE jointly influence students' behavior and interaction with STEM subjects and potential STEM careers. This study's findings are in support of Tarieh (2021) who reported that the more a student doubts their STEM capabilities, the more anxious they are about being discovered as intellectual frauds. When students have a firm grasp and comprehension of the topics they learn, and when they are able to challenge their cognitive abilities in studying these subjects, they are less likely to show signs of Impostorism in this domain. Participants provided examples of students who doubted their cognitive math abilities regardless of their good grades. In some way this reiterates the viewpoint of another participant who stated that students show signs of STEM IS when they have not yet mastered that particular STEM subject because they have only been concerned with their performance.

Limitations

The perspective-based nature of the study as well as the qualitative method it employs complicates its replication by other researchers. This denies us the ability to support the defense of its reliability for the purpose of increasing confidence in the merit of our results. Suffice it to say the results of this study may be subjective and may not be generalizable to the average STEM teacher's classroom experience, as well as that of the average adolescent student. Secondly, while the teachers in this study provided insight into how STEM IS is experienced by STEM learners, the study did not investigate the specific teaching strategies that participants may have utilized in the past to enhance their students' S-SE. To gain a deeper understanding of effective teaching methods in STEM education, it is recommended that future studies explore teachers' personal experiences and testimonies regarding the implementation of various successful teaching strategies.

CONCLUSION

In order to understand the factors that contribute to students' general disinterest in STEM careers (Funk and Parker, 2018), it helps to delve into the concept of mental states and self-perceptions. This is what inspired the study of STEM IS and S-SE among adolescents. In our study, we found that an individual's mental state (Clance and Imes, 1978) and self-perceived ability to learn can influence adolescent STEM learning. Therefore, it is vital that adolescent STEM learners are supported early in their engagement with STEM subjects.

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Review Article

Parental Involvement in STEM Education: A Systematic Literature Review

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ABSTRACT

STEM education has been a significant subject in the world and it has been studied by researchers. But parental involvement to STEM education hasn't been on the agenda enough. In this study, findings were reached by examining 24 studies determined by literature review and PRISMA criteria. When analysis on the studies; it was concluded that there was an increase in 2021, the most in article type were written, they were mostly made in the USA, mostly primary school students were the subject, and the studies were mainly conducted in the survey model. It has seen that the subject of family participation in the STEM program (parent-child activities) is and their positively results frequently pointed. The positive effects of family career and their emotional characteristics on STEM success are frequently studied topics. In the theme of STEM activities at home, it was concluded that studies were conducted in which parents support STEM education mostly in terms of technology. Suggestions were made for performing STEM activities with the participation of families and investigating their effects.

Keywords: STEM, parent, family, involvement, participation, engagement, systematic review

INTRODUCTION

Informal practices are also very important besides formal practices in education. The literature on "informal education" or "Out-of-School-Time (OST)" learning is developing rapidly (Kruchten and O'Malley, 2016). Parental involvement is critical for academic success, motivation and self-efficacy (Varma, 2019). Parental involvement is effective in increasing the success of the child, especially at the pre-school and primary school level, where children are more easily affected (Desai, 2021). When Hill and Duke (2009) analyzed studies on parental involvement in secondary school; they determined that parent involvement positively affects success. Thomas et al. (2020) reported that parent involvement improves social, emotional and character development, reduces high school dropouts, improves attitude towards school, academic motivation, academic performance, and self-efficacy. An et al. (2018) had exemplified parents' participation in education in three areas: Behavioral, cognitive and emotional (**Table 1**).

Asoka De Silva et al. (2018) stated that home-based parent involvement has a stronger effect on students' motivation compared to school-based participation. Dani and Harrison (2021) state that with family participation science nights are important for teachers to get to know different families and ensure interaction. It is known that parents' introducing children to mathematical concepts early, guiding them to explore and talk can have a positive effect on children's mathematics learning (Zippert et al., 2017). Parental beliefs about children's math skills; it is a stronger predictor than the child's self-perception in mathematics and the child's previous mathematics

Table 1. Species for parental participation in education (An et al., 2018: 44)

Parental participation	Behavioral participation	Cognitive participation	Emotional participation
Home-based participation	Parent supervision and help parent-children communication	Providing cognition stimulating materials	Education beliefs and expectations
School-based participation	Parent-school communication participation in school activities	Participating in parent-school cooperation	
Community-based participation	Providing after-school privative tutoring opportunities or providing rides, waiting visiting community facilities	Participating in studies during private tutoring	

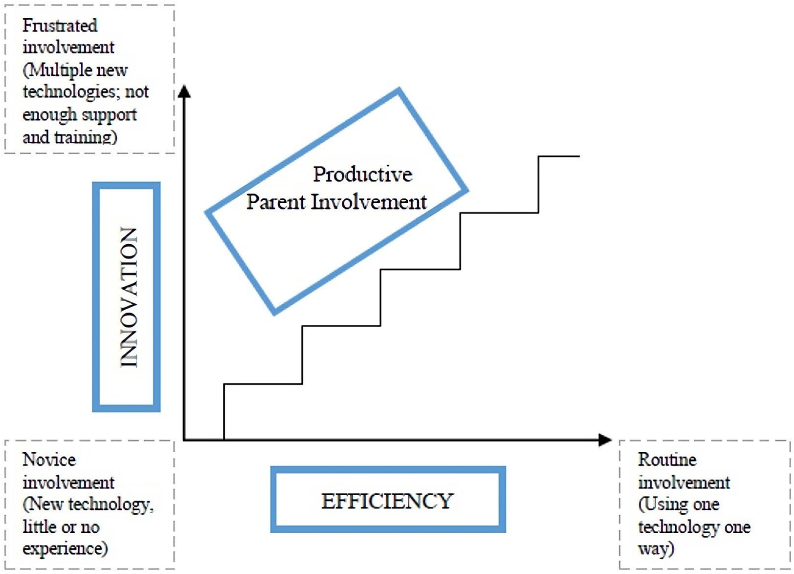

Figure 1. Technology user and productive parent involvement model (Varma, 2019: 6).

performance (Ansberry and Morgan, 2019). However, there are barriers related to the role of the teacher, demographic barriers, psychological barriers and school climate barriers in front of parents' participation in their children's education (Desai, 2021). More study is needed to examine the parent factor, which is so effective and predictive for the future.

Parental Involvement in STEM (Science-Technology-Engineering-Math) Education

Young children's everyday scientific thinking often occurs in the context of parent-child interactions (Crowley et al., 2001). The parents are less involved in their children's education in science than in reading and mathematics (Kaya and Lundeen, 2010). The family factor in STEM education offers an untapped resource that has the potential to increase students' motivation and success (Šimunović and Babarović, 2020). Parents' involvement in their children's STEM learning is a key determinant of a child's academic success in this area, but this can be difficult for parents without a STEM background (Sheahan, 2016).

Many parents believe that they are not qualified to do STEM activities with their children and that STEM can only be taught in formal school settings (Ansberry and Morgan, 2019). Barriers to home implementation of STEM education by families are that parents do not know how to lead their children to scientific inquiry, the thought that science education is only the school's duty, and the scarcity of resources supporting inquiry-based STEM education (Mei, 2017). There is a lack of resources for adult amateurs who will learn at home with their children (Sheahan, 2016). In some cases, the use of technology can help parents. Varma (2019) has developed a scheme for the balance of innovation and effectiveness in the model for the participation of parents with technology (**Figure 1**).

Fleer et al. (2020) state that STEM education starts from infancy and make suggestions about the work parents can do with their babies. Salvatierra and Cabello (2022), who examined the studies on parental involvement in STEM education in early childhood, stated that STEM activities can encourage parent involvement and positively affect children's STEM learning. The development of children's scientific literacy takes a long time, and the parent's accompanying them increases the effect (Mei, 2017). The suggestions are that for parent involvement in STEM (Ansberry and Morgan, 2019: 66):

- STEM learning in everyday situations (identifying geometric shapes of household items, swimming-sinking experiments, reading new inventions, designing creative solutions to everyday problems).
- To do activities by using the guides about STEM activities at home.

- To organize school activities with the concept of STEM Nights that parents can attend with their children.

In STEM education, children's interest, curiosity and imagination can be stimulated by the use of building toys, lego, board games, experiment kits, and robotics toys (Mei, 2017). Homemade materials can be prepared using nature in STEM education (Mei, 2017). Activities such as home cooking, grocery shopping, outdoor games can support children's science and math knowledge (Zucker and Yeomans-Maldonado, 2022). Christenson (2017) states that ways to solve naturally occurring real-world problems of children like scientists or engineers should be sought, and gives the following example:

> "Let's say the toast in the toaster is stuck. With the child, this problem can be solved like an engineer. 'Let's unplug the machine first for safety. Now how do we make the toast? The weather is very hot and we can burn ourselves. What tool do we need?' When the child answers 'fork', 'Yes, we use a fork to remove the toast and the problem is solved. It can be said that the fork is a technological tool."

Craig et al. (2018) quoted a university student named Katrina who chose a science career in their study, describing what she did with her scientist father, as follows:

> "It was not following a workbook. It was not 'do this,' 'do that.' It was 'let's try to figure out how to do this … It was exciting. I became pumped by science taught as inquiry … I had so many ah-hah moments … I would get so excited …"

Although STEM is mostly handled within the framework of the teacher-student relationship in school environments, there are also things for parents to do.

Problem Statement of this Study

While there are many important studies on parent involvement in science and mathematics education independently, it is limited in STEM learning (Thomas et al., 2020). Asoka De Silva et al. (2018) stated that parent involvement increased students' internal and external motivation and established a strong relationship with their science learning and self-efficacy. Despite the large literature on the impact of formal factors in schools on STEM education, the issue of how informal factors such as parents and social groups influence STEM education has been little studied (Plasman et al., 2021). Despite the importance of family-child interaction in STEM education, study in this area is quite scarce (Salvatierra and Cabello, 2022; Šimunović and Babarović, 2020; Thomas et al., 2020). There is also a gap in parent-child interactive learning activities (Sheahan, 2016).

Milner-Bolotin and Marotto (2018) had examined the literature on family involvement in STEM education and gathered under five headings: STEM education as a bridge between school and family, STEM education as a gateway for children's future economic success, STEM education as a tool to develop student communication skills, STEM education and applied inquiry, increase of students STEM participation. Thomas et al. (2020) had identified three themes in their study, which aimed to create an international perspective on parent involvement in STEM education: academic advantages related to parent involvement, culture as a context for parent involvement, and teacher/school perspectives and parent involvement. There is a need for research describing and summarizing the trends in research on family involvement in STEM education.

In this study, it has been tried to review as systematic, STEM education from a parent-child perspective and studies conducted in the international arena. The study sub-problems determined for this purpose are as follows:

1. What are the descriptive features of studies on parental involvement in STEM education?
2. What are the common results of studies on parental involvement in STEM education?

METHOD

A systematic literature review was made in the study. In the study, compliance with the PRISMA 2009 checklist was carried out and the criteria in the list were applied in the screening, study, synthesis and reporting sections (Moher et al., 2009).

The literature review of this study was conducted in April 2022. ERIC, Taylor & Francis, Elsevier, Springer, Google Scholar databases were searched. The study was limited to studies that define parental involvement within the framework of STEM education, and studies that deal with four sub-fields in an interdisciplinary manner rather than just science-technology, mathematics-engineering interaction were examined. Searches were made by writing "parental involvement", "parental engagement", "parental participation", "family participation", "family engagement", "family involvement" expressions next to the word "STEM" in the searches made in the databases. It was taken as the main criterion that the studies included direct parent involvement (behavioral, cognitive or emotional participation). The stages followed according to the PRISMA criteria are summarized in **Figure 2**.

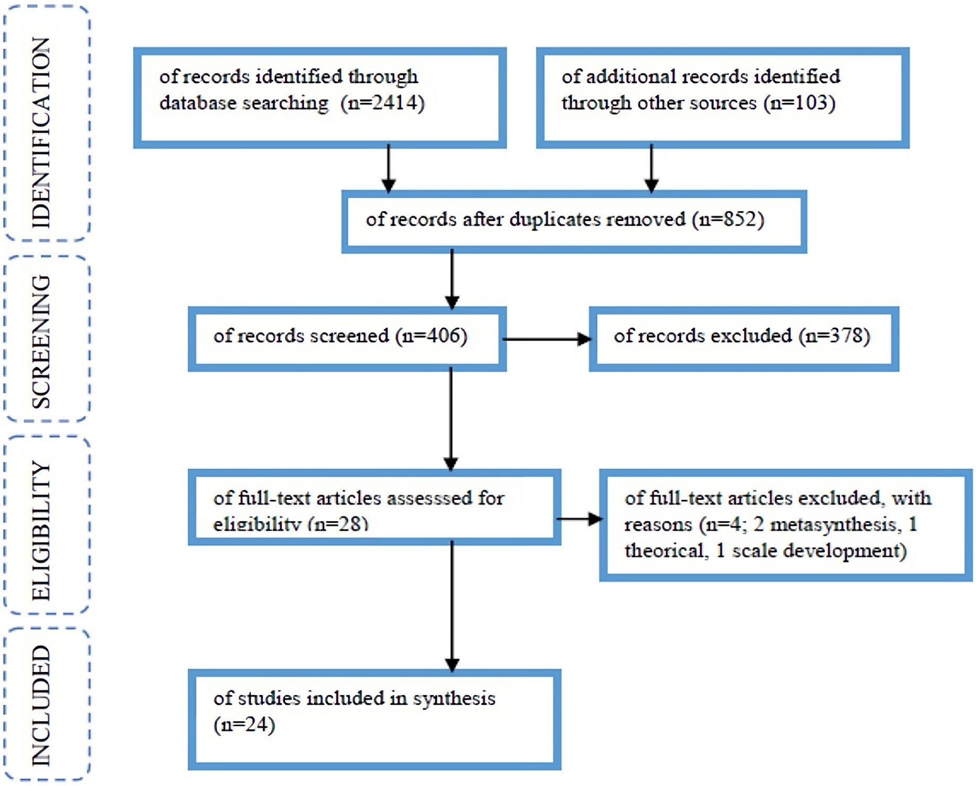

Figure 2. PRISMA flow chart in the study

In this study repeated recordings, meta-synthesis studies, theoretical studies, scale development studies, and studies that did not contain the direct parent involvement were eliminated. As a result of the eliminations, 24 studies were determined. The studies had classified according to year, study type, country, student level, number of participants, study model, data collection tools and main results (**Appendix A**). The analysis of the data in the research was made through descriptive analysis. The codes were transformed into themes in terms of the descriptive features and results of the studies. Comparisons between the themes were made and the findings were tabulated. In the findings related to the basic results of the studies, the type of activity and the effect of the activity were coded in the studies involving application. In relational studies, dependent and independent variables were coded. After the coding, the studies were organized under common themes.

FINDINGS

In this section, the findings that will answer the study problems are presented in tables and interpreted.

1) Findings for problem "What are the descriptive features of study on parental involvement in STEM education?"

The findings of the descriptive features such as the year, type, country of the study, the student group concerned, the number of people in the study group, and the model of the study are presented.

Table 2. Findings regarding the years of study

Years of study	Number of study (f)	Percentage of study (%)
2014	3	12.5
2016	2	8.3
2017	2	8.3
2018	3	12.5
2019	2	8.3
2020	3	12.5
2021	7	29.16
2022	2	8.3
Total	**24**	**100**

As can be seen in Table 2, studies on parent involvement in STEM education started in 2014. While significant increases have not been observed in the following years, it is seen that study has made a significant leap in 2021 (29.16%). The increase in studies in 2021 may be due to the increased interest in the subject, as well as the fact that the COVID-19 epidemic process brought the participation of families in education more on the agenda. The number of studies in 2022 is low since the survey was carried out in April, that is, in the first months of 2022.

Table 3. Findings regarding the type of study

Type of study	Number of study (f)	Percentage of study (%)
Article	17	70.83
Conference paper	5	20.83
Study report	2	8.3
Total	**24**	**100**

As can be seen in Table 3, most of the studies (70.83%) examined are in the type of articles.

Table 4. Findings regarding the country of study

Country of study	Number of study (f)	Percentage of study (%)
USA	17	70.83
China	2	8.3
Croatia	2	8.3
Canada	1	4.16
Sweden	1	4.16
Turkey	1	4.16
Total	**24**	**100**

As can be seen in Table 4, it can be stated that most of the studies (70.83%) on the subject are originated from the USA.

Table 5. Findings regarding the student group of study

Student group of study	Number of study (f)	Percentage of study (%)
Pre-school	7	26.92
Primary school	9	34.61
Secondary school	5	19.23
High school	5	19.23
Total	**26***	**100**

* As more than one student group was handled in 4 studies, the total number was higher than the number of studies.

As can be seen in Table 5, most of the studies (34.61%) focus on primary school children. However, the number of studies in other student groups is close to this.

Table 6. Findings regarding the number of people in study

Number of people in study*	Number of study (f)	Percentage of study (%)
1-10	4	16.66
11-50	6	25.00
51-100	3	12.50
101-1000	5	20.83
More than 1000	6	25.00
Total	**24**	**100**

* While categorizing the number of people, the number of a group was written if the students and parents participated together.

As can be seen in Table 6 that the number of people in the study group handled in the studies is between 10-50 (25.00%) and over 1000 (25.00%). It can be stated that there are large-scale studies and in-depth studies that work with small groups.

Table 7. Findings regarding the model of study

Model of study	Number of study (f)	Percentage of study (%)
Survey	10	41.66
Case study	6	25.00
Experimental	5	20.83
Longitudinal	2	8.30
Design-based	1	4.16
Total	**24**	**100**

As can be seen in Table 7, it is seen that the most preferred study model on the subject is the survey (41.66%).

2) Findings for problem "What are the common results of study on parental involvement in STEM education?"

When the results of the studies were examined, the prominent points were coded. In the coding, "dependent-independent variable" or "activity type-effect of the activity" were examined according to the type of research. According to the codes, 3 themes were revealed: "The effect of family participation (parent-child activities) in the STEM program" (11), "The effect of family history and perceptions in STEM learning" (8), "The effect of implementing STEM activities at home" (3).

Table 8. Findings regarding the common results of studies

Themes of general results of study (f)	Codes of affecting/affected situations in study (f)	
The effect of family history and perceptions in STEM learning (8)	**Independent variable** Family career and history (2) Parental support (2) Parent enthusiasm (1) Parental perception (1) Emotional involvement (1) STEM importance (1)	**Dependent variable** STEM success (5) STEM self-efficacy (2) STEM career (1) STEM importance (1) *One study addressed both achievement and self-efficacy
The effect of family participation (parent-child activities) in the STEM program (11)	**Activity type** Family Math-Science Days/Nights (4) STEM program (3) Tinkering lab (1) Engineering (1) Coding (1) Parent meeting (1)	**Effect of activity** Positive effects (6) Developing parent-child speech (2) Attitude and behavior development (1) STEM career (1) Participation in parent meetings (1)
The effect of implementing STEM activities at home (5)	**Activity type** Technology (2) STEM activity (1) Engineering (1) Homeschooling (1)	**Effect of activity** Positive effects (2) Parent roles (1) No positive effect (1) Developing parent-child speech (1)
Total (24)		

The themes were formed by coding the general results of the studies and presented in Table 8.

An important theme in study is the effects of family history and perceptions on STEM education. The effects of family career and emotional characteristics on STEM success are frequently studied topics. Parental support, enthusiasm, perception, STEM importance are among the variables studied. It has been reported that children have positive effects on STEM self-efficacy, STEM importance, STEM career, especially on STEM success.

When the themes created for the results of the studies are examined, it is seen that the subject of family participation in the STEM program (parent-child activities) is frequently studied. The positive effects of Family Mathematics and Science Days/Nights were determined in studies involving this theme. Applications were made through specially applied STEM programs, technology-intensive applications (tinkering lab, coding), engineering practice and parent meetings. In these studies, effects such as activation of parent-child conversation, development of behavior and attitude, and STEM career desire were observed.

In the activities for the implementation of STEM activities at home, the issue of parents' use of technology and support for STEM education was studied. It was seen that STEM activity; engineering activity and homeschooling studies were evaluated in terms of STEM.

RESULTS AND DISCUSSION

In this study, it was aimed to determine general trends by examining STEM studies containing parental involvement. The conclusion reached regarding the first study problem for summarizing the descriptive features of the studies is as follows: In the studies on parent involvement in STEM education, it was concluded that there was an increase in 2021, the most articles were written, they were mostly made in the USA, mostly primary school students were the subject, the studies were mainly conducted in survey model. The summary of the main results of the studies in response to the second study problem is as follows: It is seen that the subject of family participation in the STEM program (parent-child activities) is frequently studied. The positive effect of Family Math and Science Days/Nights is among the important issues. The effects of family career and their emotional characteristics on STEM success are frequently studied topics. In the theme of STEM activities at home, it was concluded that studies were conducted in which parents support STEM education mostly in terms of technology.

It is important that the literature on parental involvement in STEM education is an emerging topic. An international meta-analysis study on parent involvement in STEM education was conducted by Milner-Bolotin and Marotto (2018). This study differs in that it constitutes an international systematic analysis of parental involvement in STEM education. Systematic analysis studies on parent involvement in STEM education have been addressed from different perspectives: The effect of parental beliefs on STEM education (Šimunović and Babarović, 2020), the effect of parents' STEM career on children's STEM success (Thomas et al., 2020), and the effect of parents on STEM education in early childhood (Salvatierra and Cabello, 2022). Therefore, this study is important in terms of presenting a general perspective of parental involvement in STEM education.

Discussions about the descriptive features of the studies that were systematically reviewed in this study are as follows: Similarly examining STEM study on parent involvement in early childhood, Salvatierra and Cabello (2022) reported that most of its study was conducted in the USA. The result on increase in studies in 2021 may be due to the increased interest in the subject, as well as the fact that the COVID-19 epidemic process brought the participation of families in education more on the agenda. Indeed, the pandemic period has been a catalyst for eradicating the school-home separation, creating a compelling reason for parents to participate in pedagogy (Haisraeli and Fogiel-Bijaoui, 2021). The fact that studies on parental involvement in STEM education are mostly at primary school level is because it is thought that parental influence on children's education is greater at younger ages (Desai, 2021; Zippert et al., 2017). Although the fact that the studies are mostly in the survey model means reaching more participants, it also reveals the need for in-depth and experimental interventional studies. It is thought that activity-based studies involving parent-child communication will set important examples in this field (Ansberry and Morgan, 2019; Mei, 2017; Salvatierra and Cabello, 2022; Sheahan, 2016). In their bibliometric study of study involving parent involvement, Addi-Raccah et al. (2021) suggested that it be extended to extracurricular activities beyond school-related topics. Salvatierra and Cabello (2022) stated that activities involving parent participation in early childhood are mostly done in the field of science. It can be stated that importance should be given to activity studies in which the interdisciplinary nature of STEM is emphasized.

