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EDITORIAL

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In this issue of J-STEM, we have four articles focusing on diverse issues in STEM education. Mäkelä, Fenyvesi and Mäki-Kuutti (2020) designed a pedagogical framework for learning environments (LEs) based on feedback from students, teachers, school directors, parents, and STEM professionals. They recommended considering a wide range of different LE design principles to support multiple ways of teaching and learning, and to develop both subject-related and cross-curricular knowledge, skills, attitudes, values, and ethics, instead of focusing on singular design principles.

Hatisaru, Fraser and Beswick (2020) address the effective leadership position and understanding of STEM learning environments. They have drawn on a drawing test called (D-STEM) to investigate school principals' perceptions of STEM learning. The findings of the research make valuable contributions to different aspects of the STEM learning environment.

Relkin and colleagues explore informal learning experiences with robots and their parents' support. The focus group of the research constitutes 5-7 ages child and their parents. Findings indicated that parents predominantly used cognitive scaffolding strategies, such as asking questions, offering suggestions, and verbally acknowledging their child's actions.

Stohlmann (2020) from the University of Nevada, explores the STEM integration for high school mathematics teachers. This article discusses three methods that high school mathematics teachers can utilize for integrated STEM education. Stohlmann emphasized that by focusing on open-ended problems through engineering design challenges, mathematical modeling, and mathematics integrated with technology, high school students are more likely to see mathematics as meaningful and valuable.

Collectively, the articles in this issue of J-STEM make unique contributions to the STEM education literature ranging from early childhood education to teacher recruitment.

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RESEARCH REPORT

Developing a Pedagogical Framework and Design Principles for a STEM Learning Environment Design

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Abstract: *The need for effective and attractive learning environments (LEs) for science, technology, engineering, and mathematics (STEM) has been internationally recognized. Additionally, the connection between STEM learning and cross-curricular skills such as creativity, innovation, and entrepreneurship has garnered attention. A deep theoretical and empirical understanding is required when designing STEM LEs. In this study, a pedagogical framework for STEM LEs has been developed based on feedback from students, aged 10–18 years old, teachers, school directors, parents, and STEM professionals, and supported by the literature. First, representatives of key stakeholder groups in Belarus, Finland, Germany, Greece, and Spain (total n = 132) were invited to co-design focus group (FG) 1 sessions to collect their wishes related to STEM LEs. The data was collected through an online survey with open-ended questions. The analysis of the data led to the design of the pedagogical framework, which was validated by the same stakeholder groups (total n = 137) in FG2 discussions. The empirically and theoretically grounded framework entails general design principles as well as principles related to ways of teaching and learning, socio-emotional aspects, and cross-curricular skills. Both the results of this study and the previous literature suggest that different pedagogical design principles are highly interrelated. For instance, novel tools and methods, collaborative methods, reflective learning, and entrepreneurial skills may support creativity and innovation, and vice versa. Therefore, instead of focusing on singular design principles, we recommend considering a wide range of different LE design principles to support multiple ways of teaching and learning, and to develop both subject-related and cross-curricular knowledge, skills, attitudes, values, and ethics.*

Keywords: *STEM, learning environment, pedagogical framework, pedagogical design principles, focus group, co-design*

Introduction

The need for effective and attractive learning environments (LEs) for teaching and learning science, technology, engineering, and mathematics (STEM) has been recognized on both the European and global levels (see, e.g., European Union, 2016). Additionally, STEM learning is expected to be connected with cross-curricular skills related to creativity, innovation, entrepreneurship, and professional skills as well as with environmental, social, cultural, and economic sustainability (Edwards-Schachter et al., 2015; European Commission, 2018; Frisk & Larson, 2011).