Discussions about the results of the studies that were systematically reviewed in this study are as follows: It has been shown that family background and support can have an impact on children's STEM achievement. Among the STEM activities involving family participation, the positive effect of family STEM days/nights has been noted. The positive effects of technology-supported STEM activities of this kind have been reported. It has been observed that STEM activities at home are carried out with technology support.

It has been reported that positive effects were detected in the theme of "The effect of family participation in the STEM program (parent-child activities)", which was the most studied among the determined themes (Ata-Aktürk and Demircan, 2021; De Leon and Westerlund, 2021; Klein-Gardner, 2014; Kruchten and O'Malley, 2016; Marotto and Milner-Bolotin, 2018; Pagano et al., 2020; Respres et al., 2022; Sheahan, 2016; Sheehan et al., 2019). Family Science and Math Days/Nights had been the subject of many studies (De Leon and Westerlund, 2021; Kaya and Lundeen, 2010; Landerholm et al., 1994; Marotto and Milner-Bolotin, 2018; Milner-Bolotin and Milner, 2017; Respres et al., 2022). The organizations where Family STEM activities (Laux, 2021; Reinking et al., 2017) are held, especially for STEM education, can improve parent-child interaction. Technology-based activities have produced important results especially in terms of providing parent-child conversation (Pagano et al., 2020; Sheehan et al., 2019). With family involvement engineering activities are also programs that have positive effects for STEM education (Ata-Aktürk and Demircan, 2021; Klein-Gardner, 2014; Pagano et al., 2020). Klein-Gardner (2014) showed that parents who participated in homework and engineering project presentations through the STEM summer institute program increased their daughters' desire to enter an engineering career. In addition to the effects on children, positive effects on parents have also been reported by studies. Sheahan (2016) stated that STEM design activities involving parent-student interaction improved parents' attitudes and behaviors regarding STEM issues. Especially mothers with STEM careers have higher self-efficacy for STEM participation (Zucker et al., 2021). De Leon and Westerlund (2021) found that the parents' tendencies were mostly to talk about science and visit the library. Zucker et al. (2021) stated that 56% of parents read with their children every day, only 35% reported any daily STEM activity. Kaya and Lundeen (2010) reported that parents were less involved in their children's science education than in reading and mathematics education. It is stated that family participation improves children's attitudes and achievements in science education (Fleer and Rillero, 1999). Kaya and Lundeen (2010) found that parents participating in family science night activities increased their interest in science learning and family interactions were positively affected. Willard et al. (2019) showed that children can be encouraged to explore or explain through parent-child interaction in the science museum. In a study of family conversations Crowley et al. (2021) noted an important finding of gender disparity, finding that parents were three times more likely to explain science to boys than girls when using interactive science exhibits at a museum. There are experimental studies indicating that science education with family participation is effective in improving the scientific process skills of preschool students (Ulutaş and Kanak, 2018; Yılmaz et al., 2018). It has been found that students' success is positively affected by interactive assignments shared by families in secondary school (Van Voorhis, 2003). It is clear that STEM education, which expresses an interdisciplinary approach, which is a few steps beyond this, has not received enough attention and has not been studied enough. In particular, parent involvement in STEM education improves quantitative skills and problem-solving skills (Thomas et al., 2020). For these reasons, standard science education activities should now be transformed into STEM activities.

The children's STEM success was the most researched variable in the theme of "The effectiveness of family background and perceptions in STEM learning" (An et al., 2018; Dotterer, 2021; Haden et al., 2014; Ing, 2014; Jungert et al., 2020). The participation of parents with a STEM background in STEM teaching is an important predictive factor (Dotterer et al., 2021; Haden et al., 2014; Zucker et al., 2021). Emotional involvement of parents in STEM education is also an important issue (An et al., 2018; Jungert et al., 2018; Šimunović et al., 2018). Dotterer (2021) stated that parents' STEM participation was a predictor of adolescents' success in STEM courses and was related to adolescents' STEM self-efficacy. While this result refers to the role of parents in STEM education, it also points to an important inference that this effect exists even in older adolescents. Ing (2014) made a comparison with STEM fields and found that parental support was related in mathematics, but no relation was found in science education. The result of this research suggested that specialized studies could be conducted for the sub-dimensions of STEM education. An et al. (2018) stated that the education level of the parents is highly effective on STEM success, the effect of family income is weak, and that emotional involvement can compensate for the negative effects of some negative family factors. The studies that indicate that family members' being in the STEM profession and their beliefs about STEM are effective in their children's STEM learning are also frequently encountered (Thomas et al., 2021). There are many studies examining the relationship between the profession of parents and children's STEM careers. There is the essential role of perceived parental expectations in shaping STEM career aspirations for teenagers (Chen et al., 2022). Nurtured by their parents, students enter STEM disciplines and STEM-related careers through multiple pathways in addition to the anticipated pipeline (Craig et al., 2018, 2021). Šimunović and Babarović (2020) found that parents' STEM beliefs have the potential to explain the differences in students' STEM-related achievement motivation, performance, and career choices. Plasman et al. (2021) finds that high school students whose parents are STEM professions related to the participation rate of STEM courses, proving the growing transfer of scientific capital from parent to child. Adams et al. (2018) found that among CFA Institute members, women are more likely than men to have parents (especially STEM mothers) who work in STEM fields, and that significant early role models, particularly female role models. Chise et al. (2020) found that the influence of fathers outweighed that of mothers in their career in science and was greater for boys than for girls. Ikkatai et al. (2019) said that improving field-specific negative perceptions may contribute to increase parental support for girls' choice of STEM fields. Plasman et al. (2021) stated in their literature synthesis that there is a positive relationship between the profession of parents and the STEM achievement of high school students, and that this effect is more on girls and minority students. The results of this study indicate that many variables related to the effect of parents on their children's STEM learning and these should be investigated.

Positive effects are also seen in the studies under the theme of "The effect of implementing STEM activities at home" (Gann and Carpenter, 2017; Hightower et al., 2019; Marcus et al., 2021; Mei, 2017; Zucker and Yeomans-Maldonado, 2022). With family involvement technology activities at home Hightower et al. (2019) noted positive results, while Burušić et al. (2021) stated that they did not contribute significantly. The prominence of technology use in study on STEM education at home is also a remarkable result. Similarly, there are many studies that enable parent participation in education through technology (Walsh et al., 2014; Olmstead, 2013; Patrikakou, 2016). Marcus et al. (2021) stated the positive effects of home engineering activities. Examining the relationship between the opportunity to learn at home and students' acquisition of science proficiency Liu and Whitford (2011) characterized the students who achieved science proficiency: Of having more than 100 books at home, not taking extracurricular courses and of their parents having a graduate education. This research is important in terms of describing the relationship between reading skills, the effect of parents' educational status, and the science teaching environment in science education. It is obvious that this type of description should also be done on STEM education.

The studies show that the interaction between school-parents and children's inter-active experiences are important (Thomas et al., 2020). STEM education studies involving family participation is important in terms of bringing a different perspective to STEM education. In the light of the results of this study, the following suggestions are made for future study:

1. While there are studies on teaching only science, mathematics and technology disciplines to parents in the literature, it is obvious that STEM in which these are discussed together, is a new research topic. Research can be conducted on parents' perceptions of holistic and interdisciplinary STEM education and their application with their children.
2. It is recommended to conduct studies in which STEM education is handled within the framework of parent-child interaction.
3. It is recommended to increase study on the impact of family involvement in the education of adolescents (especially career choices) as well as the education of young children.
4. Since there is a need for experimental studies on parent-child studies in which STEM activities are carried out, it is recommended to conduct study on this subject.
5. It is suggested that Math and Science Days/Nights, which have an important place in the literature, should be organized as STEM Days/Nights in interdisciplinary formatting.
6. The studies should be carried out on the importance of parental support in normal times by turning the idea of "supporting of education by parents", which has been passed necessarily due to the COVID-19 pandemic, into an opportunity.
7. This research is limited to studies that include the topic of STEM education. Specialized studies can also be conducted on other related dimensions and areas of STEM education.
8. In this study, a systematic analysis of general trends was made. Meta-synthesis studies can also be carried out by in-depth content analysis.

Ethical Statement

As the study does not involve the use of human subjects, it does not require ethical approval. There is no conflict of interest in the article.

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APPENDIX A

Table A1. Characteristics of the studies examined in the research

Study	Species of research	Country	Level of student	Number of participants	Model of research	Data collection tools	Main results
Haden et al. (2014)	Article	USA	4-8 age	130 parents	Experimental with control group	Photo narrative Buildings	The results have implications for understanding family conversations and children's STEM learning in families from diverse backgrounds.
Ing (2014)	Article	USA	Secondary school	3116 students	Longitudinal studies	Parental support and STEM career tests	Perceived early parental support was associated with growth in math achievement for men, but not for women. There was no association between perceived early parental support and growth in science achievement for both men and women.
Klein-Gardner (2014)	Conference paper	USA	High school	28 girl students and their parents	Case study	Unfinished work	The STEM summer institute program increased the willingness of their daughters to enter an engineering career by participating in homework assignments and engineering project presentations.
Kruchten and O'Malley (2016)	Conference paper	USA	5-7. grade	60 gifted students and their parents	Survey	Interview	It demonstrates value at the intersection of gifted education, OST learning, STEM content, and the arts.
Sheahan (2016)	Research report	USA	Primary school	5 children and their parents	Experimental	Survey Interview Observation	With the STEM design activities involving parent-student interaction, parents' attitudes and behaviors about STEM subjects have improved.
Gann and Carpenter (2017)	Article	USA	High school	29 parents	Case study	Survey Interview Observation	Parents of homeschooled students provided the roles of facilitator, consultant, presenter and teacher in STEM education.
Mei (2017)	Conference paper	China	Pre-school	3 children and their parents	Case study	Observation	STEM activities at home support learning.
An et al. (2018)	Article	China	Secondary school	12724 parents	Survey	Survey	The model in which parents emotionally participate in their children's school education has the greatest impact on children's STEM academic success.
Marotto and Milner-Bolotin (2018)	Article	Canada	Primary secondary school	29 parents	Mixed methods case study	Questionnaire	Family Math & Science Day activities, it was determined that the parents were satisfied with their children's STEM education and thought that family support was important.
Šimunović et al. (2018)	Article	Croatia	Primary school	1,071 students and their parents	Survey		Children's importance value of the STEM school fields was best explained by their perceptions of parental values and behaviors in STEM.
Hightower et al. (2019)	Conference paper	USA	Primary school	12	Experimental	Survey Interview	Parents finding and incorporating different forms of media into their child's informal learning.
Sheehan et al. (2019)	Article	USA	4-5 age	31 children and their parents	Case study	Interview	Coding practices with parent-child interaction improve children's ability to respond and demonstrate task-related speech.

Table A1 (Continued).

Study	Species of research	Country	Level of student	Number of participants	Model of research	Data collection tools	Main results
Jungert et al. (2020)	Article	Sweden	High school	288 student and their parents	Survey	Survey	Intrinsic motivation mediated the relation between teacher and parent enthusiasm and change in academic success.
Muenks et al. (2020)	Article	USA	High school	117 students and their parents	Relation survey	Survey	Parents who perceived that their child had higher mental manipulation ability were more likely to encourage their child to pursue a STEM career.
Pagano et al. (2020)	Article	USA	6-8 age	61 parents	Experimental	Survey	Tinkering lab activities parent–child engineering talk during tinkering mediated the association between the program design and engineering talk when reminiscing.
Ata-Aktürk and Demircan (2021)	Article	Turkey	Pre school	2 teachers, 5 children and their parents	Design based research	Survey Interview	It was concluded that it could be used in early childhood by focusing on engineering and encouraging parent involvement.
Burušić et al. (2021)	Article	Croatia	Primary school	1205 students and their parents	Survey		The general conclusion is that engagement in technology-based activities at home does not substantially contribute to STEM achievement.
De Leon and Westerlund (2021)	Article	USA	9-12 age	18 parents	Survey	Survey	As a result of the family science nights event, it was determined that the parents' tendencies were mostly to talk about science and visit the library.
Desai (2021)	Research report	USA	K-8	7 parents	Survey	Observation Interview	In STEM Academy using various forms of communication, separating parent meetings by grade level, and implementing child involvement into parent meetings was recommended.
Dotterer (2021)	Article	USA	High school	24000 students and their parents	Longitudinal research	Survey	It has been found that parents' 9th grade STEM participation predicts the cumulative grade point average in adolescents' STEM classes.
Marcus et al. (2021)	Article	USA	4-9 age	63 children and their parents	Case study	Photo narrative reflection	The majority of families completed a building activity with different materials at home, and the majority evidenced learning transfer of the building principle demonstrated at the museum.
Zucker et al. (2021)	Article	USA	3-5 age	208 parents	Survey		Mothers with STEM careers have higher self-efficacy for STEM participation. While 56% of parents reported that they read with their children every day, only 35% reported any daily STEM activity.

Table A1 (Continued).

Study	Species of research	Country	Level of student	Number of participants	Model of research	Data collection tools	Main results
Respres et al. (2022)	Conference paper	USA			Survey	Survey	As a result of the parent cafe, family workshops, family nights, and family STEM days applications, 93 percent of the parents stated that their children were positively affected.
Zucker and Yeomans-Maldonado (2022)	Article	USA	Pre school	181	Experimental with control group	Survey	Co-learning STEM activities for poor families during the COVID period have positive effects.

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Synergistic Collaborations among K-12 Technology, STEM Coaches, and Tech-Industry Partners

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ABSTRACT

This project focused on how two technology coaches, a K-12 Technology Coach and a Science Technology Engineering Mathematics (STEM) Coach collaborated with their coach colleagues and tech-industry partners to offer teachers resources and embedded professional learning (PL). As part of a multiple-case study of coaching models of PL, over the course of two academic years, the researchers gathered observational data during classroom coaching sessions, small group professional learning sessions, and professional development workshops hosted by a tech-industry partner. Additionally, the coaches and a subset of middle school teachers participated in one-on-one interviews and the coaches had discussions in a focus group. Data analyses distilled two main themes: (1) coaches appeal to and collaborate with tech-industry partners; and (2) coaches solicit support and collaborate with school district administrators. Conclusions suggest that technology and STEM coaches serve an integral role in the implementation of technology across the district when collaborating with tech-industry partners. Recommendations include the need for technology coaches to be resourceful and initiate and foster tech-industry partnerships as well as dedicate time to collaborate with other coaches to enhance their own professional knowledge and skills.

Keywords: coaching, school administrators, technology procurement, knowledge brokering

INTRODUCTION

With continuous technological advancements, it is becoming increasingly imperative that students understand the applications of different technological resources and learn how to utilize them for various purposes. School districts recognize the saliency in supporting classroom teachers in utilizing technology to enhance their teaching practices (Liao et al., 2021) and support students in learning how to use such technology. As a way to provide such support, districts often utilize coaches (specialists in the area) to assist teachers in integrating technology in their classrooms and practices, provide technical support, plan professional development (PD), and fulfill the responsibility of purchasing technology and other resources (Liao et al., 2021). However, limited research has examined how technology coaches procure such resources and ensure ongoing support is provided by the tech-industry partners.

This two-year multiple-case study documented the collaboration among a K-12 Technology Coach, a STEM Coach, and their coach colleagues (a Digital Consultant, a Librarian Consultant) and tech-industry partners in providing elementary school teachers with resources and job-embedded professional learning (PL). The purpose of this research was to learn how school district coaches and consultants (with a focus on technology integration) procure resources and work with tech-industry partners to improve their own professional practice and that of their teachers, while leveraging the knowledge and resources of each respective party. This study sought to answer the research question: How might STEM and Technology coaches impact the implementation of technology through collaboration with tech-industry partners? The findings provide insight into how coaches appealed to and collaborated with both tech-industry partners and their school district administrators when incorporating technology into the classroom for STEM lessons.

BACKGROUND LITERATURE

The Role of Technology and STEM Coaches

Trusting relationships among teachers and coaches is integral to support collaborative professional development (Stover et al., 2011). As coaches understand and appreciate teachers' professional knowledge, skills, and experience, the more this trusting relationship is fostered, the more effectively coaches can support teachers in their professional growth. When the needs and interests of teachers are acknowledged and considered, opportunities for collaboration among colleagues are provided, reflective practices are fostered, and meaningful change can occur (Stover et al., 2011). When teachers become invested partners in their own learning, they continue to pursue ongoing support from their coach and sustained growth in their practices (Stover et al., 2011).

In addition to ongoing coach support, providing teachers with the opportunity to collaborate with colleagues through goal-directed, self-regulated learning and critical reflection, can support teachers' ability to enhance their knowledge and beliefs (Gutierez, 2016). Recommendations within the research (Kopcha, 2010, 2012; Lowenhaupt et al., 2014) have called for the development of collaborative communities of practice, reinforced by a mentor to support teachers' learning of how to integrate technology in their classrooms and how to overcome the barriers they may face. Specifically, there needs to be a focus on barriers related to time spent learning, planning, and implementing technology; teachers' beliefs about the importance of, and confidence with, technology; teachers' access to technology; and their abilities to use technology to enhance the curriculum and teach through student-centered approaches (Kopcha, 2012).

Technology coaches have deep knowledge of the local curriculum, understand how to make curriculum connections and address grade-level standards (Sugar, 2005), and how technology can best be implemented in the classroom – this knowledge can be imparted to the teachers with whom they work. In addition to this support, technology coaches can also foster teacher collaboration, and provide technical and maintenance assistance (Sugar and Slagter van Tryon, 2014). To remain current in STEM instructional approaches and meet teachers' needs, technology coaches must serve as a connector among people and resources; a procurer of grants and funding; a coordinator among individuals within and beyond the school community; as well as an educator for both students and teachers (Giamellaro and Siegel, 2018). Technology coaches must also provide necessary instructions for technology applications to assist sometimes apprehensive teachers (Sugar, 2005). Finally, technology coaches must foster healthy coaching relationships with teachers that promote in-depth communications, provide opportunities for guided practice in integrating technology, and supply teachers with resources that assist them with such technology integration (Liao et al., 2021).

Professional Learning (PL) of Teachers

The educational context is continually changing, and it is imperative that teachers dedicate time to their ongoing professional learning (PL) to ensure their knowledge, skills, and practices remain current and relevant to best support their students (Australian Institute for Teaching and School Leadership Limited (AITSL), 2020; Durksen et al., 2017; Karacabey et al., 2022). Teacher professional learning (PL) differs from professional development (PD) in that, PL '… places the focus and responsibility for learning on teachers and their evolving needs' in comparison to PD, which 'referenc[es] activities that are arranged *for* teachers' (Durksen et al., 2017: 53-54) that focuses on further developing their knowledge, skills, practices, and expertise (Campbell et al., 2017; Labone and Long, 2016). Teachers become active participants in their own learning and become responsible for their growth as professionals through processes embedded in their daily activities (Labone and Long, 2016).

The four main components of PL outlined in the literature involve quality content, learning design and implementation, support and sustainability (Campbell et al., 2017), and reflective practice (Avalos, 2011). A series of key features provide a foundation for each component. When considering quality content, professional learning should be *evidence informed*, prioritize *pedagogical and subject specific content knowledge* to support various learners' needs, *focus on student outcomes*, and allow for a *balance of system-directed PD and self-directed learning*. The design and implementation of PL should provide *active and variable learning*, whereby teachers are able to engage in various learning and inquiry opportunities; provide *collaborative learning experiences* within their own and neighbouring schools and districts, as well as outside professional networks; and provide *job-embedded learning*. As is often highlighted with PL, the learning is *ongoing*, should provide teachers with access to *resources*, and should be *supported by system and school* *leaders* who engage in the practice of PL themselves (Campbell et al., 2017; Hilton et al., 2015; Machado and Chung, 2015). The PL of teachers and school leaders should not, however, be limited to attending such opportunities, but instead include some level of reflection whereby they analyse their learning needs, recognize problems they are experiencing, consider if and/or how the processes and practices they use must change, and evaluate how their beliefs have evolved (Avalos, 2011). Each of these components can be supported by knowledgeable technology coaches to support teachers in their professional learning related to technology and STEM integration, with recent research (Giamellaro and Siegel, 2023) documenting how a STEM coach enhanced teachers' practices by bridging and broking relationships and knowledge between educators and field-based STEM workers (e.g., state park rangers, engineers). Although the role of coaches in teachers' professional learning has been well documented in the literature (e.g., Knight, 2011), research on digital resource procurement in K-12 schools, collaboration with tech-industry partners, and administrator support of such partnerships within school districts are relatively unexplored in the coaching literature. This paper addresses this void in the literature.

Educational Technology Resource Procurement

Educational technology (ed-tech) resources have been adopted by school districts at an exponential rate over the past three decades as a means to enhance student achievement (Morrison et al., 2019). Morrison et al. (2019) have proposed an operational framework that aligns with the process school districts typically follow in the procurement of ed-tech products. This operational framework has been presented as a series of five key action points: the allotment of funding, assessment of needs, discovery of ed-tech products, product quality and effectiveness evaluation, and acquisition of selected products. Morrison et al. (2019) note that the action points within this framework should be seen as overlapping (at times) and interactive, as procurement of ed-tech is typically not a linear process (Machado and Chung, 2015), and action points might be entirely skipped depending on the school or district's approach to resource procurement (Dexter et al., 2021; Morrison et al., 2019).

The rapidly evolving and increasing need for ed-tech products – a challenge in and of itself – is also met with several additional challenges for both tech-industry partners and school districts (Morrison et al., 2019). Both parties acknowledge the overwhelming number of products currently available on the market. This overabundance of resources negatively impacts tech-industry partners' ability to market products to the proper individuals and the likelihood that the districts are receptive to the resources. It is impossible for districts to be aware of and knowledgeable about every ed-tech product and software available, and given the constant and rapid changes to technology, districts also struggle with staying up to date with the new technologies and required infrastructure (e.g., reliable internet connections) (Morrison et al., 2019). Additionally, school districts have highlighted challenges associated with insufficient funding for ed-tech programs (Morrison et al., 2019). The increasing cost of ed-tech products coupled with the decreasing budgets school districts have for resource procurement, emphasizes their struggle with adequate funding. Tech-industry partners find the purchasing process to be a significant challenge, as they are often unfamiliar with how to respond to requests for proposals (RFPs), the buying cycles of school districts, and the procurement processes districts utilize, which can be time consuming for tech-industry partners (Morrison et al., 2019).

Despite the significant challenges both tech-industry partners and school districts experience, Morrison et al. (2019) share several factors that facilitate the procurement process. Opportunities for schools to pilot and trial products is viewed as an important evaluation practice as districts require testing before investing in a larger district-wide purchase; this also affords tech-industry partners an entry point into that same district. Tech-industry partners have shared that a product's features, its compatibility with current platforms and existing hardware, available PD, ongoing user support, and ease of use, are key factors for districts when deciding on such purchases (Morrison et al., 2019).

Partnerships/Collaborations within Private Sector or Industry

Based on the limited research available on K-12 schools partnering with the private sector or other industries, the focus of these partnerships tends to emphasize authentic classroom instruction and the creation of 'real-world' student learning experiences (Badgett, 2016; Willems and Gonzalez-DeHass, 2012); there is often limited consideration of school funding for PD and supplies (Wieselmann et al., 2021) or provision of ongoing teacher supports for procured resources. Interestingly, teachers and school district administrators view ongoing relationships with tech-industry partners as an integral component of their partnership (Morrison et al., 2019). In the context of procured resources, instead of focusing on selling the latest technology as soon as it becomes available, school district administrators are seeking vendor support before, during, and after the purchase (Morrison et al., 2019). They see this as the most important part of the partnership, so much so that the tech-industry partners' ongoing support (or lack thereof) influences the district's decision to purchase additional products and/or software licenses. There has also been increasing interest in deliberately expanding

> '(…) the number and types of adults with whom students interact [with] about STEM careers and learning' (Gamse et al., 2017: 32)

to foster interest and engagement among students. Now schools are typically collaborating with tech-industry partners who are STEM researchers, STEM-related business employees, or workers in the health-care sector (Gamse et al., 2017). Through experiencing the work of tech-industry partners, students have the opportunity to learn from experts in the field. These partnership opportunities, whether resource or knowledge and experience focused, are only feasible if school and district administrators are actively involved, and staff (such as technology coaches) are deployed as liaisons (Morrison et al., 2019).

Administrators' Support in the District

School and district administrators serve an influential role in the PL of teachers as well as the receptiveness of teachers to integrate new teaching methods (Karacabey, 2021) and resources into their classroom (Kafyulilo et al., 2016; Machado and Chung, 2015). As Karacabey (2021: 62) notes,

> 'the value attributed to professional development by school district administrators can play a motivating role for teachers to pay more attention to the subject'.

Teachers who engage in PL not only support their own learning, but the learning of their students as well. We can see this as a trickle-down effect – the more enthusiastic and motivated school district administrators are in advancing their practices and those of their teachers, the more eager and inspired teachers will be to continue advancing their practices. This continuous dedication that teachers have for PL, can help ensure students are open to learning as well (Karacabey, 2021). Accordingly, to promote positive change, it is integral that school district administrators support teacher PL regarding technology use.

It is clear that school and district administrators serve a dominant role in the selection and acquisition of technology resources (Morrison et al., 2019). Research has also demonstrated the impact school district administrators have on teachers' receptiveness to integrating technology in their practices with a strong relationship among the school district administrators' influence on teachers' practice in the promotion or prevention of successful technology integration (Kafyulilo et al., 2016; Machado and Chung, 2015). Although some teachers are unaffected by their school district administrators' perspectives on utilizing technology in the classroom, teachers' technology use increases or decreases depending on the support (or lack thereof) the school district administrator provides (Machado and Chung, 2015). When administrators believe that student achievement increases when technology is effectively utilized, they more readily invest in technology tools, develop a schoolwide vision for integrating technology, and promote necessary PL opportunities for teachers (Machado and Chung, 2015). In addition to school district administrator support, teachers look for school district support such as release time to learn about new resources and how to effectively utilize them in the classroom, and access to funding for technological resources to integrate into their practice. Technology coaches need school district administrators to value the integration of technology in the classroom and validate their time to support teachers' practices (Machado and Chung, 2015). This school district administrator support coupled with the affordances of collaborating with tech-industry partners was explored throughout this project.

PROJECT DESCRIPTION

The context for this two-year study was within two different neighbouring (approximately an hour apart), medium-sized, publicly-funded school districts (District A and District B) in Southern Ontario, Canada. In District A, a technology coach (Helen) and her coaching team explored technology initiatives to introduce robotics, coding mini-computers, and 3D printing in middle-school classrooms. In District B, STEM coach (Jodi), worked on incorporating design thinking and 3D printing within middle-school classrooms. Jodi was assisted by a Digital Consultant (Tessa) and a Librarian Consultant (Paige). In both of the districts, the teachers received one-on-one coaching sessions to support them in implementing design thinking practices – there was a distinction between the districts on the type of technology focused on. The coaches in both districts were responsive to the teachers' requests to provide support for topics, content and/or instructional methods that they believed their students would benefit from and aligned with provincial curriculum standards.

The last two of the authors had pre-existing working relationships with Helen and Jodi from previous projects related to PD/PL, classroom demonstrations, and coaching, and actively encouraged a collaborative, professional learning, working relationship among them. These two coaches did not know each other before the collaborative project was developed.

During the first year of the collaborative project, in District B, there were PD sessions hosted by the tech-industry partners in collaboration with the coaches. The former became cognizant of the importance teachers place on classroom implementation. Accordingly, there was a focus on integrating design thinking and STEM activities in the classroom through the use of 3D printers and coding mini-computers. These sessions also provided teachers with opportunities to discuss their current practices and share instructional strategies with their colleagues. In Year 1, there were three sessions (2 hosted by Jodi and her staff; 1 hosted by Jodi and attended by Helen).

In Year 2, all four coaches and consultants took part in four collaborative STEM meetings (2 hosted by Jodi and her staff; 2 hosted by Jodi and attended by Helen). At these meetings the coaches and consultants shared how they were supporting teachers' design thinking and STEM instructional practices with reference to a book study that they were engaged in with one of the researchers (see: Gallagher et al., 2023). They also discussed how to connect what they were learning about in the book study with technological applications and devices that their industry partners were providing. These collaborative STEM meetings were instrumental in allowing the coaches and consultants to translate theory-to-practice-to-resources.

It is important to note that the one-on-one coaching sessions, as well as the PD sessions hosted in the second year of the study were limited in comparison to Year 1 because of the unexpected, provincially-mandated school closures as a result of the COVID-19 pandemic. Of the sessions that took place, the focus was still on STEM integration, but there was additional emphasis on cross-curricular connections and the use of design thinking.

METHODS

Generic qualitative methods (Creswell, 2012) were employed to extract meaning from the fieldnotes, artifacts and transcribed interview data. Generic qualitative methods were used as they provide space for interpretation and the opportunity to explore the perspectives of each participant within their context without being constrained (Caelli et al., 2003; Kahlke, 2014). Additionally, generic qualitative research elucidates the documented attitudes, beliefs, personal opinions, or reflections of one's experiences (Percy et al., 2015). This method was utilized in this study, as the perspectives of the coaches were garnered and evidence of their practice was gathered.

Participants

This study spanned two academic years (2018-2019; 2019-2020) in two neighboring, publicly-funded school districts (District A and B) with consistent coach participants and some changes to teacher participants year-over-year. The coaches represented the entire potential participant sub-sample (i.e., these were the only coaches in one district and two of the three coaches in the other district) and the teacher participants were among those teachers that were coached by them and willing to participate in this study.

In District A, Helen, worked as both a Technology Coach (referred to by the district as a Digital Learning Coach) and Design Thinking Coach while at District B, Jodi was a STEM Coach. In District B, Tessa served as a Digital Consultant and her role was dedicated to the broad integration of technology into classrooms and also school sites as a whole. Paige worked as a Librarian Consultant with an emphasis on supporting School Librarians with technology within school-based library settings. Pseudonyms have been assigned to all participants.

Data Collection and Analyses

This study employed qualitative methods to gather data. Over the course of the two years, researchers collected artifacts and field notes during coaching and PD sessions and interviewed both coach and teacher participants. (Note: Meta-data are not openly available due to university and school district research ethics board restrictions).

Field Notes. In the first year, nine field notes were collected during observations: two from one-on-one coaching sessions with Jodi (the STEM coach) and four from co-teaching sessions. There were also three observed STEM PD Days introduced by Jodi and facilitated by Tessa and a tech-industry partner with approximately 10 to 15 teacher attendees.

In the second year, five field notes were collected. One observation was from a one-on-one STEM coaching session with Julie (middle school teacher) and STEM coach, Jodi. Two observations were during a collaborative STEM meeting between the coaches (Helen and Jodi) and the consultants (Tessa and Paige in a supportive role), and the two additional observations were during design thinking PD Days with approximately 40 to 100 teacher attendees at each session (3D printing and coding mini-computers for computational thinking and procedural writing).

Interviews. During the coaches' interviews, they were asked to discuss their vision for their coaching initiatives, their collaborations with tech-industry partners, how they support teachers' learning how to integrate STEM and design thinking in their lessons, and their greatest accomplishments/challenges in the role. In addition to the one-

Table 1. A summary of the participants and data collection

Year 1 and 2 coaches				
District	**Name**	**Role**	**Years experience as**	**Data (2 years)**
A	Helen	Technology coach and design thinking coach	4 (coach); 17 (teacher)	4 interviews; 2 fieldnotes
B	Jodi	STEM coach	10 (coach); 25 (teacher)	5 interviews; 14 fieldnotes
B	Tessa	Digital consultant	9 (consultant); 18 (teacher)	4 fieldnotes
B	Paige	Librarian consultant	8 (consultant); 19 (teacher)	2 fieldnotes
Year 1 teachers				
District	**Name**	**Grade**	**Years experience**	**Interviews**
A	Caitlin	3	24	1
A	Trisha	3/4	14	1
A	Matthew	7/8	13	1
B	Melody	8	5	1
B	Jane	8	15	1
Year 2 teachers				
A	Jayden	K	19	1
B	Julie	7/8	12	1
B	Molly	6/7	2	1
B	Jane	8	15	1

on-one interviews, both Jodi and Helen participated in a focus group specific to collaborative conversations about their role as technology and STEM coaches, challenges they have encountered, and the technology being utilized.

Across the two years, during the teachers' interviews, they were asked to discuss their coaching experiences, what PD they found effective, and any challenges they have needed to overcome throughout the school year in relation to the respective PL projects that they were participating in. Refer to **Table 1** for a summary of the participants and data collection.

Artifacts. During the study, artifacts were also collected. These included email communications, handouts from PL sessions and a researcher prepared summary of a shared coaching design-thinking focused PL resource.

To analyse the data, all field notes, interview transcripts, and artifacts were uploaded into qualitative software, NVivo (QSR International Pty Ltd, 2015). Once the excerpts were read within the NVivo program, nodes were created using its open-ended coding process. There were 23 nodes (teachers' affect; teachers' impact; teachers' implementation; teachers' learning; general teacher support; support for barriers; technology support; lack of technology; technology challenges; time restraints; technology integration; student-peer interactions; coach-student interactions; coach-coach collaborations; coach-coach mentoring; self-determined teacher professional development; online resources; technology resources; technology enhancements; professional development; researcher role; technology leads) that were then clustered into nine categories (coach role; coach learning; relationships; teacher learning; teacher support; technology tools and strategies; technology challenges; resources; professional development) illustrating the data set. This clustering process is reflective of axial coding (Johnson and Cristensen, 2004). The nine categories were discussed by the researchers and then clustered into two common themes with four and three respective subthemes (Saldana, 2009) – these are presented below as the findings. Quotes pulled from the raw data are thematically presented in the findings below.

FINDINGS

The findings describe the influence, integral role, and impact these STEM and technology coaches had on the implementation of technology in the classroom through collaboration with tech-industry partners. More specifically, the findings explore how **Coaches Appeal to and Collaborate with Tech-Industry Partners**, and how **Coaches Solicit Support and Collaborate with School District Administrators**. These two broad thematic findings are elaborated on next with a series of sub-themes.

Coaches Appeal to and Collaborate with Tech-Industry Partners

Through collaborations with tech-industry partners, the STEM and technology coaches utilized *knowledge brokering as a function of their partnership*, developed *robust PL opportunities for teachers*, introduced the opportunity to *elicit ongoing support for tech resources*, and *fostered ongoing dialogue and support* with and from tech-industry partners.

Knowledge Brokering as a Function of Tech-Industry Partners. The tech-industry partners' ability and willingness to translate and transfer their knowledge of instruction technology into an 'educator-friendly' format was appreciated by both coaches and classroom teachers. For example, during a PD session, the tech-industry partners played a video with steps for the participants to set up their coding mini-computers. When

> "a complicated step happen[ed] on the screen, [the teacher] participants [said] 'pause! Pause!'. [The tech-industry partner] was waiting for the explanation to end… [before] explain[ing] in layman's terms what the video was saying" (Research Assistant's Field Notes, November 2019).

This served as an important aspect of the partnership, as the technical and educator-friendly language that coaches and teachers are exposed to, assisted them in implementing the technology in their classrooms in a manner for students to understand. By providing teachers with opportunities to learn from tech-industry partners, coaches also provided them with the chance to learn 'tips about the design to ensure success in printing,' which, as one 'teacher note[d], she finds this one-on-one support from [the tech industry partner] to be invaluable' (Researcher's Field Notes, June 2019).

The tech-industry partners also benefited from partnering with the coaches, as they learned key factors that impacted the implementation of their devices and software by educators. For example, Jodi shared that tech-industry partners are used to 'a private system (…) and (…) hav[ing] one-to-one devices with the best Wi-Fi (…)' but when '(...) trying to run the Wi-Fi in a public setting, (…) it's slow' (Interview, December, 2018). Schools do not have the luxury of the best Wi-Fi, and this can have implications on the ability to utilize certain tech resources – this is something that tech-industry partners must consider with product development and classroom integration and keep these limitations in mind when developing or updating resources to be utilized in the classroom. Through these partnerships, those in the tech-industry also learned more about supporting K-12 teaching practices, as during PL sessions,

> '[the coach] is the real expert when it comes to the curriculum and planning' (Researcher's Field Notes, June 2019).

These partnerships also provided tech-industry partners insight into how coaches and teachers work together to learn and implement these resources in the classroom. This knowledge brokering that occurred during discussions between tech-industry partners, coaches, and teachers, was apparent during co-delivered PL sessions.

Development of Robust Professional Learning (PL) Opportunities. Robust PL opportunities were developed by coaches for teachers to share others' knowledge and experiences when collaborating with tech-industry partners. While tech-industry partners are experts in the use of their devices/software and are able to troubleshoot quickly, coaches have a strong understanding of how the technology fits within the curriculum, and how it can best be implemented in the classroom. During a STEM PL session, the researchers noticed the synergistic collaboration (i.e., interaction that when combined produces effects greater than the sum of the individual contributions) between Jodi and a tech-industry partner, and

> 'wonder[ed] if they both [saw] the other as interdependent – [the tech-industry partner] needs Jodi's [district's] buy-in and Jodi needs their tech support' (Researcher's Field Notes, April 2019).

When considering the long-term implications and implementation of specific PL for teachers using the resources afforded by tech-industry partners, coaches were aware that it 'takes years to get the team in place and the thinking behind creating a long-term plan' (Researcher's Field Notes, April 2019). Developing robust partnerships and PL sessions does not occur overnight. When working with tech-industry partners, either as co-facilitators of PL workshops or with tech-industry partners as resource providers, the coaches aimed to ensure their PL sessions were

> 'hands on and exploratory for the teachers (…) [and] (…) [they] want[ed] to [be able to] follow up with the attending teachers' (Researcher's Field Notes, October 2018).

They focused on helping teachers in the 'here and now' to build their knowledge and skills related to technology integration in the classroom and potentially supporting them in taking what they learned into their teaching for future years.

Affordance of Partnerships to Elicit Ongoing Support for Tech Resources. Collaborating with tech-industry partners not only afforded these school districts with the opportunity to incorporate these new resources in their classrooms and leverage complimentary technology, but also provided a foundation for initial and ongoing support. Coaches here recognized the need to creatively problem solve and support schools in leveraging free technology resources. For instance, when working on increasing the number of 3D printers within the school district, Helen was faced with competing initiatives for free printers. Of the printers the district had obtained, 34 were placed at schools where a 'teacher or the [school district administrator] (…) applied for the printer' through an internal district competition that Helen encouraged each of them to apply for (Helen, Interview, September 2019). As a way to provide broader access to these 3D printers, the agreement was that the printers

> 'stay at the school (…) [either] at the library (…) [or] on a rolling cart… [so that] the teacher [could] use it and help train the other teachers' (Helen, Interview, September 2019).

With the 3D printers, in Jodi's school district, the tech-industry company agreed to

> 'go to [the] school[s] with the equipment and (…) set the equipment up (…) and (…) walk [the school staff] through [how to use] it,'

and the staff would then be able 'use it on the PD Day (…) or session' (Jodi, Interview, February 2019).

It is important to recognize that the support from these partnerships extended beyond the initial setup and access to the free technology. When incorporating technology in the classroom, teachers and students often ran into challenges with the devices and/or software being utilized. For example, during a STEM PD session, Jodi spoke with a tech-industry partner that offered professional development and tech resources about an issue she was experiencing with some of the devices. One of the tech-industry partners 'said it is a firmware issue and that he [could] update it through the software' (Research Assistant's Field Notes, November 2019). This brings to light the need to ensure tech resources stay up-to-date which is something only tech-industry partners can help to ensure.

Partnerships Foster Ongoing Dialogue and Support. Educators must consider the long-term impact and feasibility of utilizing technological resources in classroom instructional practices. When speaking of the school district's partnership with a professional development and digital resource company, Jodi highlighted that

> 'they can help us look forward over two or three years and really support the teachers' (Interview, February 2019).

Jodi also shared that this is

> "One of the things that they talked about in the expert panel [within the provincial Ministry of Education] (…) that if we're going to go deeper with technology with kids, we have to give teachers the knowledge of what to do and that's not just (…) one session" (Interview, February 2019).

In order to foster student success and teachers' willingness to adopt the new resources, these tech-industry partnerships need to be developed and maintained for long-term involvement. This was acknowledged here. For instance, during a 3D printing workshop,

> 'as the teachers continue[d] to co-plan, [the coaches and tech-industry partners] talk[ed] about what is needed to support the teachers for [the following] year' (Researcher's Field Notes, June 2019).

During this discussion with the tech-industry partner it was

> 'note[d] that they need [to provide] support for 3D printing first, and then [they can] support the process of the designing software' (Researcher's Field Notes, June 2019).

It was recognized that it is not enough to just obtain or gain access to resources as implementation in the classroom is most effective when teachers are provided with the ongoing support to utilize it.

Coaches Solicit Support and Collaborate with School District Administrators

As coaches collaborated with school district administrators, they learned the impact of *school district administrators' receptiveness* in implementing STEM initiatives, the importance of *ensuring technology equity across the district*, and how to *foster multilevel teamwork and collaboration* within the partnership.

School District Administrator Receptiveness. In addition to collaboratively developing and delivering PL opportunities for teachers with tech-industry partners, coaches recognized that

> '(...) it is not enough to fly in an expert, that the teachers need to know that the [district] is interested [in these partnerships] in the long-term and not going against their values and vision' (Researcher's Field Notes, November 2019).

Teachers were more open to integrating technology in the classroom and their daily practices when their school district administrators (principals and superintendents) intended to engage in these partnerships over time. In some cases, principals served as a connector among the coach and teachers – inviting coaches into the school, encouraging teachers to sign up for coaching sessions, and just keeping the momentum going. When school district administrators were fully supportive, they had ambitious implementation plans and

> 'really pushed (…) for tech everywhere (…) [and were] good at allocating [the] budget [to those resources]' (Researcher's Field Notes, February 2019).

It is important to note that the school district administrators' receptiveness was not limited to obtaining and incorporating technology resources within the classrooms, but also included PL opportunities for teachers to learn how to effectively implement such technology. During a district-wide PD session, it was noted that the

> 'day [was] well planned, [and that] clearly, Jodi and Tessa have the 'buy in' from their superintendent and is obvious in the support that they have for this' (Researcher's Field Notes, November 2019).

During discussions with Helen, Jodi shared

> 'how she [did] a presentation to the board of directors [about incorporating coding mini-computers in every grade 6 classroom] and had a student (…) do the presentation [to get] the buy-in (…) and the funding from them [the school district]' (Researcher's Field Notes, April 2019).

She further shared how this

> 'roll out (…) [was] part of their [school district's] strategic plan and [that] they [had] the endorsement of the superintendent' (Researcher's Field Notes, April 2019).

This highlights how teachers not only require school district administrator buy-in, but that this support is also required at the school district level.

Technology Equity Across Schools with Tech-Industry Partners. Technology equity across schools within a given district was an ongoing challenge, but was supported through the coaches' teamwork and collaborations with the tech-industry partners. Beyond securing funding for technology and partnerships with the tech-industry, coaches also needed to consider how these resources were dispersed among schools within the district. Helen shared that, since the

> 'Ministry [of Education] Report came out (…) [we] really [had to] look at [if] we [were] hitting target schools that have [technology resources, and] those schools [that] don't have the Chromebooks to be able to [address all the needs]' (Interview, December 2018).

Jodi noted that 'a lot of [her district's] lower income schools (…) are loaded with technology' that has been acquired through various programs (Interview, December 2018). Despite their best efforts to ensure technology equity across the school districts, the coaches did work with some schools that had limited access to devices given their locations, and as a result, it was imperative that both the teachers and coaches did what they could with the resources available.

Fostering Multilevel Teamwork and Collaboration. Working together in both the planning and implementation of educational technology serves as an essential component of school district tech-industry partnerships. Learning about the devices/software and how to use them fostered collaboration and teamwork at four levels: among tech-industry partners and coaches; coaches themselves; teachers and coaches; and students, teachers and coaches. During several PD sessions, the coach(es) and tech-industry partners would circulate the room to assist groups of teachers during the facilitation. This teamwork among the coaches and tech-industry partners supported teachers in developing their understanding of concepts in relation to the technology being used. The collaboration among the coaches and tech-industry partners was not limited to the PD sessions as it was further enhanced through ongoing dialogue and support. When coaches were afforded opportunities to collaborate with coaches in other school districts, they were able to share their knowledge, experiences and practices. More specifically, they had the opportunity to share what their district was working on as well as future goals, and discuss how other districts might adopt similar practices and projects. For example, during the first collaborative STEM meeting,

> "Jodi ask[ed] Helen about the projects that she [had] going on in [her school district] and she share[d] with her what they [were] doing in a roll out capacity [in their school district]" (Researcher's Field Notes, December 2019).