It is generally acknowledged that it is vital to base LE designs on a deep educational understanding that is both theoretical and empirical. Previous studies have suggested that it is important to integrate the perspectives of students, teachers, and designers in participatory LE designs (Könings et al., 2014). In addition to students and teachers, inviting parents or external experts to the design process is useful for improving the connections between home, school, and the wider community (see Mäkelä & Helfenstein, 2016). The challenge, however, is developing pedagogical frameworks that entail design principles (i.e., principles guiding the design of LEs) that

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integrate both theory and various stakeholders' views in a balanced manner (see Jiménez Iglesias et al., 2016).

This paper presents a study in which primary, lower secondary, and upper secondary school students, teachers, school directors, parents, and STEM professionals in Belarus, Finland, Germany, Greece, and Spain were involved in the participatory co-design of a hybrid (virtual, physical, formal, and informal) STEM LE. The first aim of this paper is to present the validated results regarding the participants' wishes on teaching, learning, assessment, and motivation both in general and in relation to STEM subjects and cross-curricular skills (see the Results section). The second aim is to integrate the participants' wishes with the research literature to create a theoretically and empirically grounded pedagogical framework and design principles to support STEM LE designs in particular and LE designs in general (see the Discussion section).

This study is part of a broader European research project named Science, Technology, Innovation, Mathematics, Education for the Young (STIMEY), funded by the European Union's Horizon 2020 research and innovation program (2016–2019). The project researches and develops a hybrid educational environment with the aim of making STEM education more attractive to young people aged 10 to 18 years old. The STIMEY LE consists of components such as a social web platform, e-portfolio, robots, serious games, entrepreneurial tools, and a digital radio. It connects various stakeholders in shared efforts to engage and increase both female and male students' interest and motivation in STEM education, innovations, and careers from a young age.

In addition to STEM subjects, the STIMEY project focuses on cross-curricular skills (also referred to in the literature as transversal skills or competencies, twenty-first century skills, or key competences with different overtones in different contexts) particularly related to creativity and innovation, entrepreneurship, and professional life, as well as skills related to sustainability. For instance, a model for entrepreneurial tournaments was developed to engage learners in innovative processes and to stimulate their creative thinking. In the context of presenting the STIMEY pedagogical framework and design principles, we decided to use the term "cross-curricular skills" to underline the integrative, holistic (i.e. "cross-curricular") nature of the underlying theoretical and pedagogical efforts, and the active and learnable character of the fostered competencies (i.e., "skills"). As Amadio (2013, p. 7) pointed out, none of the skills included in cross-curricular configurations are especially new. However, what makes their role central in the current policy discussions is "the increased attention paid to the application of knowledge and skills to 'real life situations' as well as to the labor market demands arising from the changes in society due to the globalized economy and the information age." The cross-curricular design principles, in particular, play an important role in ensuring that the STIMEY LE does not only follow, but in many respects, proactively enhances the application of knowledge and skills (Wright & Davis, 2014). Furthermore, by offering several digital tools and opportunities for participation, networking, and play (Jenkins, 2006), the cross-curricular design principles are intended to facilitate the transition from the traditional "teacher-based approach" toward an active "learning-based approach" (Thomas & Brown, 2011).

In the first phase of the pedagogical framework development, participating Finnish and Greek stakeholders' wishes in relation to teaching and learning in general, and STEM subjects in particular were analyzed, and the results were discussed in light of the literature (Mäkelä et al., 2017). The present analysis was then extended to participants in Belarus, Germany, and Spain during two rounds of stakeholder involvement in all participant countries. In addition to stakeholders' wishes in relation to teaching and learning in general, and STEM subjects in particular, stakeholders' responses regarding cross-curricular skills were also analyzed, and the analysis was supported by a more extensive body of literature.

Method

Stakeholders were involved in the development of the pedagogical framework from the beginning. Thus, not only previous studies and theories, but also relevant aspects for the key stakeholders were included. A participatory design approach (Könings et al., 2014; Mäkelä &

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Helfenstein, 2016) and focus group techniques (Duarte et al., 2015) were combined in the focus group (FG) co-design sessions (see also Mäkelä et al., 2017) with various stakeholders.