These connections fostered a willingness to share knowledge and resources among colleagues, and support cross-district teamwork and collaboration. As Helen shared,

> '[Jodi and I are] not in the same [district] which is nice, and [there is a] willingness to share (…) her wealth of knowledge (…)' (Interview, June 2022),

further adding that

> '[Jodi] (...) discussed what she did with her [school district], and the design thinking model. [How] it passed on and moved forward (…). To see how it was successful with them and how we can do that with our [district]' (Interview, June 2022)

was extremely helpful for her PL. This collegial collaboration was also seen at the teacher-coach level when integrating new technology into the classroom and supporting students with the technology. As one teacher also shared, it was a positive experience learning from fellow teachers in the district as well, as

> 'there are teachers in this [district] that are so tech-savvy! So just embracing that. You can learn from them too' (Jane, Interview, June 2020).

Interestingly, discussion about student

> 'engagement seem[ed] to depend on teacher presence. The students [were reportedly] more engaged when the teachers [were] directly involved with the group' (Research Assistant's Field Notes, January 2020).

The relationships that the coaches fostered with students in the classrooms where they visited, supported student engagement, a desire to learn, and an eagerness to work with the coach again.

RESEARCH FINDINGS SUMMARY

Although the technology and STEM coaches were responsible for appealing to and collaborating with both tech-industry partners and school district administrators in order to develop robust PL opportunities that supported teachers' technology integration practices, their own practices were informed in the process. Through *knowledge brokering as a function of such partnerships*, they learned specific ed-tech product terminology, how to utilize the provided resources and how to troubleshoot when issues with the technology arose. They were able to further refine their abilities in *developing robust PL opportunities* for teachers through their collaboration with tech-industry partners. Coaches began to recognize the importance of maintaining *ongoing support from tech-industry partners for tech resources*, as both partners saw each other as interdependent. They learned how to obtain *school district administrator buy-in* for the implementation of STEM initiatives within select schools, while highlighting the importance of ensuring *technology equity across the district*. Through their work with both tech-industry partners and school district administrators, the coaches were able to foster *teamwork and collaboration at multiple levels*. These responsibilities held by both the technology and STEM coaches, speak to the complexity of their roles.

DISCUSSION

As part of the complex role of technology coaches, they are required to support teachers with integrating technology in their classrooms through PL and provide on-site assistance to resolve technology issues that arise (Sugar, 2005). When teachers receive technology coaching, they are able to more effectively implement it in their classroom, feel more confident in using the technology available, and are more prepared in navigating usage obstacles that may arise (Kopcha, 2012). However, the task of securing and distributing technology among schools can be challenging as well as providing ongoing implementation supports (e.g., Morrison et al., 2019). This research has provided insight into how can coaches appeal to and collaborate with tech-industry partners, as well as how they solicit support and collaborate with school district administrators in order to distribute technology and provide the necessary PL opportunities for successful technology integration. We bear in mind that the dynamics among coaches and those with whom they collaborate can be regionally unique and the literature on technology coaching collaborations is limited. Like all coaches though, it is essential for technology coaches to nurture meaningful relationships with the teachers (Skues and Cunningham, 2013). Significantly, this study supports and extends recent research that has demonstrated the benefits of a STEM coach bridging and brokering relationships with educators and field-based STEM workers (Giamello and Siegel, 2023), by documenting the impact and beneficial effects of technology coaches developing such relationships with tech-industry partners and school district administrators.

As coaches collaborated with tech-industry partners, both parties were afforded the opportunity to learn from one another and foster synergistic relationships. Each are specialists in their field and are able to respectively reach users and learners, but it is the robust learning experience as a function of working together that has the potential to support many students and teachers while also providing school districts and tech-industry partners opportunities to build capacity. Existing literature tends to examine these partnerships as a school-to-work pathway or as a means of procuring resources (Sugar and Slagter van Tryon, 2014), however, by approaching these partnerships with an emphasis on knowledge brokering, they extend the impact of their relationships with each other, and foster ongoing dialogue that supports the learning of all parties involved. It is important to highlight that these partnerships do not always entail resources, materials, etc. (for free or at a nominal cost), but instead focus on knowledge and data sharing. The reason such partnerships are formed and maintained, is thus dependent on the intended, mutually beneficial outcomes of the partnership.

In this current project, this mutually beneficial partnership served as a driving force for the collaboration between both parties in the procurement, implementation and maintenance of ed-tech resources. Through such collaborations, tech-industry partners are afforded an entry point into the district – a competitive advantage over other tech-industry partners working for their chance to be noticed by the district among an overabundance of ed-tech products available on the market (Morrison et al., 2019). This, in turn, provides schools with the opportunity to pilot such products or explore the other components of their partnership (e.g., available PD, platform and hardware compatibility assessment, etc.) (Morrison et al., 2019). In this project, the coaches and tech-industry partners recognized the independence they respectively had throughout the process, while each party was benefitting. When coaches and teachers engage with the ed-tech products or implement suggestions provided by tech-industry partners, they gain experience with the resources, while also providing the school district (Morrison et al., 2019) and tech-industry partners with their end-user feedback. This can serve as a key factor in the school district's determination of whether to continue with the implementation of such ed-tech resources, and it is an opportunity for tech-industry partners to learn more about the successful implementation of their products, where schools require additional supports in the use of such resources, and how the products could be modified to better assist end-users – this was the intention in this current project. However, as data collection in this project was cut short by the COVID-19 pandemic, regrettably we were unable to ascertain the longitudinal effects of the tech-industry partnerships here.

The potential synergistic collaboration among coaches and tech-industry partners would be limited if school district administrators were not receptive to the partnership themselves. Although school district administrators often do not work as closely with the tech-industry partners, their willingness to welcome partnerships into their schools influences teachers' openness and dedication to the resources, support, and professional learning (Karacabey, 2021; Kafyulilo et al., 2016; Machado and Chung, 2015). Clearly, school district administrators need to be amenable to these partnerships to encourage teacher buy-in and promote collaborative teamwork. School district administrator receptiveness is also needed to support district-wide technology equity.

Implications for Practice

Technology coaches need to be resourceful and savvy to initiate and foster productive tech-industry partnerships. For instance, coaches could collaborate with tech-industry partners in a manner that provides schools with free materials in exchange for end-user feedback and programming data that records how the resource is being utilized. Alternatively, coaches may provide curriculum, planning, and assessment advice and feedback to tech-industry partners in exchange for ongoing support for educators and students.

Although often not conducted, needs assessments are seen as an important factor in facilitating resource procurement (Morrison et al., 2019). Employing needs assessments not only ensures products are purchased to meet an identified gap, but also ensures that school districts evaluate what is essential and possible, to guarantee that their needs are met. School districts and tech-industry partners should also consider implementing a formal purchasing process that includes detailed product features and criteria for attaining the best value for the product (Morrison et al., 2019). This ensures that the districts are able to afford and equally distribute resources across schools, and it also ensures that the tech-industry partners receive the appropriate funds to not only produce the materials, but also provide the ongoing support school districts are often seeking.

Districts rely on teachers' review of ed-tech products given their end-user involvement as a deciding factor in purchasing technology with the assurance that it will be well implemented in the classroom (Morrison et al., 2019). They also look to peers (often from other school districts) for recommendations for product selection, specific to the effectiveness of the technology and overall product evaluation. Given the preference to refer to colleagues from other schools and districts in comparison to relying on the research provided by ed-tech companies, districts should consider cross-district collaborations. This might provide coaches with the opportunity to collaborate with other coaches and enhance their own professional knowledge and skills.

Coaches should plan opportunities for teacher collaboration and support, beyond PL sessions with teachers and tech-industry partners to ensure continuous, effective programming implementation. Coaches can support teachers with curriculum requirements and lesson development, while tech-industry partners can provide insights into using the resources or software towards a specific instructional goal, and assist teachers with troubleshooting any issues that may arise. It remains imperative that technology and STEM coaches continue to connect individuals within the school community to external partners and resources, procure grants and funding, and work with teachers and students to support their learning in the classroom (Giamellaro and Siegel, 2018).

Limitations and Future Research

There are existing limitations to this research project. Unexpectedly, educational sectors in Canada, like many jurisdictions in the world, were required to suddenly shift to online learning in March 2020 in response to the COVID-19 pandemic. This shutdown resulted in many district PD and PL initiatives being paused – in some cases, indefinitely. This led us as researchers to end our data collection for this project early, halting our intentions to follow the tech-industry partners, coaches and teachers as their synergistic relationships continued to be established. There is a rich opportunity for other researchers to explore the longitudinal effects of tech-industry partnerships like those developed and explored here.

Given that this study only followed two school districts in Ontario, it is unclear how these partnerships are developed, encouraged, and maintained in districts beyond Southern Ontario. It also is unclear how tech-industry partners viewed their role in their partnerships, as interviews were not conducted with tech-industry partners. Future research could focus more closely on the perspectives of the tech-industry partners, and what the partnership with districts specifically affords them. Despite the sessions being focused mainly on STEM education, technology was at the forefront which resulted in less focus being placed on science, engineering and mathematics. Potential studies should explore changes in teachers' practices year-over-year, when working with technology and/or STEM coaches, and tech-industry partners. As well, future research could investigate technology integration in STEM within the classroom and across the curriculum and student achievement outcomes.

CONCLUSION

This two-year multiple case-study has demonstrated the importance of technology and STEM coaches synergistically collaborating with tech-industry partners to improve their practice and support the PL of elementary school teachers. It became apparent that the effectiveness of such partnerships is influenced by the school and district's receptiveness to such partnerships, as their beliefs impact teachers' willingness to engage in the collaborative process within the partnership themselves. Further work should continue to explore how all parties (coaches, tech-industry partners, school district administrators, teachers, and students) play an active role in the formation and maintenance of these partnerships.

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Inclusive STEM Teaching from a Language Perspective: Teacher Learning in a Professional Development Program

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ABSTRACT

Worldwide, pupils with migrant backgrounds do not participate in school STEM subjects as successfully as their peers. Migrant pupils' subject-specific language proficiency lags behind, which hinders participation and learning. Primary teachers experience difficulty in teaching STEM as well as promoting required language development. This study investigates how a professional development program (PDP) focusing on inclusive STEM teaching can promote teacher learning of language-promoting strategies (promoting interaction, scaffolding language and using multilingual resources). Participants were five case study teachers in multilingual schools in the Netherlands ($N = 2$), Sweden ($N = 1$) and Norway ($N = 2$), who taught in primary classrooms with migrant pupils. The PDP focused on three STEM units (sound, maintenance, plant growth) and language-promoting strategies. To trace teachers' learning, three interviews were conducted with each of the five teachers (one after each unit). The teachers also filled in digital logs (one after each unit). The interviews showed positive changes in teachers' awareness, beliefs and attitudes towards language-supporting strategies. However, changes in practice and intentions for practice were reported to a lesser extent. This study shows that a PDP can be an effective starting point for teacher learning regarding inclusive STEM teaching. It also illuminates possible enablers (e.g., fostering language awareness) or hinderers (e.g., teachers' limited STEM knowledge) to be considered in future PDP design.

Keywords: inclusive STEM education, teacher learning, multilingualism, scaffolding language, professional development

INTRODUCTION

Worldwide, teachers face the challenge of providing high quality teaching to pupils with migrant and heterogeneous language backgrounds (henceforth: migrant pupils). Many of these pupils do not feel included in education and do not achieve in line with their academic potential (OECD, 2016, 2018). Although the school careers of migrant groups show upward mobility, the achievement gap is significant and persistent (Andon et al., 2014). This problem is particularly pressing for STEM education, as it causes serious loss of potential (Van den Hurk et al., 2018). Society nowadays demands professionals with backgrounds in STEM. Many pupils show interest in STEM, but their attitudes decline in the middle grades (Barmby et al., 2008) and relatively few teenagers opt for

STEM in higher education (Van Tuijl and Van der Molen, 2016). Amongst migrant pupils, STEM careers are less popular (OECD, 2008).

For migrant pupils' inclusion and achievement in STEM, language is one of the key factors. Language is fundamental to thinking and social interaction (Schleppegrell, 2004; Vygotsky, 1962). The latter comes to the fore in the discursive nature of STEM education, in which classroom interaction, the elaboration of ideas and the explanation of natural phenomena are central. Participation in STEM discourse strongly depends on proficiency in discipline-specific language (Gibbons, 2002) and teachers play a crucial role in migrant pupils' development of such language. Many teachers, however, experience difficulty in teaching STEM to migrant pupils (Banilower et al., 2013; Lee et al., 2007; Ünsal et al., 2016; Weinburgh et al., 2017). They tend to simplify or avoid language in STEM classrooms, as a result of which migrant pupils miss opportunities for (second) language development, widening the aforementioned gap (Lee, 2005) and reinforcing deficit views of migrant pupils (Van Laere et al., 2014). Consequently, migrant pupils are particularly disadvantaged in STEM education (Lee and Buxton, 2010).

The context for this study is a project where we aimed to promote primary teachers' inclusive STEM teaching from a language perspective through a professional development program (PDP). Rather than viewing (second) language development as a remedial endeavor taking place *outside* the mainstream classroom (as criticized by García, 1988), we centralized subject-specific language development *within* the mainstream content classroom (Bravo et al., 2014). Such content-based approaches have been argued to not only contribute to (all) pupils' language and content knowledge development simultaneously (Karlsson et al., 2019; Leckie and Wall, 2017; Rutt and Mumba, 2020), but to also reduce the achievement gap between native speakers and migrant pupils in the classroom (Gibbons, 2009). Research has yielded several strategies that have proven successful in promoting language development in the subjects. These include promoting classroom interaction around subject matter such as science (Osborne, 2007), language scaffolding (Gibbons, 2002; Smit et al., 2013), and the use of mother tongues for learning (also referred to as pedagogical translanguaging; García and Wei, 2013).

Despite the available knowledge regarding language-promoting strategies, teachers in several countries, such as the Netherlands and Nordic countries, have been found to struggle with the uptake of these strategies in their teaching practices (e.g., Onderwijsraad, 2017; Ragnarsdottir, 2015). The aim of this study is to investigate how a PDP focusing on inclusive STEM teaching from a language perspective can help overcome these difficulties, and what factors support or hinder teachers to use the strategies that are known to be effective.

THEORETICAL BACKGROUND

Fostering Inclusion in STEM Education: Meeting Discipline-Specific Literacy Demands

In this study, we adhere to the notion of inclusion as "an ongoing process aimed at offering quality education for all while respecting diversity and the different needs and abilities" of pupils (UNESCO IBE, 2008, p. 18). As noted by UNESCO (2008), many children in education drop out when their mother tongue is not the official language of schooling. This implies that another approach to language in the STEM classroom is needed to allow for all pupils' participation. Such an approach requires teachers' understanding of the discipline-specific language demands to foster migrant pupils' access to curricular content (DiCerbo, 2014).

STEM has been advocated as a powerful instructional context for language-promoting STEM education (Stoddart et al., 2002). It involves a teaching and learning process that is similar to practices of professional scientists, and thus includes inquiry-based elements (National Research Council, 2007). Through inquiry-based STEM, pupils engage in sequences of predicting-observing-explaining (White and Gunstone, 1992), usually by conducting hands-on investigations (Windschitl et al., 2008). As argued by Furtak and Penuel (2019), scientific inquiry should not encompass content-free investigations, but rather promote pupils' incremental sense making and explanations of natural phenomena. This inevitably requires proficiency in academic language (Lemke, 1990), that is, "the language used in school to learn, speak and write about academic subjects" (Valdez et al., 2005, p. 127). STEM concepts central to inquiry (e.g., 'sound', 'plant growth') should be introduced and used in connection to other related concepts and phrases, rather than in isolation. Language functions that are fundamental to STEM, such as hypothesizing, describing, justifying, and explaining, should also gain explicit attention (Bunch, 2013). This requires teacher proficiency concerning the establishment of productive classroom talk, as well as awareness of genres for schooling needed to make meaning in the subjects (Derewianka, 1990).

Language-promoting Strategies

To centralize discipline-specific literacy demands, several language-promoting teaching strategies have been put forward in previous research. Four of these strategies, with their roots in different disciplines (e.g., STEM education, second language acquisition theory), formed our operationalization of inclusive STEM teaching.

First, *promoting interaction about STEM content* (both verbal and written) is crucial for inquiry STEM learning (OECD, 2016). Teachers are to deliberately elicit pupils' active contributions to classroom interaction, for instance, by allowing wait time, or by posing open and thought-provoking questions (Osborne, 2007; Scott, 1998). All modalities used in subject-specific classroom interaction (listening, speaking, reading and writing) should be part of STEM teaching (Gibbons, 2002).

Second and third, *interactive* and *designed scaffolding* can foster inclusive STEM classrooms. Originally introduced by Wood et al. (1976), scaffolding typically refers to a kind of temporary, adaptive help, offered by a teacher to pupils, and directed at handover to pupils' independence (i.e., skills or competence; Van de Pol et al., 2010). In this study, scaffolding is directed towards academic language development. Two types of language scaffolding are distinguished (Gibbons, 2002). *Interactive scaffolding* is help offered adaptively in live interaction with pupils. Interactive scaffolding strategies include: reformulating pupil (spoken and written) utterances, asking for more precise (spoken and written) language, referring to features of the targeted language, asking how written text can be produced or improved, repeating correct (spoken and written) utterances, and making explicit the quality of pupil contributions (Smit et al., 2013; Van Driel et al., 2018). *Designed scaffolding* refers to planned language support for reading, talking and writing that is embedded in instructional materials or activities. Examples include writing frames that offer support in the writing (e.g., explanations, reports), model texts, and word lists including STEM concepts and formulations.

Fourth, *using multilingual resources* (i.e., home languages) that pupils bring to the classroom has been advocated (García and Wei, 2013). Previous research suggests that using home languages can improve children's participation in STEM education and can have socio-emotional (Infante and Licona, 2021) as well as cognitive benefits (Espinosa and Herrera, 2016). Using multilingual resources enables pupils to access the knowledge and skills they master in different languages. These resources can be human (e.g., other pupils or teachers who share the same home language), digital (e.g., translation tools, or multilingual websites) as well as paper based (e.g., books in multiple languages).

Promoting Teacher Learning for Inclusive STEM Education

To promote inclusive STEM education from a language perspective, teacher beliefs regarding linguistic diversity, the integration of language in content teaching, and the use of home languages are key (Garza and Arreguín-Anderson, 2018; Tan, 2011; Ticheloven et al., 2021). STEM teachers, however, often have low expectations of migrant pupils and regard pupils' home languages as an obstacle rather than a mediating tool for learning. Consequently, they are often resistant towards a focus on language (Lucas and Villegas, 2013). Such beliefs have proven difficult to alter (Lee et al., 2007), all the more because in most countries teacher education programs do not prepare teachers for teaching in linguistically diverse settings (Lyon, 2013; Rutt and Mumba, 2020). Complicating matters further, primary teachers often lack a knowledge of STEM, have limited pedagogical content knowledge, and demonstrate low self-efficacy with regard to teaching STEM (Traianou, 2006; Van Aalderen-Smeets et al., 2012). As such, the challenge of promoting inclusive STEM teaching is multifaceted.

To address challenges in professional development of teachers, Bakkenes, Vermunt, and Wubbels (2010) have put forward four learning activities: 1) learning by experimenting, such as trying out new instructional materials; 2) learning in interaction with others, such as teachers or researchers); 3) using external sources, for example viewing exemplary video materials; and 4) consciously reflecting on one's own teaching practices, for instance by filling in logs. Other key features of teacher professional development mentioned in the literature include a strong focus on subject content (Desimone, 2009; Van Veen et al., 2012), adaptivity to teachers' contexts and needs (Lyon, 2013; Putnam and Borko, 2000), as well as the opportunity for teachers to take ownership of their learning and enactment (Davis, 2002). Furthermore, a connection between what teachers learn to their classroom instruction has been advocated (Borko et al., 2010). Specifically in the context of inclusive STEM teaching, working with instructional materials that focus on subject-specific language use seems crucial. Research has shown, however, that even when working with such language-supportive materials, the enactment of language-based STEM teaching remains challenging for teachers (Lee et al., 2007; Smit et al., 2018).

Instructional Materials, Professional Development Program and Research Question

In this section, we first describe the design and nature of instructional materials that were provided to participating teachers so as to promote inclusive STEM teaching in their classrooms. Second, we describe the overarching professional development program (PDP) in which these instructional materials were central, leading to the research question.

A multidisciplinary, international project team designed three language-promoting STEM teaching units on sound, maintenance and plant growth. These topics were chosen to cover a wide range of (primary) curricular content (see **Table 1**). The project aimed to develop natural matches between different types of science and

Table 1. Central concepts and learning goals of the three teaching units taught by teachers of this study

Teaching unit	Unit 1: Sound	Unit 2: Maintenance	Unit 3: Plant growth
Central concepts	Sound, vibration, frequency, volume, decibel, pitch, bright/dark tones, resonance, echo, model, outer-middle-inner ear, ear canal, eardrum, hammer, anvil, stirrup, air, weight, density.	Maintenance, sustainability, production costs, function, safety, appearance, design, reparation, life expectancy	Plant, animal, photosynthesis, carbon dioxide, oxygen, gas, sugar, nutrients, energy, light, water, root, stem, leaves, embryo sprout, soil, seed coat
Content learning goals	Describe how sound is produced, how it travels and is perceived by the ear. Identify and describe characteristics of air and its composition.	Describe how a product can be designed in such a way that maintenance can be carried out. Describe reasons for maintenance related to function, sustainability and cost.	Identify and describe central characteristics of plants and seeds: embryo, food storage, seed coat, root, stem, leaves and flower and explain the function of these parts. Identify and describe factors that influence plant/seed life and growth, such as water, sunlight, carbon dioxide gas.
Inquiry-based learning goals	Perform simple systematic inquiries based on given plans (design, carry through and evaluation). Participate in the process of formulating questions and experimental follow up plans that can be systematically carried through. Document the inquiries with tables, images and in written reports. Search for information about science using different sources and reason about the usefulness of the information and sources.		

Report: Maintenance (lime removal)

Introduction
This experiment shows that…

Method (*you can use words and drawings. Use verbs in the past tense to show what happened*)
The experiment was conducted in the following way:
We…

Observations
- Before the vinegar was added, we saw that…
- After the vinegar was added, we saw that…

Conclusions
Lime can be removed by liquids such as…
We call that process…
That is useful for materials such as … and …, because …

Figure 1. Example of a writing frame used as a designed scaffolding tool in the maintenance unit of the PDP

technology pedagogies and the four strategies for language development, with a focus on inquiry-based learning but not limited to this pedagogy. For instance, the 'sound module' was more oriented toward a conceptual change approach, whereas the module 'plant growth' was based on a mix between inquiry-based learning (seed germination) and conceptual change (photosynthesis). Inquiry-based learning is a term for an approach that is more commonly associated to science pedagogy rather than technology. However, in this project, the 'maintenance' unit also incorporated inquiry elements. For example, the worksheet 'inquiry around a product' provided scaffolds for the students to strengthen their investigation of 'form, function and possible optimization'. The worksheet not only promoted investigation, but also the gathering and analyzing information (typical of scientific exploration).

Following a design-based research approach (Bakker, 2018), the design process allowed for empirical findings to influence subsequent material development and, consequently, teaching practice. The aforementioned four strategies for inclusive STEM teaching (promoting interaction, interactive and designed scaffolding, and using multilingual resources) were embedded in the instructional materials. For instance, the description of lessons included the use of designed scaffolding (e.g., model texts or writing frames; see **Figure 1**) or suggestions for the use of home languages during teaching (e.g., small group discussion in shared home languages, see Gómez Fernández, 2019). Explicit attention was also paid to targeted language in instructional activities.

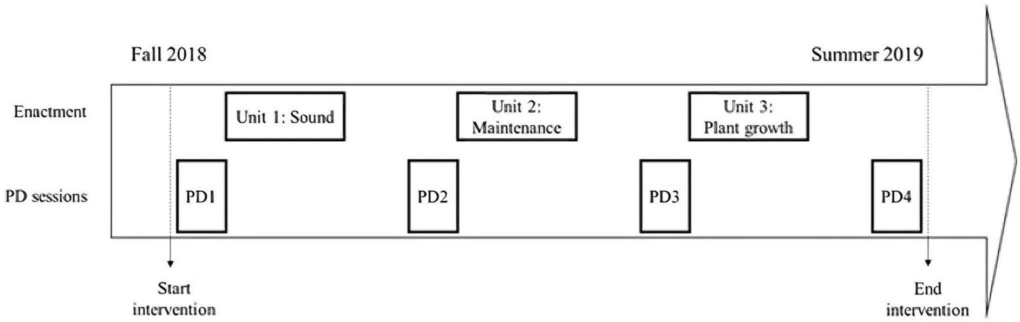

Figure 2. Timeline of the PDP on inclusive STEM teaching from a language perspective

The PDP was developed by researchers from the three participating countries and included four sessions that were similar in terms of objectives, key topics, and PD activities across countries. The sessions lasted between two and a half and four hours, and took place between fall 2018 and summer 2019 in all three countries (see **Figure 2** for a timeline of the PDP). Program participants were 23 primary teachers. Twelve teachers were from the Netherlands, six from Norway and five from Sweden (21 women, two men, M_{age} = 39.7 years, age range: 23–64 years). The total number of hours participants spent on the program, including preparation and enactment of STEM lessons, was about 50 h. They had an average of 13.6 years of experience (range: 1–40 years). Three of them grew up with a mother tongue other than the national language (Turkish, Berber Moroccan and Albanian). Participants taught in 4th to 8th grade classrooms with a percentage of migrant pupils that ranged from 15 to 100%. From this group of participants, five teachers constituted the case studies reported in this study.

The sessions were led by researchers-educators from the local teams. The first three sessions were developed so as to help teachers become acquainted with the three STEM topics and the instructional materials, to promote their awareness of language use in STEM, as well as to gradually foster their independence regarding the uptake of language-promoting strategies (cf. Smit et al., 2018). To realize the latter, each language-promoting strategy came across several times in the PD activities; at first by introducing them and verifying teachers' familiarity with them; later on, by asking teachers to reflect on their own or others' use of the strategies (for instance by watching and discussing classroom video fragments, or by reading and discussing excerpts of classroom interaction).

To promote teacher learning during the PDP, the aforementioned four learning activities (Bakkenes et al., 2010) were included in its design. To promote teacher reflection, for example, teachers were asked to verbally reflect on their teaching practices, on the quality and their use of the instructional materials, and on pupils' participation and progress in response to the inclusive STEM lessons. Reflection was also promoted by filling in reflective logs after enacting each of the teaching units. Learning by experimenting was combined with a focus on STEM content, so as to empower participating teachers regarding their knowledge and self-efficacy in STEM. During sessions, participating teachers were themselves exposed to scientific inquiry (i.e. did science experiments), in order to experience and more deeply understand the scientific phenomena at stake (cf. Minner et al., 2010). Furthermore, teachers were encouraged to adapt instructional activities for use in their own contexts.

When teachers are to implement innovative approaches that have proven to be effective (e.g., the enactment of language-promoting strategies for content learning) they have to understand how they work and how they can be enacted adaptively within their own contexts. *Evaluating teacher learning* is a crucial step as it can show how the professional development program (including instructional materials) has the potential – as a proof of principle – to help teachers realize the innovative approach, in this case inclusive STEM teaching (cf. Bakker, 2018). For investigating what teachers learnt during the PDP, we adhere to Bakkenes et al.'s (2010) conceptualization of teacher learning as "an active process in which teachers engage in activities that lead to a change in knowledge and beliefs (cognition) and/or teaching practices (behavior)" (p. 536). To evaluate teachers' uptake of language-promoting strategies in their own contexts, and as such provide a proof of principle regarding the potential of the designed PDP for inclusive STEM teaching, we ask: *what did teachers learn during a PDP focusing on realizing inclusive STEM education?*

METHODS

Setting: Three National Contexts

The three participating countries that worked as contexts for this study share the fact that they have one official language spoken by the majority of the population (Dutch, Swedish and Norwegian; the two other official languages are Frisian in the Netherlands and Sámi in Norway). These majority languages play an essential role in

Table 2. Teaching and classroom information for the five case study teachers participating in this study

Teacher	Country	Years of teaching experience	Classroom year/group	Approx. percentage of children with multilingual background in the classroom/s (%)	Home languages present in the classroom/s
Tina	the Netherlands	40	7/8	30	Arabic, Egyptian, English, Finnish, German, Moroccan, Serbian, Turkish
Sarah	the Netherlands	9	6	100	Moroccan, Somali Turkish
Charissa	Norway	15	7	8	Arabic, Polish, Somali
Katy	Norway	22	6	13	Arabic, English, Serbian, Somali
Melany	Sweden	2	4	15	Arabic, Danish

citizenship and education. The three countries are also inhabited by speakers of minority languages which arise from regional variations of the official languages or from migrant communities. This landscape makes these countries different to others, like Canada or Switzerland, where more than one majority languages are spoken. The three countries thus face similar challenges as to inclusion of migrant pupils in STEM classrooms (e.g., achievement gaps in STEM, language support difficult to realize in the classroom). There are, however, remarkable differences in approaches across the three national contexts in terms of policies and support for teaching in multilingual classrooms (Hajer et al., 2018; NAFO, 2020; Onderwijsraad, 2017). In general, Sweden puts language scaffolding at the core of national professional development programs, while Dutch and Norwegian governments offer only general guidelines to teachers. Sweden has more availability of staff such as special educational needs experts, second language teachers, and mother tongue support teachers than Norway and the Netherlands. In Sweden, newly arrived pupils go to mainstream education as soon as possible, while in the Netherlands and Norway they are separated from native peers for a period of time. Finally, although mother tongue instruction is common and encouraged in Sweden, this is not as much the case in Norway and hardly in the Netherlands.

Participants

Participants in this study were five case study teachers out of the 23 that participated in the inclusive STEM program. The case study teachers were all women (M_{age} = 44.4 years, age range: 28–64 years).Two are from the Netherlands, among whom one has Berber Moroccan as mother tongue, two from Norway and one from Sweden. **Table 2** shows information related to the teaching experience and classrooms of the case study teachers.

The case study teachers were selected both based on their willingness to fill in logs and participate in interviews, and the variety of national contexts, years of teaching experience, and percentages of migrant pupils in the classroom (see **Table 2**). When the project started it was not common practice to consult ethics committees for ethics approval. However, we did take steps to be transparent. Verbal informed consent was obtained from participants in the study, after explaining the project's focus to interested teachers (verbally as well as in writing). All participants entered the project voluntarily and had the right to withdraw from the study without giving any explanation and at any time. In **Table 2** and this article, names of the teachers have been modified, and other identifying information from participants has been left out, in an effort to protect participants' privacy to our best knowledge.

Instruments and Data Collection

The main source of data for this study are individual interviews with the five case study teachers, conducted after each teaching unit of the PDP (three interviews per teacher in total). An interview format was developed. The format was based on specific teachers' answers as written in the digital logs after completion of the teaching unit, as well as follow-up questions formulated by a researcher from the national team aimed at further elaboration on the teacher's digital log answers (e.g., *Can you give examples of how you tried to include all pupils in classroom interaction?*). Particular attention was given to log answers that included a clear change in knowledge, beliefs, or practice regarding inclusive STEM teaching, or in which a particular challenge was expressed (e.g., regarding the use of home languages). The interviews were conducted by researchers from the three national teams. They were audio recorded and transcribed verbatim.

A supplementary source of data are the digital logs themselves, filled in by the teachers after each teaching unit of the PDP before the interview (three logs per teacher in total, except for the teachers from Norway, which only filled in the first two logs). The digital logs were devised using a reflective log format with 13 questions, informed by the aforementioned four learning activities by Bakkenes et al. (2010) and focused on teachers' use of the instructional materials, their pupils' participation during the unit, and the enactment of the language-promoting strategies (e.g., *Which language-promoting strategies did you enact while teaching the STEM lessons?).*

Table 3. Categories of teachers' self-reported changes along with description and examples (cf. Bakkenes et al., 2010)

Category (code)	Description	Example
Changes in Knowledge/ Beliefs (CKB)	The teacher explicitly reports a change in (or confirmation of) what he/she knows or believes regarding his/her teaching in relation to the PD program.	"I only now realize that language may be central to learning."
Intentions for Practice (IP)	The teacher explicitly reports an intention to change (or hold on to) teaching practice(s) as a result of the PD program.	"I want the children to write more, so far they have only spoke out loud about the experiments."
Changes in Practice (CP)	The teacher explicitly reports a change in his/her teaching practice as a result of the PD program.	"I see myself, right now, as being more careful when formulating questions in all my courses and with all my pupils."

Data Analysis

To answer the research question, we investigated case study teachers' learning processes during the program based on the interview data. The analysis was conducted by the first, second and sixth authors.

To conduct the analysis, we drew on the framework developed by Bakkenes et al. (2010) for studying teacher learning in the context of educational innovation. It distinguishes four main categories of self-reported teacher learning: Changes in Knowledge and Beliefs, Intentions for Practice, Changes in Practice, and Emotions. The first and second authors used the framework to build a codebook containing a description of each category and examples of words and statements that could be indicative of each category (cf. Smit and Van Eerde, 2011). Because teachers hardly *explicitly* reported on emotions during the interviews and because these statements were hard to code reliably, we decided to leave the category of emotions out (cf. Smit et al., 2018). The three remaining categories used in this study are summarized and illustrated in **Table 3**.

The second author selected and coded teacher utterances that expressed self-reported learning in an explicit way. Subsequently, the sixth author coded a subset of 16 utterances independently (sec. the $2n^2$ rule, see Cicchetti, 1976). The coding of both authors was compared in terms of interrater reliability: substantial agreement was obtained ($\varkappa$ = .70).

Based on the coding, we wrote up a descriptive summary for each case study teacher regarding their learning outcomes in relation to the four language-promoting strategies. Subsequently, all summaries were compared (cross-case analysis; Borman et al., 2012) resulting in an integrative narrative per strategy including 1) a summary of the *distribution of reported learning outcomes* (among the categories of Changes in Knowledge and Beliefs, Intentions for Practice and Changes in Practice), and 2) an overview of remarkable *common learning outcomes* and *individual learning outcomes*.

Last, researchers from the three national teams validated the narratives based on their reading. No contradictions were found between national researchers' experiences and our findings. For reasons of space, we only include the integrative narratives per strategy in the results section.

The digital logs were used as a means of triangulation, specifically, for the corroboration of the descriptive summaries. The second author read the digital logs filled in by the teachers, and, as with the interview data, selected and coded teacher utterances that expressed self-reported learning in an explicit way. The coded utterances from the digital logs (n = 13, in total for the five teachers) were then compared against the descriptive summaries of each teacher. We found no contradictions between interviews and logs and the self-reported changes found in the logs were related to those found in the interviews. However, the interviews contained additional reported changes to those of the logs, probably because interviews gave teachers more space for elaboration.

RESULTS

Promoting Interaction around STEM

Concerning the strategy of promoting interaction around STEM, all five teachers reported learning in the category of Changes in Knowledge and Beliefs (see **Table 4** for frequencies of this category in the interviews). Three teachers, Sarah (NL), Charissa (NO) and Melany (SE), also reported having incorporated this strategy more permanently in their teaching practice (Changes in Practice). The two Dutch teachers, Tina and Sarah, spoke about having intentions of incorporating this strategy into their future practice (Intentions for Practice).

Comparing teachers' reported learning accounts brought several commonalities to light. They all deemed promoting interaction around STEM a crucial strategy for the realization of inclusive inquiry-based STEM teaching. The most salient commonality concerned the value four out of five teachers attributed to *small group work*.

Table 4. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of promoting interaction around STEM

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	7	3	2	5	1
Intentions for practice	4	3	-	-	-
Changes in practice	-	1	-	4	1

Charissa appreciated the "constant reminder of the importance of collaboration" in the instructional materials. Tina repeatedly shared the gained insight that more pupils participated in whole-class interaction if it was preceded by interaction in small groups. Katy (NO) realized to be better able to guide pupils' learning when they worked in small groups. Sarah reported in the first interview to have more actively promoted pupil collaboration and interaction in her STEM lessons – a remarkable change in practice, considering the more traditional, teacher-led whole-class culture in which she started the PDP.

A few other commonalities in reported learning were found, all occurring in two or three of the five teachers. The importance of *posing the right questions* was mentioned several times, albeit in different ways. While Tina became aware of posing open questions for provoking thinking, Sarah reported the belief that questions in STEM should make pupils curious. Charissa related this topic to her own knowledge of STEM, by stating that being well prepared allowed her to pose "better follow-up questions when spontaneous situations [arose in classroom discussion]". Also Tina came to understand the importance of "know-how" (in STEM) and "more background knowledge", and expressed the intention to read more about a STEM topic before its introduction in the classroom.

Both Tina and Melany expressed the belief for a *safe classroom climate* to be a prerequisite for promoting interaction around STEM. Inclusive STEM, in the following account by Melany, involves social norms such as helpfulness and honesty:

> you ask them to help each other and not make it into a weird thing by trying to cover it up, trying to have a pretty open climate. (…) we have to make sure that we help each other and they are pretty aware of who needs more help.

Another commonality across teachers concerned a focus on *more active STEM lessons*. Sarah expressed the intention to use less reading material and include more active (i.e. inquiry-based) assignments in her future STEM lessons. Melany, in the same vein, stated to have changed her teaching practice towards less reading of texts and more inquiry. Last, two teachers reported learning with regard to *writing in STEM*: Tina expressed the intention to incorporate writing so as to promote interaction, while Charissa reported to have included writing as part of her lessons.

Notable individual learning mainly concerned instances of raised awareness, for example regarding the importance of wait time for inclusion, which Charissa articulated as follows: "If I want the pupil to reflect, then I am very conscious that they should have ten seconds to think by themselves first." Other instances of awareness concerned the difficulty of realizing *all* pupils' participation in classroom interaction (Sarah), and the experience that promoting interaction helped pupils "who are otherwise more passive" to become more eager in STEM learning (Katy).

Scaffolding

In the case of *interactive scaffolding*, all teachers reported learning as Changes in Knowledge and Beliefs (**Table 5**). While only Sarah (NL) and Melany (SE) gave examples of Changes in Practice, the two Dutch teachers and Charissa (NO) reported having an intention to enact this type of scaffolding more in the future (Intentions for Practice). In four out of five teachers, reported learning of *designed scaffolding* was distributed over the categories of Changes in Practice and Intentions for Practice, with the only exception being Charissa, who reported a change in knowledge and beliefs once (**Table 6**).

Interactive Scaffolding

Table 5. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of interactive scaffolding

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	9	2	3	1	2
Intentions for practice	1	1	-	1	-
Changes in practice	-	1	-	-	2

The comparison of case study teachers' reported learning with respect to interactive scaffolding demonstrated several commonalities. These included all teachers' *increased awareness* of the role of language in STEM and the importance to support (or scaffold) language development. In the third and final interview, for example, Katy (NO) stated that she had "become much more aware of learning language. (…) scientific concepts, expressions, everyday words, and the link between them. And that one has to be conscious of that all the time." Tina (NL) noted that her increased awareness of the importance to scaffold language led to a high degree of effort on her part, as she had become "busier" with the language aspect of her practice, in addition to content knowledge.

Interactive scaffolding strategies reported by four out of five teachers included *asking pupils for reformulation and/or asking for elaboration of their utterances*, in four teachers present in the forms of Changes in Knowledge and Beliefsand, in addition, Changes in Practice or Intentions for Practice. Sarah exemplified her enactment of this strategy as follows: "Today somebody said 'that thing'. And then I'll try to steer them: 'which thing are you talking about exactly?' So I focus very much on their language. How do you put something into words?" Sarah explicitly reported on asking pupils both for reformulation and elaboration. However, in the second interview, she remarked not having been able to ask for elaboration as much as in the previous unit on sound. This may be related to her lack of familiarity, also experienced by the other teachers, with the STEM content of the second unit (maintenance). This may have hindered teachers' realization of this interactive scaffolding strategy.

Another commonality concerned the *importance of introducing pupils to and reminding them of targeted STEM language*, explicitly expressed by three of the case study teachers (Tina, Sarah and Katy). Sarah explicitly reported a change in practice already after unit 1: "what I do differently than before, for example, is that I try really hard to use the right words. (…) I try to use not only everyday words, but also the content-related vocabulary." The same three teachers also expressed the importance of their own adequate language use (or "the need of facilitating terminology", cf. Katy) in STEM lessons. Notable is the focus on words (or concepts) when it comes to how these three teachers seem to envision language in STEM learning. As Katy put it: "And we worked on words and concepts all the time." Rather than focusing on ways of talking in STEM, or on language functions such as hypothesizing or explaining, the case study teachers tended to centralize STEM vocabulary.

Three teachers (Tina, Charissa and Melany) brought the act of *diagnosing* to the fore, albeit in different ways. While Tina reported on pupils' mastering of STEM words after frequently repeating them, Charissa expressed the challenge of diagnosing conceptual development both orally and in writing. Only Melany related STEM content knowledge to language, as she reported on diagnosing pupil understanding through their use of everyday or STEM language.

Other topics of learning were found for only some teachers. Two Dutch teachers expressed having incorporated the scaffolding strategies also in other subjects than STEM. Only Katy and Melany stated to *differentiate* in their enactment of scaffolding strategies, that is, to respond to levels of language proficiency in pupils, as centralized several times during the PDP. Finally, Melany was the only case study teacher who claimed, in the enactment of unit 2, to "say the same thing but in another way" (also called 'message abundancy' in scaffolding literature, cf. Gibbons, 2002). After unit 3 she stated to be already familiar with interactive scaffolding. These statements may be explained by Melany's Swedish context in which teachers are induced into scaffolding theory and practice from teacher education onwards.

Designed Scaffolding

Table 6. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of designed scaffolding

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	-	-	-	1	-
Intentions for practice	2	1	4	-	-
Changes in practice	2	1	1	-	1

Common learning for designed scaffolding involved having incorporated tools to *support pupils' writing*. Four out of five teachers reported on having used tools such as a writing frame (in this study: a template for a report with sentence starters) and "Meet in the Middle" (a placemat in which pupils could collaboratively write hypotheses and predictions; Jakobsson and Kouns, 2021). Tina (NL) and Melany (SE) also discussed having incorporated the use of *visual materials*, such as drawing or printing pictures and linking them to new words. Designed scaffolding was also realized by writing up key words on the board or on word lists hanging on the wall.

The PDP, including the inclusive instructional materials, may have helped teachers to enact this strategy and to evaluate its usefulness for their practice. This can be seen in Tina's reflection after unit 3, "it is because of the previous units that I realized that writing on the [black]board is really good".

A final commonality concerns the fact that three out of five teachers expressed their intentions of using this strategy during units 1 to 3, and two of them also in the future (and in other subjects). However, teachers gave different individual arguments to explain the perceived usefulness of this strategy. Sarah (NL) explained that using a template allowed her to ensure that *all* pupils were involved in the writing tasks and in reflection upon science experiments. Tina remarked on the writing tools being useful to support pupils' predictions in science experiments. Katy explained in unit 1 that designed scaffolding tools were especially helpful for pupils to learn new vocabulary:

> I felt that they learned quite a few new words, but that I should try to get all the words in next time (…) we have to make some space for the words, so they are hanging there and they can see them all the time.

In sum, teachers' reported learning regarding interactive scaffolding concerned mainly Changes in Knowledge and Beliefs, while for designed scaffolding they concerned mainly Intentions for Practice and Changes in Practice. Despite this difference, which suggests that designed scaffolding – being embedded in teaching materials – may have been easier to incorporate in practice, both types of scaffolding strategies were deemed useful for inclusive STEM education, judged by teachers' increased awareness and altered beliefs, as well as their intentions to use scaffolding strategies in the future and in other subjects.

Using Multilingual Resources

Table 7. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of using multilingual resources

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	-	3	-	7	-
Intentions for practice	-	3	-	-	-
Changes in practice	-	-	-	-	-

For the strategy of using multilingual resources, only two out of five teachers (Sarah, NL, and Charissa, NO) reported learning in the category of Changes in Knowledge and Beliefs (**Table 7**). Sarah was the only teacher to report learning in the category of Intentions for Practice. We found no explicit reports of Changes in Practice for this strategy in any of the teachers, showing that none of them explicitly reported having incorporated the strategy more permanently in their teaching practice.

Common reported learning for the strategy of using multilingual resources concerns three topics. First, both teachers (Sarah and Charissa) reported on Changes in Knowledge and Beliefs related to the use of *digital tools* to employ home languages in STEM. Charissa, for instance, stated that she realized that the use of digital tools "depends on how strong the student is. [The student] needs to be resourceful and independent". Second, both teachers mentioned *external staff* (such as parents, language teachers) to be important for the realization of this strategy. Third, both teachers reported on raised awareness concerning the challenge of *guiding pupils' conceptual understanding* when they are not proficient in home languages used. Sarah, for instance, expressed "you can't make sure they've formulated it correctly, or check to see if they've understood. (…) I don't think [how to best use this strategy] is clear to all of us [teachers]." We found one individual reported learning outcome for this strategy: It included Sarah's reflection on the need for *being prepared* for lessons to be able to use home languages, as well as the fact that it "requires a bit of daring".