Key stakeholder groups' wishes were first collected in FG1 co-design sessions in all participant countries. Framework and design principles were constructed based on an analysis of the participants' wishes. Then, in FG2 sessions, the framework and design principles were presented to the stakeholder groups as a form of member check or member validation (see Koelsch, 2013). The aim was to receive feedback from the participants and assure the truthfulness of our data interpretations as well as pragmatic validity or usefulness for the construction of the pedagogical framework. This allowed the participants to provide critical evaluations of the findings and to either confirm their accuracy and completeness or add aspects that they considered relevant. After this, theoretical and empirical literature was used to support the selection of the design principles for the framework. In this article, the support literature is presented in the Discussion section.

Participants

The participants representing the main stakeholder groups relevant to this project included primary, lower secondary, and upper secondary school students, aged 10–18 years, school directors, teachers, parents, and professionals working in STEM careers, all of whom were invited to FG sessions. It was ensured that the participant sample was gender balanced.

FG1 Sessions

Table 1 displays the number of participants in FG1 sessions for each stakeholder group by country and as a whole. Of the participants, 55% were female and 45% were male.

Table 1.
Stakeholder Groups per Each Country in FG1 Sessions

Stakeholder groups/countries	**Finland n =**	**Germany n =**	**Belarus n =**	**Greece n =**	**Spain n =**	**Total n =**
Primary school students	4	11	2	2	4	23
Lower secondary school students	6	2	6	2	5	21
Upper secondary school students	2	7	2	2	4	17
Teachers	3	2	3	6	2	16
Directors	3	3	3	3	2	14
Parents	5	3	4	6	4	22
STEM professionals (business and research)	2	0	2	3	1	8
University students	2	2	5	0	2	11
Total n =	27	30	27	24	24	132

FG2 Sessions

The aim was to include the same participants in FG2 that were in FG1, but also to invite new participants who would evaluate the results without prior participation in the project. Of the participants, 49% were female and 51% were male. Table 2 displays the participants in FG2, representing different stakeholder groups. As can be seen, 49% of the participants had also participated in FG1 sessions.

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Table 2.
Stakeholder Groups per Each Country in FG2 Sessions

Stakeholder groups/countries	Finland n =	Germany n =	Belarus n =	Greece n =	Spain n =	Total n =
Primary school students	7	12	1	2	4	26
Lower secondary school students	7	6	7	2	5	27
Upper secondary school students	2	10	2	3	4	21
Teachers	3	2	4	6	2	17
Directors	2	0	3	4	1	10
Parents	3	1	3	6	2	15
STEM professionals (business and research)	2	4	2	2	1	11
University students	1	2	5	0	2	10
Total n =	27	37	27	25	21	137
N (%) of participants from the FG1	12 (44%)	8 (22%)	12 (44%)	15 (60%)	20 (95%)	67 (49%)

Materials

FG1 Sessions

Materials for FG1 sessions involving various stakeholders in the STIMEY LE design were developed in collaboration with the research partners participating in the STIMEY project, first in English and then translated into local languages. FG discussions collected participants' wishes related to the main topics covered in the STIMEY project: teaching and learning, STEM subjects, cross-curricular skills, social media, games and gamification, digital platform, radio, social robots, gender, and safety issues. These topics were presented to the participants on slides displaying inspirational images of each topic. Participants' wishes related to each topic were collected using an online survey with open-ended questions.

Materials were designed based on the grounded theory approach (Strauss & Corbin, 1998). Instead of referring to specific theories on learning and motivation and pre-defining these concepts for the participants, we were interested in their ideas related to these topics. This document concentrates on an analysis of the participants' responses to the following main topics and their subsections relevant for the framework development: wishes on (1) teaching and learning (1.1. teaching, 1.2. learning, 1.3. assessment, and 1.4. motivation); and (2) STEM subjects (2.1. teaching, 2.2. learning, and 2.3. motivation). In addition, wishes on specific (3) cross-curricular skills (3.1. creativity, 3.2. sustainability skills, 3.3. entrepreneurship, and 3.4. connectedness with professional life) were included in the analysis. These topics and skills were considered most relevant for the STIMEY project's objectives.