DISCUSSION

The present study examined teachers' learning of inclusive STEM teaching from a language perspective against the background of a PDP. In response to our research question, two overall conclusions can be drawn. First, teachers increasingly recognized the importance of language-promoting strategies for inclusive STEM teaching, as apparent from changes in awareness, beliefs and attitudes over the course of the PDP. Second, Changes in Practice and Intentions for Practice were found to a lesser extent, implying teachers' struggles in the actual enactment of language-promoting strategies (in particular interactive scaffolding and using multilingual resources).

One obvious limitation of our study concerns the small number of teachers participating in this study. Further to this, our PDP only spanned four sessions, which leaves the question open whether a PDP of longer duration would have allowed teachers to not only increase their awareness but to also incorporate inclusive strategies more permanently in their STEM teaching practices (cf. Smit et al., 2018). Another limitation concerns the fact that this study did not include evidence of teacher learning beyond that presented through self-report (e.g., through classroom observations).

We now turn to factors brought to the fore by the case study teachers as key to their realization of inclusive STEM teaching, so as to tentatively inform the design of future PDP's.

Implications for Future PDP Design on Inclusive STEM Teaching

Teachers were asked to internalize a repertoire of language-promoting strategies in a relatively short amount of time, and to enact them responsively in their STEM lessons – a challenging task. The varying degrees of success with each strategy's enactment suggests, in general terms, that more attention should be given to teachers' previous experiences with the strategies (e.g., perhaps through a pre-entry questionnaire) and this information could then be incorporated in PDP design.

To realize the *promotion of interaction around STEM*, two factors seemed of relevance. First, teachers stated that a safe classroom climate is a prerequisite for inclusive STEM teaching (in line with Mercer's ground rules for talk, 2000, and with Yackel and Cobb's social norms, 1996). This implies that a PDP should include the topic of classroom interaction norms, so as to prepare teachers and pupils for inclusive teaching. Second, teachers realized that STEM content knowledge is a key factor for promoting productive interaction around STEM. This resonates with previous research highlighting the need for teachers to have an adequate level of subject matter knowledge in order to convey this knowledge to pupils (e.g., through explanatory representations, Hashweh, 1987). This aspect turned out to be underrepresented in the PDP reported here, as several teachers experienced their limited content knowledge as a shortcoming (particularly mentioned after Unit 2, on maintenance).

Concerning the strategy of *interactive scaffolding,* teachers particularly reported on increased awareness, both related to the central role of language in the subjects of STEM, as well as to their own modeling role for developing language proficiency in pupils. This finding reinforces awareness as an important step towards teachers' enactment of language scaffolding (cf. Smit and Van Eerde, 2011). To foster awareness, we promoted reflection on classroom practices in the PDP, for instance by watching and discussing video recording. A closer look at teachers' interactive scaffolding accounts brought an emphasis on STEM words rather than on language functions (e.g., predicting, observing or explaining) to the fore. A genre-based approach to subject teaching (Martin, 2009), in which teachers explicitly pay attention to a (text) genre's specific purpose (e.g., to *explain* a phenomenon), the particular overall structure (text organization in terms of stages or moves) and specific linguistic features (e.g., words and formulations; tenses and verbs used), could help students understand how language enables them to fulfil communicative goals in school and society and, more specifically, how they can use language themselves to make meaning in STEM (e.g., to *describe* an experiment). To promote genre-based rather than vocabulary-focused STEM teaching, we advocate the inclusion of a functional (genre-based) approach to language in future PDP design. Another recommendation is the incorporation of content knowledge development in PDP's designed for inclusive STEM teaching, because teachers' limited content knowledge may have hindered a functional approach to language in STEM, for it is primarily in language functions that the close relation between subject matter knowledge and academic language proficiency is established. *Designed scaffolding* proved an accessible strategy as it was embedded in the teaching materials. Providing teachers with such language-oriented instructional materials is therefore recommended as well for future PDP design focusing on inclusion. Capitalizing on students' writing in STEM, too, is another recommendation, based on teachers' accounts.

Explicit learning outcomes concerning *the use of multilingual resources*, last, were scarce. As in other studies, teachers expressed general positive attitudes toward the use of home language in the classroom (cf. Alisaari et al., 2019; Rutt and Mumba, 2020), but learning to enact this strategy appeared challenging. Individual accounts pointed to feelings of uncertainty surrounding the use of digital translators and the guidance of pupils using home languages unfamiliar to the teacher. As an enabling first step towards enacting this language-promoting strategy, teachers mentioned interaction with peers, parents or teachers who share pupils' home language(s). Concerning the results on the use of multilingual resources it is important to note that a richer picture could be obtained when adopting a broader analytical lens than explicitly reported learning only. Based on the study reported here we recommend to include conditions as to how home languages can be used by teachers who do not master these in PDP design, as well as to how external multilingual resources such as digital tools or parents can be used.

CONCLUSIONS

The findings of this study provide a proof of principle regarding the potential of professional development as an effective starting point for teachers' learning and enactment of inclusive STEM teaching from a language perspective. Features of future PDP can be adjusted to promote more (permanent) changes in practice in teachers, and to increase the employment of more challenging or unfamiliar strategies, such as using multilingual resources.

This study supports the idea that teacher professional development is key in the promotion of reform-oriented practices (Hart and Lee, 2003), in this case, the realization of inclusive STEM teaching from a language perspective.

In particular, the connection between STEM content knowledge and a focus on language development (cf., Leckie and Wall, 2017) was crucial, as reported by participating teachers. This study also supports our operationalization of inclusive STEM teaching from a language perspective. Teachers accepted and valued the set of language-promoting strategies as a repertoire that could be enacted in an integrated way, despite the challenges they experienced. Future research should further inquire, at the theoretical level, how language pedagogies relate to subject-specific demands, and at the practical level, how professional development and strategies can be refined to accommodate teachers' previous experiences and unique learning pathways.

LIST OF ABBREVIATIONS

NL – the Netherlands
NO – Norway
PDP – professional development program
SE – Sweden

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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Understanding the Relationship between Students' Perception of Environmental and Psychological Variables and Their STEM Learning in Qatar: A Structural Equation Modelling Approach

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ABSTRACT

This research sought to investigate the relationship between students' perceptions of various environmental and psychological factors and their STEM learning. The study incorporated quantitative exploratory design, including data from 1,625 students (preparatory & high school) in Qatar. It examined the relationships among five key variables, i.e., (a) the quality of teaching, (b) satisfaction with school, (c) the positive perception of the importance of mathematics/science for students' future, (d) the fear of asking math/science questions, and (e) their STEM learning. The results of the regression analysis and structural equation modelling analysis demonstrated a significant relationship between the explored variables. A positive correlation has been computed between "quality of teaching," "satisfaction with school," "recognition of the importance of mathematics/science for the future," and "students' STEM learning". In contrast, the variable "fear of asking mathematics/science questions" was found to be negatively associated with "students' STEM learning." This study research offers important recommendations for policymaking and suggests avenues for further investigation and research in this area.

Keywords: STEM learning, structural equation modeling, mathematics, science, Qatar

INTRODUCTION

Qatar's endeavors to transform into a knowledge-based society are at the heart of the country's strategic national development goals outlined in the *Qatar National Vision 2030* (*QNV 2030*). Central to these goals is the need to invest in human capital (Tan et al., 2014). A critical step towards achieving this is the importance of reforming K-12 and higher education, both of which are acknowledged as critical to the progress and prosperity of the nation.

As Qatar strives to transition to a competitive knowledge-based society, a major challenge it faces is the shortage of skilled labor in STEM (Science, technology, engineering & and mathematics) fields. Indeed, the high demand for STEM professionals required for sustainable development in the country is still persistent. After almost two decades of education reforms, however, national and international indicators show that little has been achieved regarding academic achievements in STEM (Nasser, 2017; Wiseman and Anderson, 2012). Numerous factors influence students' STEM achievements and, consequently, their career aspirations in STEM fields (Sellami et al., 2023a). Thus, this study aims to investigate several important environmental-based and psychological-based variables and their interconnections with STEM learning. The key variables under examination include the students' perceptions regarding the effectiveness of STEM-based pedagogies employed, school satisfaction, a positive outlook on the significance of mathematics and science in students' futures, apprehension about posing mathematics/science-related questions, and their STEM learning.

The significance of this study lies in its potential to provide insights into crucial factors influencing STEM learning, which, in turn, can contribute to the development of a more proficient pool of STEM professionals within the country. Furthermore, it will enhance our understanding of the rationales behind students' decisions to pursue or not pursue STEM as their majors and careers. The structure of the paper is organized as follows: The subsequent section provides an overview of the pertinent literature, followed by a detailed explanation of the methodology employed in this study. The subsequent sections sequentially concentrate on presenting and discussing the results obtained from this research, along with the limitations and recommendations.

REVIEW OF LITERATURE

Engaging in STEM-related education and pursuing a career in STEM fields is a multifaceted process that encompasses a wide range of intricate factors and influences, such as personal (age, gender, grade, nationality, etc.), motivational (self-efficacy, performance, interests, confidence, expectation, etc.), and environmental (school-related factors such as teachers' support, pedagogical approach, support from parents/peers/society, etc.) (Sellami et al., 2023a). In this study the explored variables are quality of teaching, fear of asking mathematics and science questions, satisfaction with school, and positive perception regarding the importance of studying mathematics and science for future educational and career endeavors (Falloon et al., 2020; Wahono et al., 2020). The first variable investigated in the study is the "Fear of asking mathematics/science questions".

Fear of Asking Mathematics/Science Questions

The apprehension of asking questions about mathematics and science in the classroom is closely linked to students' overall fear of these subjects, anxious teachers, negative experiences, etc. (Beilock and Willingham, 2014). To address this issue, it is crucial to emphasize enhancing students' interest and engagement in these subjects by adopting engaging curriculums, introducing a sense of belongingness, and creating positive classroom environments, etc. Though there are many hurdles and solutions pertaining to the given context, the primary importance must be given to the quality of teaching. Therefore, educators and researchers from around the world should collaborate to develop modern teaching approaches that offer comprehensive, high-quality education and exceptional STEM instruction (Kennedy and Odell, 2014). Cooper et al. (2020) have reported that the fear of asking questions in mathematics and science, as well as student anxiety, diminish when students receive effective teaching with an active learning approach.

Quality of Teaching

The quality of the teacher is reported to be strongly correlated to the student's achievement (Akram, 2019), which is measured by students' outlook toward teacher-adopted instructional practices (Adu-Boateng and Goodnough, 2022), and teacher-mediated encouragement (Raph et al., 2022). Engaging students in high-quality STEM education through rigorous curriculum, instruction, and assessment, helps promote scientific learning and better career orientations (Kennedy and Odell, 2014). All students must be a part of the STEM vision, and all teachers must be provided with the proper professional development opportunities preparing them to guide all their students toward acquiring STEM literacy (Fauth et al., 2019). Though the quality of teaching remains of utmost significance while driving students to STEM trajectories (educational/career), there exist other psychological factors such as satisfaction with schools and positive perception regarding STEM.

Satisfaction with Schools

Satisfaction with school is a key determinant of students choosing future educational/career trajectories. Correspondingly, the initiatives from school and type of classroom activities (environmental factor) also tend to impact students' STEM learning and career aspirations. School environment and curriculum that actively supports formal and informal scientific investigations aid in better STEM learning (Franz-Odendaal et al., 2016). A longitudinal study by Ketenci et al. (2021), has investigated students' STEM aspirations based on gender, math self-efficacy, socioeconomic status (SES), school type, and urbanicity as predictors.

Students' Mathematics/Science Self-Concepts

Likewise, students' mathematics/science self-concepts (positive perceptions regarding STEM) affect their intensity of engagement with STEM, and ultimately their educational/career plans (Christensen et al., 2014). Sikora and Pokropek (2012), building upon this research, further argued that STEM career expectations rely on two key self-assessments. The first assessment involves one's confidence in handling the future demands of their chosen career. The second assessment revolves around the personal benefits or importance they perceive from their subject and career choice. Correspondingly an individual's career/educational belief evolves through a combination of experiences and self-perceptions. This underscores the significance of early experiences and exposure to mathematics and science in the decision-making process regarding one's education/career choices.

CONCEPTUAL AND THEORETICAL FRAMEWORK

The conceptual framework of this study is grounded on the prior studies by Sellami et al. (2017a, 2017b, 2023a, 2023b, 2023c). The purpose of these studies was to explore a variety of factors that influence students' inclinations toward STEM, including their interests, learning experiences, and career aspirations in STEM fields. The theoretical framework of the study is underpinned by the social cognitive career theory (SCCT). Most research investigating the impact of environmental and psychological factors on students' STEM learning and goals has relied on the framework of SCCT, as outlined by Lent and colleagues in their works from 1994 and 2000 (Lent et al., 1994, 2000). SCCT attributes career aspirations to a combination of factors, encompassing individual characteristics, social influences from the environment, and motivational aspects. By adopting SCCT as a theoretical framework, this study posits that the Quality of teaching/teachers, educational institutions, and self-perceptions play a significant role in shaping students' STEM learning and their career aspirations.

Research Questions

Numerous studies have highlighted a noticeable shift in students' attitudes away from STEM interests and career aspirations. The factors contributing to this shift are diverse and to preserve and attract students' interest in STEM, it is imperative to embrace more effective STEM-based active learning models, better school environments, etc. Thus, the primary objective of this study was to investigate the connection between students' perceptions of student-related, teaching-related, and school-related variables and their STEM learning. More specifically, the study sought to address the following question: What are the direct and indirect effects associated with the quality of teaching, fear of asking mathematics/science questions, satisfaction with school, the importance of studying mathematics/science for students' future studies and careers and their STEM learning. Thus, the hypotheses that have been analyzed in the study are as follows:

- H1: The more students are afraid of asking mathematics/science questions in class, the more negative impact this is likely to have on students' STEM learning.
- H2: The higher the quality of teaching, the more positive impact this is likely to have on students' STEM learning.
- H3: The more students are satisfied with school, the more positive impact this is likely to have on their STEM learning.
- H4: The more students perceive the importance of mathematics/science to their future, the more positive impact this is likely to have on their STEM learning.

METHODOLOGY

Sample Design

The survey targeted students of grades 8, 9, 10, and 11 as the population of interest. To select the survey participants, a sampling frame was created by the Social and Economic Survey Research Institute (SESRI) using an extensive list of all the public and private schools in Qatar, which was provided by the Ministry of Education. In this frame, all schools are listed with information pertaining to their school names, addresses, school gender, school type/curriculum (independent, international, private, or other type of schools), and the number of students in grades 8, 9, 11, and 12.

Drawing on the information about the school size, school type, gender, and grade, the sampling frame has been divided into several subpopulations (i.e., stratum). This stratification divided members of the population into subgroups that were relatively homogenous before the commencement of the sampling procedure. It has been ensured that every member of the population has the same probability of being selected (i.e., self-weighting) so proportionate sampling was employed to make the proportion of students in each stratum similar between the frame and the sample. In other words, the number of sampled schools was proportionate to the number of respondents across strata in the frame (assuming that the same number of students was selected from each school). Inside each stratum, students were randomly selected following a two-stage sampling process. In the first stage, the school was selected with probability proportionate to its size. This gives an equal chance of selection for students while allowing for a similar number of students to be chosen from each school from each stratum. In the second stage, for ease of the fieldwork, we randomly selected one class for each grade in the school and all students in the class were included in the survey. Students in grades 11 and 12 in the secondary schools and students in grades 8 and 9 in the preparatory schools were selected.

Thus, this study encompassed a sample size of 1,625 students (grades 8, 9, 10, 11) from 34 schools (public and private). The maximum sampling error for a percentage is +/-2.6 percentage points for the student survey. The calculation of this sampling error considers the design effects (i.e., the effects from weighting, stratification, and clustering). One possible interpretation of sampling errors is: that if the survey is conducted 100 times using the same procedure, the sampling errors would include the "true value" in 95 out of the 100 surveys.

Instrumentation (Questionnaire Construction)

Drawing on the literature review and discussion with experts in this area, the researchers in the study constructed an appropriate survey instrument (Keir et al., 2014; Koyunlu Ünlü et al., 2020; Blotnicky et al., 2018). The questions were designed in English and then translated into Arabic by professional translators. The Arabic version was checked carefully by fluent Arabic-English bilingual researchers at SESRI. Next, the questionnaire was tested in a pre-test of four randomly selected schools, yielding valuable information that allowed us to refine question-wording, response categories, instructions, and the length of the questionnaire. Using this information, the final version of the questionnaire was created and then programmed for data entry purposes.

Survey Administration

Prior to administering the survey, all commissioned field researchers participated in a training program covering the fundamentals of school surveys, interviewing techniques, and standard protocols for conducting survey instruments. All interviewers were taken through the questionnaire before going to the schools. Interviewers were required to enlist the cooperation of schools and students, encourage students to respond and provide answers that best represent their thoughts, clarify any confusion or concerns students may face, and observe the quality of responses students provide. Data were collected from students using paper questionnaires based on the Paper-and-Pencil Interviewing (PAPI) technique.

Data Analysis

After the data collection process was completed, responses from students were entered by interviewers manually into Blaise, a computer-assisted survey interview processing tool. The responses were then merged into a single Blaise data file. The dataset was then cleaned, coded, and saved in STATA format for analysis. After weighing the final responses, the data were analyzed using STATA 14. Tables and graphs were generated using Microsoft Excel and Word.

RESULTS

Factor Analysis and Construct Validation

The questionnaire has been constructed after thorough research and is grounded on prior literature in the field (Keir et al., 2014; Koyunlu Ünlü et al., 2020; Blotnicky et al., 2018). Only items having the 5-point Likert scale were used in exploratory factor analysis. Factor analysis was carried out as a data reduction technique and a test of the construct validity of the questionnaire (instrument). Two statistical tests were conducted to determine the suitability of factor analysis. First, the *Kaisers-Meyer-Olkin (KMO)* measure of sampling adequacy score of 0.783 was well above the recommended level of 0.50. Second, Bartlett's test of Sphericity was significant (Chi-Square = 3782, *p-value* < 0.00), indicating that there are adequate inter-correlations between the 14 valid items which allow the use of factor analysis. Principal axis factoring was employed as an extraction method and oblique rotation as a rotation method. Using an Eigenvalue greater than one criterion, five factors (variables) were extracted. The following factors (variables) have been finalized (1) Quality of teaching, (2) Satisfaction with school, (3) Fear of asking mathematic/science questions, (4) The importance of mathematics/science to the students' educational/ career plans and, (5) STEM learning. Among these five variables, "STEM learning" has been considered as the dependent variable and the rest as independent or explanatory variables.

Table 1. *Coefficients* analysis

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	.766	.087		8.845	.000
	Quality of teaching	.216	.031	.235	7.019	.000
	Fear of asking math and science questions	-.037	.018	-.058	-2.030	.043
	Satisfaction with school	.069	.023	.096	2.962	.003
	Importance of math and science to educational and career aspirations of students in Qatar	.240	.025	.291	9.791	.000

Dependent variable: STEM learning employing direct instruction and discovery learning models. Significant at 0.05.

Assessing Internal Reliability Employing Cronbach Alpha

The first variable (Teaching Quality: *Cronbach Alpha* = 0.78) accounts for 29.52% of the total variance and is defined by four items, with factor loadings greater than 0.75. The second variable (Satisfaction with school: *Cronbach Alpha* = 0.772) accounts for 7.56% of the total variance and is defined by two items with factor loadings greater than 0.89. The third variable (Fear of asking mathematics/science questions: *Cronbach Alpha* = 0.631) accounts for 10.3% of the total variance and is defined by two items with factor loadings greater than 0.85. The fourth variable (Importance of mathematics/science to students' future studies and careers of students: *Cronbach Alpha* = 0.5) accounts for 7.196% of the total variance and is defined by two items with factor loadings greater than 0.76. The fifth variable (STEM learning based on a homework assignment: *Cronbach Alpha* = 0.775) accounts for 12% of the total variance and is defined by four items with factor loadings greater than 0.75.

Regressing "STEM Learning" on the Other Independent (Explanatory) Variables

When regressing the dependent variable "STEM learning" on the other four explanatory variables that were determined by factor analysis, results revealed that the regression equation is highly significant ($F = 71.802$, $p = 0.000$) and the R^2 is 0.231). Followingly, **Table 1** illustrates the coefficient analysis, showcasing the association between the four independent variables and the dependent variable under study. All four variables (teaching quality, satisfaction with schools, the importance of mathematics/science for educational/career aspirations) have a significant positive relationship with students' STEM learning, except one variable (i.e., fear of asking mathematics/science questions).

Path Analysis Employing Structural Equation Modelling Approach

This study utilized structural equation modelling (SEM) analysis, which seeks to understand the direct and indirect effects on STEM learning by exploring (a) the quality of teaching, (b) fear of asking mathematics and science questions, (c) satisfaction with school, and (d) the importance of math and science to students' prospective education and professions. The causal findings of this study are different from the regular variable selection using traditional computer software such as Stata, R, SPSS, EViews, or any other computer software because it attempts to distinguish intermediary variables on the causal path from other variables. It is unlike ordinary multiple regression model selection approaches which do not consider the causal relationships. This study proposes an approach for selecting a causal mechanism represented by a path diagram with an unobserved variable (factor scores).

Figure 1 illustrates the results of a path analysis of the structural causal model. The algebraic signs of the direct effects of path analysis in this study support the stated hypotheses (H_1, H_2, H_3, and H_4) and are consistent with previous research. Research findings reveal that teaching quality, satisfaction with school, and the importance of math and science to students' future is positively related to STEM learning. By contrast, the fear of asking mathematics/science questions is negatively related to STEM learning. All these relationships are statistically significant.

DISCUSSION

Findings illustrated that the first variable, the fear of asking mathematics/science questions is negatively correlated to students' STEM learning. These results are in alignment with previous research that intended to investigate students' anxieties and negative experiences in the classroom (Beilock and Willingham, 2014; Kennedy and Odell, 2014; Cooper et al., 2020). The fear of asking questions in mathematics and science classrooms is closely intertwined with students' overall apprehension of these subjects. Factors such as anxious teachers and negative past experiences contribute to this fear (Beilock and Willingham, 2014). Also, this fear may perhaps be indicative

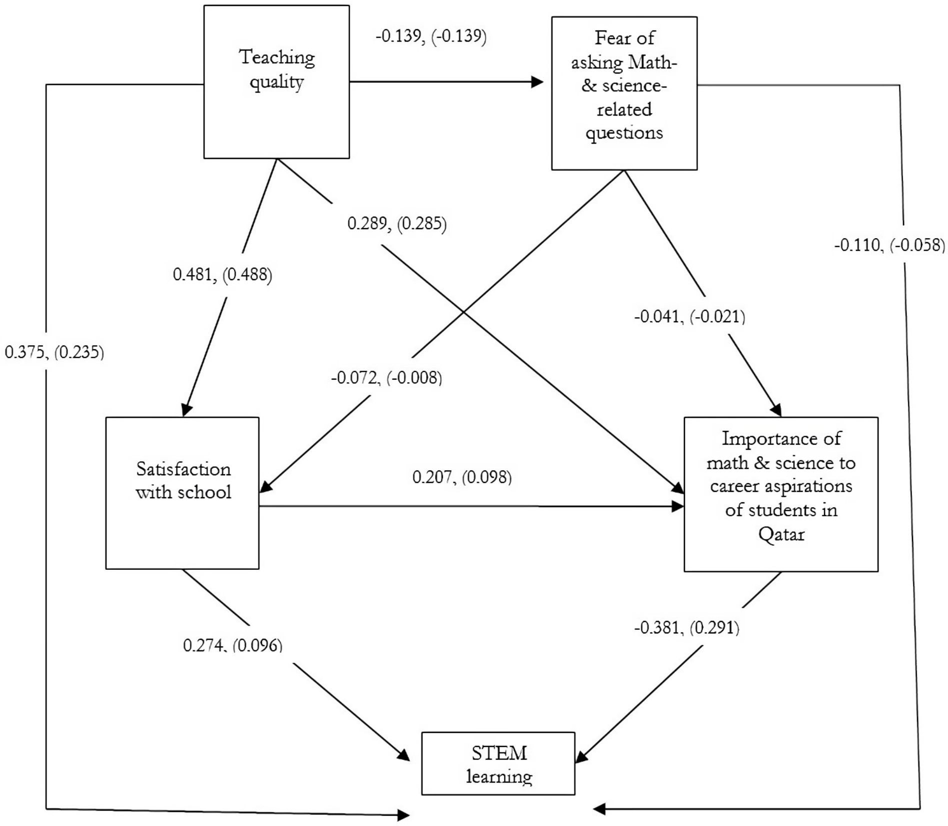

Figure 1. Path diagram employing SEM approach, illustrates relationship between investigated variables

of the classroom environment, especially when it is perceived as "an emotional minefield" (Bledsoe and Baskin, 2014, p. 33) where a teacher may be viewed as critical, judgmental, and unforgiving (Cox, 2009). Thus, when students feel insecure and anxious about mathematics and science, they are less likely to perform well in class and less motivated to study these subjects. In addition, the fear of asking questions may dissuade students from being interested in math and science and thus discourage them from pursuing further educational and occupational aspirations in these fields. Previous research has established strong evidence of a direct relationship between holding a math and science credential and better career opportunities (Fayer et al., 2017). To tackle this issue effectively, it's essential to place a strong emphasis on enhancing students' interest and engagement in these subjects. This can be achieved through the implementation of engaging curricula, fostering a sense of belonging, and creating positive classroom environments, among other strategies. The paramount importance should be placed on the quality of teaching. Hence, educators and researchers worldwide must work together in crafting contemporary teaching methods that offer all-encompassing, top-notch education and outstanding STEM instruction, as emphasized by Kennedy and Odell in 2014. Notably, Cooper and colleagues' study in 2020 revealed that the apprehension of asking questions in mathematics and science, along with student anxiety, significantly decreases when students receive proficient teaching utilizing an active learning approach (Cooper et al., 2020).

Followingly, the findings demonstrated that the second variable, the quality of teaching, is positively related to students' STEM learning. The same has been reported by many other prior studies (Akram, 2019; Adu-Boateng and Goodnough, 2022; Raph et al., 2022). The quality of teaching is often assessed through students' perceptions of the teaching methods employed by their teachers (Adu-Boateng and Goodnough, 2022) and the encouragement they receive from their teachers (Raph et al., 2022). To engage students effectively in high-quality STEM education, it is essential to provide rigorous curricula, effective instruction, and meaningful assessments (Kennedy and Odell, 2014). For this, teachers must receive adequate professional development opportunities that prepare them to guide all students toward achieving STEM literacy (Fauth et al., 2019). While the quality of teaching remains paramount in steering students toward STEM pathways, there are other psychological factors, such as overall satisfaction with schools and positive perceptions of STEM, that also play a significant role.

Therefore, the third variable that has been explored in this study is the student's perception of satisfaction with their schools. Findings reveal that if students have better satisfaction from school, they tend to have improved STEM learning outcomes. Also, research divulges that satisfaction with one's school experience plays a pivotal role in shaping students' decisions regarding their future educational and career paths (Hwang and Choi, 2019; Franz-Odendaal et al., 2016). Additionally, the initiatives undertaken by schools, along with the nature of classroom activities have a substantial impact on students' STEM learning and their aspirations for STEM careers. A school environment and curriculum that actively supports both formal and informal scientific investigations contribute to improved STEM learning (Franz-Odendaal et al., 2016). The study findings are also consistent with past work showing that student satisfaction with school is associated with their commitment to classwork and the praise or reward they receive when their work meets school requirements (Suldo et al., 2014).

The fourth variable investigated in this study is the impact of self-concept in mathematics/science towards STEM learning. Results showcased that students' positive self-conception regarding mathematics/science for their career/educational choice is directly related to their STEM learning. These findings are in alignment with prior research focusing on students' STEM identity and their STEM trajectories (Christensen et al., 2014; Sikora and Pokropek, 2012; Tseng et al., 2013). Students' self-conceptions about mathematics and science, which encompass their positive perceptions of STEM subjects, significantly influence the depth of their engagement with STEM and, consequently, their plans for education and careers (Christensen et al., 2014; Sikora and Pokropek, 2012). Tseng et al., 2013 found that knowledge of science is a significant predictor of a student's pursuit of a future career. This underscores the importance of early experiences and exposure to mathematics and science in the decision-making process related to one's educational and career choices.

This study's findings must be contemplated in the light of some limitations. While the present study relied on student surveys, it could have benefited from also analyzing qualitative data to complement the questionnaires. This would provide a more robust data set and help to investigate the perspectives of participants in more detail. Another limitation of the study is its use of a sample of students sharing characteristics specific to the GCC states, which may not be representative of populations that have different socio-economic attributes. Further research is needed to better understand the degree to which the education system in Qatar influences how students perceive the importance of mathematics and science to their future education and careers. To this end, it is particularly important to explore the perspectives of parents in order to elicit an alternative judgment. More work is also needed to understand the extent to which the findings of our study generalize to other contexts with heterogeneous student populations.

CONCLUSION AND RECOMMENDATIONS

This research aimed to explore the connections between students' perceptions of various factors related to students, teaching methods, and STEM (science, technology, engineering, and mathematics) learning. The study employed a quantitative exploratory approach and gathered data from 1625 students in Qatar, spanning both preparatory and high school levels. The investigation focused on examining the relationships among five key variables: (1) Fear of asking math/science questions; (2) The quality of teaching; (3) Satisfaction with school; (4) Positive perception of the importance of mathematics/science for students' future; and (5) STEM learning. The results of both regression analysis and structural equation modeling (SEM) indicated a significant positive correlation between the "quality of teaching," "satisfaction with school," "recognition of the importance of mathematics/science for the future," and "students' STEM learning." Conversely, the variable "fear of asking mathematics/science questions" was negatively associated with "students' STEM learning." Thus, in conclusion, this research provides valuable insights and recommendations for relevant authorities in the field of education.

The results from the present study call attention to the need for further enhancement of student STEM learning, especially in mathematics and science classes, where students must feel free to ask mathematics/science questions. It is essential to establish suitable policies and methods to guarantee that every school in the nation employs highly qualified instructors who are open-minded, composed, and flexible in their classrooms. Additionally, it is vital to provide ongoing professional development opportunities to help teachers create a supportive classroom atmosphere where students feel comfortable asking questions about mathematics and science. This is of utmost importance because when students feel at ease asking questions, it signifies their interest in these subjects, potentially leading to greater interest in pursuing STEM majors and careers. Furthermore, special focus must be given to designing pedagogical approaches that focus on student-centered models that actively engage students and remove the anxieties and fears of the subjects (especially mathematics and science). Thus, this study calls for strategies to create a non-threatening learning environment that encourages participation among students and support for students who feel insecure by employing collaborative learning.

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STEM Teachers’ Private Theories and Their Learning Design in International Schools in Hong Kong

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ABSTRACT

This paper reports on the study of private theories of Science, Technology, Engineering and Technology (“STEM”) teachers and their learning design practices at International Schools in Hong Kong. The literature emphasises that teachers are the key to successfully implementing STEM education. However, most are unprepared and ill-equipped for the task of preparing students for a sound STEM education. Teachers’ thinking is critical for their learning design, decision-making and implementation of STEM. This decision-making is underpinned by a set of private theories. Using the methodology of a qualitative multi-case study, this research focuses on five participants teaching STEM in International Schools in Hong Kong. The private theories of the cases were identified and observed for any change with the use of a learning design model for STEM education. The learning design is introduced using a novel methodology of intervention. An observable change occurs in the majority of cases after the intervention, however certain private theories remained an obstacle to the effective implementation of STEM education. To overcome the remaining private theories in effective implementation of STEM education, the study proposes a novel framework incorporating both learning design and collaboration to mediate teachers’ thinking in the context of STEM learning design.

Keywords: STEM education, private theories, learning design, RASE, collaborative professionalism

CURRENT STATE OF STEM EDUCATION

The acronym STEM (Science, Technology, Engineering and Mathematics) has gained substantial traction in education around the globe in the last decade. The expectation is that STEM education will boost students’ interest and achievement and that pursuing STEM studies will enhance their employability (van Driel et al., 2018). The second decade of the 21st century has seen governments and industry intensify their focus on STEM as a vehicle for future economic prosperity (Barkatsas et al., 2018). However, international research (Marginson et al., 2013) has demonstrated that STEM subjects are often taught in ways that fail to engage young people. Indeed, student interest and participation in STEM learning is declining, particularly in western countries and more prosperous Asian nations (Bøe et al., 2011; Kennedy and Odell, 2014; Thomas and Watters, 2015). This decline has led governments to develop policy that promotes reform and more significant investment in new initiatives for STEM-related education. Despite a sense of urgency to improve K-12 STEM education (kindergarten to Grade 12) at the federal, state and local levels in the USA (Forman et al., 2015) and elsewhere (Ritz and Fan, 2015), there remains a sense of vagueness concerning the nature and conceptualisation of STEM education, not only among educators, but also other stakeholders, including students, educational leaders and policymakers (Breiner et al., 2012; Sanders, 2009; Williams, 2011).

Teachers have a significant influence on student interest in and understanding of STEM educational pathways and careers (Autenrieth et al., 2017; Brophy et al., 2008). It is recognised in the literature that "success is brought about by extraordinary teachers who overcome a variety of challenges that stand between vision and reality" (National Research Council, 2011: 19). STEM education is an educational innovation that involves solving real world problems and novel curricular and instructional approaches (Nadelson et al., 2015). This requires teachers to focus more on student-centred learning and other related innovations and less on knowledge conveyance (Nadelson and Seifert, 2013). STEM teachers often have specialised training in one of the subject disciplines of STEM and are passionate about teaching STEM. However, classroom teachers with limited background knowledge, confidence and efficacy in teaching STEM may hamper STEM learning in their students (Nadelson and Seifert, 2013).

For STEM teachers to be effective in their practice, they must first have deep knowledge of the content they teach (Darling-Hammond and Sykes, 1999; Munby et al., 2001; Shulman, 1987; Wilson, 2011). Additionally, they must also have specialised knowledge of how to teach STEM to students, i.e., pedagogical content knowledge (Shulman, 1987). The research shows that many STEM teachers believe in STEM integration and see it as constituting the use of all four disciplines, but they have no clear understanding of how integration might be effectively enacted (Breiner et al., 2012). According to Kelley and Knowles (2016), educators and schools lack a cohesive understanding of the practice of STEM education, and yet teachers of STEM education are seen as the means to achieving the results that will ensure their students are able to learn and apply crosscutting concepts from different disciplines to solve problems (Bybee, 2010; NGSS Lead States, 2013; NRC, 2009, 2014).

All teachers hold beliefs, preconceptions and private theories (also referred to as private beliefs and the terms are interchangeable) that affect how they interpret experiences and guide their thinking as they make instructional decisions (Pajares, 1992). Vartuli (2005) stresses the importance of analysing teachers' beliefs, arguing that "beliefs are the heart of teaching," and are not merely theoretical understandings but serve to guide teachers' behaviour and decisions in the classroom. Teachers' private beliefs influence their choices regarding what and how to teach, and when, as well as how best to deal with students' problems. Their ability to implement their beliefs may also be subject to factors such as the school culture and institutional constraints (Zanzali, 2003; Cimbricz, 2002), which also play a critical role in their decision-making process when integrating technology into their classroom practices (Churchill and Wang, 2014). Hence, teachers' beliefs have drawn increased attention in education, particularly in the sciences (De Jong, 2007).

As teachers gain experience over time, so will their private theories change and alter, progressing their cognitive development (Howard et al., 2000). According to Churchill (2006), when a teacher is led to become aware of their private theories, these theories can be transformed such that there is a change in those that are dominant; this in turn leads to a change in the instructional decisions of the teacher. Churchill also articulates that it is essential to effective teaching for teachers to examine their private theories after they alter, modify or shift their thinking in any way.

A learning design is a cognitive structure that enables students to understand new information and engage in specific disciplinary thinking, problem-solving and further learning (Churchill et al., 2016). The RASE (Resource, Evaluation, Support and Evaluation) learning design framework is built on the concept that resources are insufficient for the full achievement of learning outcomes (Churchill et al., 2016), as seen in **Figure 1**, and that activity, support and evaluation are critical for teachers to ensure that learning outcomes are achieved. The RASE framework builds upon theoretical concepts such as constructivist learning environments (Jonassen and Henning, 1999), problem solving (Jonassen, 2000), engaged learning (Dwyer et al., 1985-1998), problem based learning (Savery and Duffy, 1995), rich environments for active learning (Grabinger, 1996), technology based learning environments (Vosniadou, 1995), interactive learning environments (Harper and Hedberg, 1997; Oliver, 1999), collaborative knowledge building (Bereiter and Scardamalia, 2003), Quest Atlantis (Barab et al., 2005), situated learning (Brown et al., 1989), MicroLessons (Divaharan and Wong, 2003; Churchill, 2006), and WebQuest (Dodge, 1995). It is critical to understand how teachers use and implement the learning design model in the STEM classroom to support them in teaching outside their area(s) of expertise. The RASE model focuses on what is considered essential for ensuring quality in teaching and learning and can be used in almost every program and course (Churchill et al., 2013).

Central to RASE is the emphasis on the design of activities in which students engage, using resources and producing artefacts that demonstrate learning (Churchill et al., 2013). Practically, this learning design enables teachers to develop more effective programs for their students, increasing engagement, giving students greater autonomy over their learning, and creating opportunities for deeper learning leading to the achievement of the intended learning outcomes.

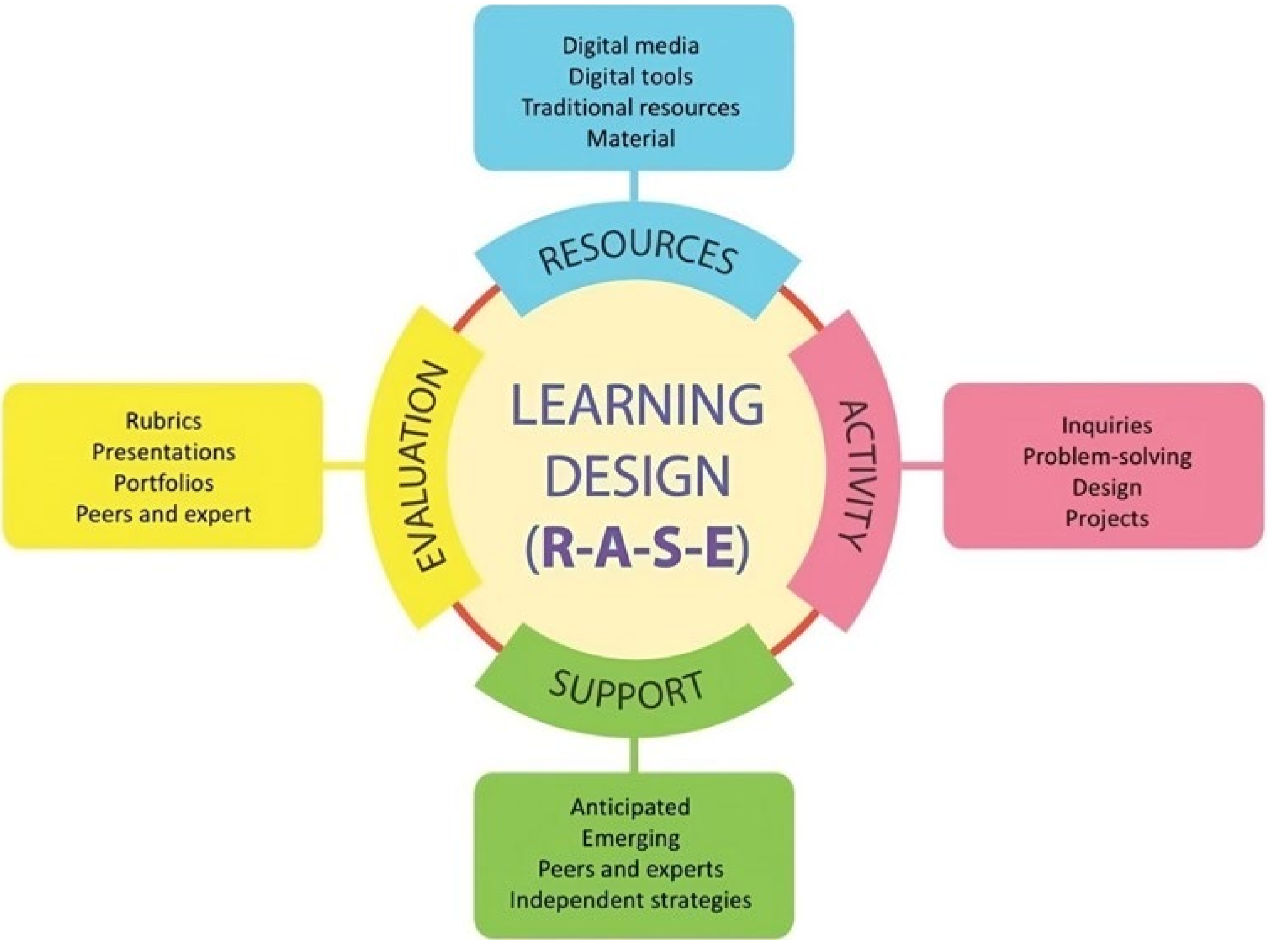

Figure 1. RASE learning design framework

METHODOLOGY AND APPROACH

The study seeks to address the following question:

How does a learning design model impact STEM teachers' private theories and approaches to learning design? In this context learning design means a strategy for transforming teachers' practices from teacher-centered to student-centered, which engages students to be more active in their learning, improved critical thinking and problem-solving skills.

Three sub-questions follow this:

(i) What private theories of the participating STEM teachers inform their instructional planning?
(ii) How do participating teachers' private theories change as they adopt a learning design framework?
(iii) What participating teachers' private theories continue to present barriers to effective implementation of a learning design for STEM education?

To answer these questions, the procedure used was guided by the recommendations from Merriam (1998), Yin (2009) and Stake (2006) and their approaches to qualitative, multi-case studies. This was essential to understand each of the case studies in-depth, exploring complex issues in a naturalistic, real-life setting. According to Yin (2009), case studies can be used to explain, describe, or explore events or phenomena in the everyday contexts in which they occur and help us to understand and explain causal links and pathways; these in turn should lead to new policy initiatives. The way this study has been approached is with an interpretivist approach to understand each of the individual cases in three stages.

During the recruitment process, the world was experiencing peak disruption from the COVID-19 pandemic. Schools ceased face-to-face lessons and replaced them with online teaching. Social distancing and the increased workload for teachers made it very difficult to gain access to potential cases to conduct selection interviews. Adding to the difficulties, classroom observations were curtailed because STEM teachers could not run their regular STEM courses or allow visitors into classrooms when face-to-face teaching was taking place. Ultimately five cases joined the study in this context and their backgrounds are summarised in **Table 1**.

Table 1. Background of the cases selected

Case	Gender	Age range	Teaching specialisation	Experience teaching STEM (years)
Bernie	Male	30-35	Design & technology, engineering	6
Moses	Female	40-45	Mathematics	6
Bridget	Female	25-30	Science	3
Milou	Male	40-45	Science	12
Freddy	Male	45-50	Science	3

Procedure

The data collection for this study was completed within a single academic year. This was significant as it provided consistency in the classes and programs, and the documentation collected. The relevant period was the northern hemisphere 2021-22 academic year.

Data collected during pre-intervention includes a semi structured interview, lesson observations and artifacts. The data collected included the teaching background of each case and findings on how the individual participants incorporated STEM education in the classroom, and how private theories impacted their teaching. The cases reported how they became involved in STEM teaching, their definition of STEM education, how STEM is implemented into their school curriculum, and the impact of their private theories on their teaching of STEM. For example, an interview question was, "When you plan a lesson what is the first thing you take into account?" During lessons, the researcher observed, amongst other things, the focus of teacher from a pedagogical perspective, and part of the review of artifacts included considering the objective of the lesson.

At the second phase of data collection, the intervention program was developed in a workshop format to provide training on the RASE learning design model, including implementing it in a unit and the classroom. The RASE learning design model according to Churchill et al. (2013) is a practical, evidenced-based learning design model with applications of technology to improve student learning outcomes and satisfaction. The program also included discussion on the challenges of STEM teaching and potential opportunities to improve their delivery. Following the pre-intervention data collection, all cases attended the workshop at The University of Hong Kong. It included a presentation by an MTR Academy representative on industry demand for STEM graduates in Hong Kong. The cases were provided with instruction on using the RASE learning design framework. Data was collected from the intervention via an open question and answer forum, which evolved organically into a participant-centred discussion on unit development for STEM education and associated challenges, primarily due to institutional constraints.

The third data collection phase was a follow-up survey individualised for each case and sent after they had had sufficient time to include the RASE learning design in a STEM unit of study. The survey's purpose was to determine whether their private theories and reflections had changed since the intervention in respect to their learning design for STEM education, and whether they considered any of their private theories an obstacle to effectively using the RASE learning design model.

RASE Learning Design Framework

The RASE learning design is practical and aims to improve student learning outcomes with an evidence-based learning design model (Churchill et al., 2013). The RASE model focuses on what is considered essential for ensuring quality in teaching and learning and can be used in almost every program and course (Churchill et al., 2013). The RASE model is suitable for STEM education due to it is practical student-centered and problem-based approach to teaching.

Central to RASE is the emphasis on the design of activities in which students engage, using resources and producing artefacts that demonstrate learning (Churchill et al., 2013). Practically, this learning design enables teachers to develop more effective programs for their students, increasing engagement, giving students greater autonomy over their learning, and creating opportunities for deeper learning leading to the achievement of the intended learning outcomes.

Analysis

Using a qualitative approach to content analysis, areas of private theories were identified in the literature and then compared with the private theories explicated in this study for each of the participating cases. Patterns and themes were identified for each case and confirmed through reference to the literature. The private belief were identified through interviews with each case and confirmed with lesson observations and documented artifacts. The researcher had to identify the private theory in every one of the three sources (interview, lesson observations and artifact) in order it to be confirmed. Investigation of patterns and themes through cross-case analysis indicated that the cases' private theories transformed after they were exposed to the RASE learning design.

Table 2. Private theories and their codes (Xue and Churchill, 2019)

Area of private theories	Code
Teacher	• Teachers' roles in a technology-based environment • Their perceptions of the affordances of technology • Their ways and experiences of using technology • Their capabilities and confidence in using technology • Their perceptions of their own professional identity
Teacher knowledge	• Teachers' content and technological knowledge • Their pedagogical knowledge about technology integration • Their own definitions of technology integration
Students	• Students' backgrounds and characteristics • The role they play in teaching and learning • Their ability in using technology for learning, and way of doing so
Learning	• How knowledge of an academic discipline is acquired • Useful teaching and learning strategies • Ways learning can be evaluated
Design	• Selection criteria for topics • Design of technology-based learning
Technology	• Relevance of technology to learning • Efficiency and limitations of technology on learning • Benefits of technology for learning • The roles of technology in students' lives
Institutional influences	• Relevance of technology to learning • Efficiency and limitations of technology on learning • Benefits of technology for learning • The roles of technology in students' lives
Educational changes	• Changes in society and their implications for education • Ways in which such changes impact teachers and students • Tendencies in technological development

Analysis was conducted from the first round of interviews which were transcribed and read by the participants and validated. Lesson observations and documents served triangulation. The data from the transcripts was then used to identified key themes in conjunction with Worksheet 2 developed by Stake (2006) and recorded. To add validity member checking (Merriam, 1998) between researchers was done. Any discrepancies that arose were discussed with a resolution reached.

According to Xue and Churchill (2019) there are key private theories held by teachers that impact their learning design. These are included in **Table 2** and were used in this as the basis of identifying the key private theories under the headings as well as the option for the identification of new theories from the cases that participated. Cross-case analysis occurred using Stake's worksheet No 4.

RESULTS: THE TRANSFORMATION OF STEM TEACHERS' PRIVATE THEORIES IN THE STUDY

Each of the cases were selected from international schools in Hong Kong. International schools were selected because they provided English language instruction and were accessible to the researcher during the COVID- 19 pandemic. Each of the schools were currently running a STEM program that had been incorporated into their curriculum.

All cases are identified with a pseudonym to protect their privacy.

Case One: Bernie

Bernie had been teaching Design & Technology (D.T.) in the United Kingdom for five years followed by seven years at an international school in Hong Kong. He commenced teaching STEM when this school introduced a non-assessable programme for students in years 9, 10 and 11. Bernie's initial tertiary qualification was a bachelor's degree in engineering at a university in the U.K..

In pre-intervention interviews Bernie identified the key private theories as 'students', 'teacher', and 'institutional influences'. He recognised that students wanting the latest technologies and innovations to support their experience solving real-world problems played a critical role in the forming of teachers' private theories. This was evident in the practical lessons and lesson plans collected from Bernie. The aim for his lesson was for students to solve problems through collaboration to create a vertical indoor hydroponic garden using the latest technology. Bernie identified the teacher was central to introduce technologies, since without these students would not receive the necessary exposure. The institution instructed the curriculum and did not encourage collaboration between faculties of the STEM subjects.

Post-implementation of the RASE learning design, Bernie identified that despite his background in Engineering and Design & Technology, a full teaching load made it very difficult to invest sufficient time in following technology trends, thus confirming 'teacher knowledge' as a continuing private theory. In addition, 'institutional influences' were evident as his institution continued to restrict STEM education to elective courses for middle school years rather than integrate with its International Baccalaureate (I.B.) curriculum. The IB is an international educational curriculum that offers a framework for students aged 3–19 years. This program is recognised worldwide and aims to develop students with strong academic, social and emotional characteristics.

Case Two: Moses

Moses has taught for eleven years, with initial training as a Bachelor of Arts majoring in Architecture. He had worked as an architect for ten years before retraining as a Science and Mathematics teacher. Moses has taught STEM for three years, currently to middle school students aged 11 to 13.

Pre-intervention data collection identified the critical private theories of 'student', 'learning', 'design' and 'educational changes'. Lessons were planned around students working on an in-class project in groups to learn from and help each other. This need for the teacher to ensure student involvement was a critical factor in how Moses decided what unit of work he would choose for students. Students were challenged with new skills outside their regular learning. The project design was explicitly planned and organised to facilitate the students learning how the final device works and the best design for high performance. It was observed that many students needed help understanding the names and purpose of the parts and were guided by an example of a completed project shown in class. The unit was adapted to teach online due to COVID-19; students could design using CAD software on their laptop computers and send to the school for printing.

Post-implementation, the private theory 'teacher knowledge' remained an obstacle for Moses as he continued to question his knowledge and understanding within the STEM disciplines. The impact of 'institutional influences' remained evident from lack of support for teachers and insufficient financial support provided for resources. The broad range of abilities in the class meant 'students' continued to be a challenge.

Case Three: Bridget

Bridget's initial training was in primary school; however she subsequently completed a Bachelor of Education in Science and Mathematics. STEM is compulsory in her school as part of its I.B. curriculum. She teaches STEM to Grades 6, 7 and 8 students.

The critical private theories that were dominant pre-intervention were 'learning', 'technology' and 'design'. Bridget's students were learning how to use a new form of technology, adapt its use in the design process, and improve their designs and ideas for possible future application. The role of the teacher was critical in this lesson; while it was a student-centred class, there were crucial instances in which the case had to lead and direct the students to enhance their understanding of what to do and how to do it.

The vital private theories that were observed to be obstacles for Bridget post her use of the RASE learning design in her STEM teaching were 'teacher', 'institutional influences' and 'educational changes'. Bridget acknowledged that while her current school was well resourced, her sense of inadequacy when teaching STEM persisted. She recognised that while her knowledge had increased, further development was still required for the STEM disciplines in which she did not have teaching experience. The institutional expectation was that Bridget would be part of additional teams within the school community, creating additional demands on her time. It also prohibited collaboration with STEM teachers from other institutions. Bridget identified the need for more connection and consistency between the STEM curriculums of the elementary and secondary schools.

Case Four: Milou

Milou has sixteen years of teaching experience, twelve of which involve teaching STEM. Her initial training was an undergraduate degree in Mathematics (Canada), followed by a Master of Science in Information Technology at the University of Hong Kong. Milou commenced teaching in Hong Kong as an English teacher, later switching to Mathematics due to personal interest and her previous training. STEM is a compulsory subject in Milou's school.

Table 3. Categories of private theories that are an obstacle (pre-intervention)

Private theories	Bernie	Moses	Bridget	Milou	Freddy
Theme 1 – Teacher	X			X	
Theme 2 – Teacher knowledge					
Theme 3 – Students	X	X		X	X
Theme 4 – Learning		X	X		
Theme 5 – Design		X	X		
Theme 6 – Technology			X		X
Theme 7 – Institutional influences	X				
Theme 8 – Educational changes		X			

The ‘teacher’ and ‘students’ were the critical private theories that played a dominant role in observed lessons pre-intervention. Milou identified the teacher as playing a pivotal role in how the STEM course is taught. She identified that students play a crucial role in her private theories and the implementation of STEM education.

However post-implementation Milou identified the impact of ‘institutional influences’. She felt frustrated with reductions by the institution of STEM planning time but did acknowledge that COVID-19 had played a role in the decision. She was hopeful that the time allotted to STEM would increase when face-to-face lessons resumed. As she also continued to emphasis the teacher’s role in implementing lessons appropriately, ‘teacher’ remained an obstacle whilst ‘Catestudents’ was no longer considered to be one.

Case Five: Freddy

Freddy trained as a Physics teacher and has more than twenty years of teaching experience in that subject area; he has been teaching at his current school for the past seven years. For the past three years he has been incorporating STEM education into Physics lessons at the school’s request. He has no formal training in STEM education and sought professional support by joining the STEM Teachers Association, a worldwide association of teachers sharing materials and project ideas.

The researcher concluded that the fundamental private theories that informed Freddy’s teaching of STEM were ‘students’ and ‘technology’. He believed student interest to be a key factor in the topics he chose to study with his class and their ability to use technology. The students are at the centre of his planning and implementation of the STEM curriculum. Technology has helped keep students engaged, especially during online lessons.

Freddy identified that ‘technology’, ‘students’, ‘educational changes’ and ‘institutional influences’ were the key obstacles for him post-intervention. He highlighted the inclusion of technology with the use of the RASE learning design as an area he wished to explore since he had not recognised the lack of a learning design model as a limiting factor in his teaching. Students and their abilities were crucial factors in implementing STEM education more effectively in the classroom. Freddy was keen to keep up with innovation in education, however he felt a lack of time due to his current workload and school expectations prevented this. The expected workload for teachers in this institution is high, which resulted in a lack of time to plan STEM lessons, and this impacted the quality of teaching and opportunities to collaborate with teachers from the STEM disciplines.

CROSS-CASE RESULTS

Private Theories That Impact the Cases Pre-Intervention

The results are synthesised from each of the participating cases’ integration of the RASE learning design, private theories identified pre- and post-intervention, how these transformed and which remained an obstacle despite the use of the learning design. Following Stake (1995), the cross-analysis allows for comparing patterns and differences between each of the cases. According to the data, the private theories of Moses and Bridget underwent the most significant transformation with the application of RASE. The private theories of Milou, one of the most experienced teachers in the study, transformed least, as observed post-intervention.

Tables developed from Stake’s (2006) worksheet three were used to identify each of the participating case’s private theories pre-intervention and how they changed. Table 3 summarises the private theories of the cases when teaching STEM education pre-intervention, i.e., before use of the RASE learning design.

Results from pre-intervention data show all cases had confidence in their ability to teach STEM education no matter their experience or qualifications – that is, none identified ‘teacher knowledge’ as a private theory impacting their teaching of STEM education; all expressed the view during pre-intervention interviews that they had enough knowledge to confidently teach students even when teaching outside their area of expertise. Four cases identified ‘students’ as a private theory; all stated in their interviews (confirmed in lesson observations and documentation), that students’ abilities and interests heavily influenced what was taught and how it was delivered.

Table 4. Categories of private theories that are an obstacle (post-intervention)

Private theories	Bernie	Moses	Bridget	Milou	Freddy
Theme 1 – Teacher			X	X	
Theme 2 – Teacher knowledge	X	X	X		X
Theme 3 – Students		X			X
Theme 4 – Learning					
Theme 5 – Design					
Theme 6 – Technology					
Theme 7 – Institutional influences	X	X	X	X	X
Theme 8 – Educational changes			X		X

Table 5. Institutional issues identified by cases

Case	Institutional issues
Bernie	• Restriction on how many years students could elect to study STEM
Moses	• Restricted by timetabling • Restricted by yearly changes in total face-to-face teaching allocated to STEM
Bridget	• Access to limited resources • Room shortages leading to STEM being taught in a regular classroom
Milou	• Institutional expectations • Academic achievements for students • Restricted by yearly changes in total face-to-face teaching allocated to STEM
Freddy	• Institutional expectations Academic achievements for students • Restricted by yearly changes in total face-to-face teaching allocated to STEM

The critical private theories of 'educational changes' and 'institutional influences' were each selected by just one of the cases studies. The researcher concluded these private theories were rarely identified because most cases had sufficiently flexibility rather than follow a strict curriculum to implement STEM education.

Private Theories That Remain an Obstacle

Post-intervention, the cases' private theories had transformed except for Case Study 4. This is attributed to her being a very experienced teacher who was already delivering STEM curriculum through organised collaboration between STEM disciplines within her school. The data revealed that all cases had fundamental private theories that continued to inform and instruct their teaching of STEM education. **Table 4** summarises which private theories remained an obstacle post the RASE learning design intervention.

'Institutional influences' was identified as a private theory by only one case pre-intervention; however, post-intervention, all the cases realised that their institution was a more significant critical factor than initially thought. Cases shared that the institution impacted how they implemented STEM, their access to relevant professional development, and their ability to collaborate with teachers at other schools. This last issue was quickly identified as being due to the institutions, all international schools in Hong Kong, competing against each other for students, and thus restricting teachers through their contracts from sharing resources. The 'institutional influences' had not been a prominent factor for most cases as they were more focused on students and not mindful of how their institution was restricting what and how they could teach. **Table 5** summarises the specific restrictive issues identified by each case within their respective institutions.

Another private theory identified in the data as a critical obstacle was 'teacher knowledge', impacting all of the cases. While pre-intervention all cases had acknowledged challenges in maintaining and developing STEM knowledge, none had self-selected 'teacher knowledge' as a critical private theory. However, post-intervention, four cases stated that they often felt out of their depth with their knowledge when teaching outside their area of specialisation. While the cases felt more confident collaborating with other teachers when using the learning design model, they became more aware of their knowledge gaps in the new units they developed. Despite feeling more uncertain and stretched, a few of the cases expressed a desire to expand on their current curriculum by collaborating with other teachers in their school in STEM disciplines in which they are not experts.

DISCUSSION OF RESULTS AND RECOMMENDATIONS

The research results show that 'institutional influences' impacted all cases in various ways, including the approach adopted to incorporating STEM education into the school curriculum, funding and resources and support or lack of it for STEM education. The results also highlighted that 'teacher knowledge' was a key private

Table 6. Distribution of the private theories that remain an obstacle

Private theory	Distribution
Institutional influences	Lack of oversight and support from the administration Limited time given to teach STEM Structure within the school Competition between schools Insufficient resources and time for curriculum development Lack of training and development from the institution
Teacher knowledge	Lack of experience and qualification Finding real world problems Student engagement Implementing STEM in curriculum Connecting STEM disciplines within the school

belief impacting all of the case studies with limited out-of-field training in the STEM disciplines. Table 6 summarises how these private theories are distributed.

Institutional Influences

STEM education in Hong Kong international schools could be improved by opening up opportunities for more teacher collaboration on developing a set cross-school curriculum. While widely evident in the pre-intervention interviews, by the post-intervention stage all cases identified 'institutional influences' as a private theory that impacted the inclusion of STEM education in a variety of ways. Of those identified, the most prevalent were lack of oversight and support from senior leadership on programming, timetabling resulting in reduced time with students.

Teacher Knowledge

It was evident in four case studies' results that the private theory of 'teacher 'knowledge' directly impacted on student engagement. While all the case studies were keen to teach STEM, some admitted post-intervention that their knowledge, or lack of it, limited their ability to visualise and incorporate a broader STEM curriculum for their students. Therefore, appropriate 'teacher knowledge' is a key requirement for the STEM teacher. In particular, teachers' lack of experience and qualification and finding real world problems were those which presented the most often across cases.

Reflections

We propose a new education model for STEM teachers to use to assist in modifying or removing the private theories that remain an obstacle to successful STEM teaching. It is a combination of the RASE learning design and Andy Hargreaves' collaborative professionalism model by Hargreaves and O'Connor (2018). The results of this study demonstrate conclusively that with the adoption of a RASE learning design framework by STEM teachers, a significant proportion of their initially obstructive private theories end up being no longer an issue. However, in this study two key private theories persisted notwithstanding the use of the learning design – 'institutional influences' and 'teacher knowledge'. The main objective in using the RASE learning design is to compensate for the knowledge gaps of the STEM teacher. It is unrealistic to require them to be specialised in all STEM disciplines; therefore, teachers who do not have the support of a learning design model like RASE may be unable to put workaround measures in place to bridge gaps in their subject knowledge that will risk compromising their students' depth of knowledge and understanding of related learning material.

STEM education aims to develop students' capability and inclination to identify questions and solve problems associated with STEM-related issues and the natural and designed world (Bybee, 2013). From the study it can be reasonably extrapolated, based on the evidence gathered, that in international schools in Hong Kong (and reasonably likely elsewhere) there needs to be greater emphasis from institutions on increasing the quality of STEM teaching. An approach needs to be adopted that will recognise, change, and transform the teachers' obstructive private theories. International schools in Hong Kong strongly aspire to being leading institutions with effective and comprehensive STEM education programs. To achieve this, they need to recognise the barriers in implementation and ensure there is a framework with a carefully planned strategic approach to overcoming the obstacle of teachers' private theories. It is evident from this study that a formalised framework assists in improving the quality of STEM programs and the teaching of those delivering them, thus advancing the cause of building and bridging gaps in student knowledge and understanding.

Selection of curriculum content from each of the individual disciplines of STEM requires knowledge of multiple sub-disciplines. Developing a STEM education program that delivers holistic and intensive learning requires focused planning and collaboration between specialised subject teachers. Planning how to fit a modern and more inclusive version of STEM into an already crowded curriculum is an ongoing challenge (Lloyd, 2013). The formalisation and inclusion of teacher collaboration is an important part of the equation for achieving this since it will dilute if not negate the impact of STEM teachers' persistently obstructive private theories. In researching collaborative professionalism, Hargreaves and O'Connor (2018) contends that the evidence that professional collaboration benefits both the student and the teacher is undeniable. He views collaborative professionalism as a deeper and more rigorous form of professional collaboration. The results of this study have shown that the use of the RASE learning design model was effective in transforming the cases' private theories and thus removing some of the obstacles associated with them whilst the two obstructive theories of 'institutional influences' and 'teacher knowledge' could not be overcome solely through use of the RASE learning design. However, it is proposed they could be overcome with the inclusion of professional collaboration. The lack of formalisation of collaboration manifested in a broad range of degrees of collaboration occurring with all the cases, only one instance of which was organised and structured. However, the inclusion of collaborative professionalism in the RASE learning design creates a deliberate, committed and professional practice of collaboration between teachers. Hargreaves and O'Connor's (2018) definitive elaboration on collaborative professionalism is relevant here.

In combining the learning design with ten tenets of collaborative professionalism the former is the foundational framework. Collaborative professionalism is a secondary step to ensure the implementation of collaboration is formalised and agreed upon by the participating teachers and embedded in each aspect of the learning design in order to remove any remaining obstacles attributable to teachers' private theories. As part of the intervention, there was a collaboration that occurred, and it did help in this respect. However, it needed to go further to entirely remove private theory-related obstacles. The researcher believes that a formalised structure of collaborative professionalism will effectively counter the obstructive effects of private theories, such as 'institutional influences' and 'teacher knowledge'.

Summary and Recommendations for Further Studies

This study contributes to the literature by investigating different approaches to effectively incorporated STEM in the classroom. Its results show that the use of the learning design model can positively transform private theories and diminish associated elements that were initially identified as STEM teaching barriers. Nevertheless, for the cases some private theories remain an obstacle, namely those of 'institutional influences' and 'teacher knowledge'. The influence of institutions did not seem to be affected by the experience or capability of the teacher in this study, with variations in nature of influence attributable to the institution itself. Gaps in teacher's knowledge appeared surmountable in one case due to a deeply experienced case utilising a form of structured collaboration, with less experienced teachers acknowledging the benefits of collaborating. The researcher proposes that the use of the RASE learning design model combined with collaborative professionalism (**Figure 1**) will remove these obstacles and enhance the ability of the STEM teacher to provide meaningful and in-depth learning experiences for students. Further, through application of this proposed combination of RASE and collaborative professionalism, the STEM teacher will have greater support and confidence in teaching STEM across the subject disciplines when working with material outside their area of specialisation and training.

The combination of the RASE learning design model with collaborative professionalism provides scaffolding for STEM teachers when teaching outside their area of training or specialisation, regardless of their teaching experience. It also incorporates a deliberate and formalised structure that can remove private theories that remain an obstacle when teaching across STEM disciplines.

Based on this study, it is recommended that the STEM teacher have specialised training in a minimum of two of the STEM disciplines. The literature highlights that current Science teachers lack an understanding of the nature of engineering, limiting their ability to effectively integrate engineering into their Science instruction (Cunningham and Carlsen, 2014). Lack of specialised subject knowledge across the STEM subject disciplines hinders students in gaining the full breadth and depth of knowledge that STEM education should provide. The use of the learning design model reduces the gap arising from 'teacher knowledge' and increases understanding of the possibilities of implementing STEM education. Still, the institution's election of the STEM teacher should seek to identify those with multiple areas of specialisation of the STEM subject disciplines in order to provide a holistic curriculum and the best opportunity for students.

Collaboration within the institution between the STEM teacher and specialist teachers of the STEM disciplines is essential to reducing the STEM teacher's knowledge gaps. Careful planning of units will ensure that students not only acquire relevant knowledge and understanding, but that they will be able to apply it to solving real-world problems in the classroom. The recognition of the need for teachers to collaborate with others paves the way to enriching and transforming the STEM teacher's ability to provide a richer learning experience for their students.

Whilst Hong Kong international schools have autonomy in how they implement their STEM curriculum, these schools must adopt a practical and proactive approach to provide the best education for their students; leadership must ensure the selection of the right STEM program and teacher, embrace collaboration between silo departments and ensure that time is allocated for this to occur. With this approach, the institution can ensure that STEM can be effectively implemented into the school and will deliver the desired results for students.

A broader study could include investigating how local schools in Hong Kong adopt and implement STEM education in their curriculum. A component of further research could also be determining how many students want to pursue a STEM career after being exposed to STEM in their formal education, and which elements of their STEM education were most influential in steering them in this career direction.

It is clear from this study that the institution is a critical private theory that impacts the STEM teacher, and there is therefore a clear need to further research the roles of institutions in improving STEM education through teacher development and support.

Future research needs to investigate further the private theories of local teachers in Hong Kong teaching STEM education. The impact of their private theories, and then a cross-case analysis between local and international schoolteachers of STEM education.

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