FG2 Sessions

Materials for FG2 sessions entailed a presentation of the pedagogical framework and design principles, which were created based on the data collected in FG1 sessions. Further, results related to wishes regarding different STIMEY LE components (e.g., platform, radio, and robots) were presented. In addition to the oral conversations and feedback received during the sessions, a gamified Kahoot survey tool was used for member check/validation. This tool displays the immediate results for the whole group, which can then be discussed together. In relation to the pedagogical framework and development of the design principles, only one survey statement applied, which was: "The presented pedagogical design principles foster learning and motivation towards STEM." The statement was formulated based on the project's goals, which focus on not only learning STEM in general, but also raising interest and motivation toward these studies. Possible answer options were 4 = strongly agree, 3 = agree, 2 = disagree, or 1 = strongly disagree.

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Procedures

FG1 Sessions

Face-to-face co-design sessions were organized in all project countries at primary, lower secondary, and upper secondary schools during the 2016–2017 school year. Participants' written consent, and in the case of minors, their parents' written consent were obtained in advance. After a short description of the STIMEY project, researchers presented the topics for discussion one by one using presentation slides. The duration of the sessions ranged from 90 to 120 minutes, which left approximately 5 to 10 minutes to discuss and write down wishes related to each topic. While open conversation enabled the elicitation of collaborative ideas between stakeholder groups, writing wishes down enabled the participants to express themselves without the pressure or anxiety of voicing their views in front of others (Duarte et al., 2015). It also gave less extroverted participants a better chance to participate. Researchers were careful not to influence the participants' ideas. The researchers clarified concepts and gave examples whenever required. Participants were told that there were no right or wrong responses. They were, however, encouraged to think about and express their wishes as representatives of their stakeholder group, instead of thinking only about their personal preferences (see also Mäkelä et al., 2017.) All sessions were recorded.

FG2 Sessions

FG2 sessions were organized during the 2017–2018 school year. In addition to face-to-face sessions, some sessions were organized as video conferences to facilitate the participation of stakeholders from different locations. Participants provided written consent prior to the sessions, and all sessions were recorded. In all participating countries, the researchers conducting FG2 sessions started each session by briefly displaying the themes identified in FG1. This served as an introduction to new participants and a reminder for participants who had previously participated in FG1 sessions. Researchers then presented an overview of the FG1 results theme by theme in the form of tables. For primary school students, language was kept easy to understand. Sessions lasted between 1 and 2 hours. After presenting the results of a specific theme, the participants were asked to answer the questions related to it on the Kahoot survey. The same procedure was repeated until all themes had been displayed and the survey questions answered. The participants also had the opportunity to express themselves orally, but especially in the 1-hour sessions, the duration of conversations was limited due to time constraints.

Data Analysis

For the purposes of this study, the analysis of the data focused on participants' wishes on a general level in order to formulate the pedagogical framework and design principles. Comparisons between countries or stakeholder groups are left out of this analysis, but these can be considered in the future.

FG1 Sessions

The data analysis was initiated following the grounded theory approach (Strauss & Corbin, 1998). First, the written data collected via an online survey were coded using open coding techniques, whereby the data were broken into meaningful conceptual components (see also Mäkelä et al., 2017). Researchers in each participant country analyzed the data in their local language, but the data were also translated into English to create a shared understanding between the researchers participating in the data analysis. The researchers shared their initial codes in English based on the data. They discussed how each concept could be related to a larger group of concepts or themes. Additionally, example responses in English were provided for each conceptual component. The researchers compared the components identified in each country, seeking similarities and differences between them. Finally, the codes were combined into wider thematic groups to create a final list of codes. After this, the second round of analysis was conducted based on a shared understanding of the thematic groups between all participant countries. Reliability of the final coding was assured; thus, after the local researchers had coded the data in their local language, the researcher in charge of the coding process revised the codes using the English translation. Discrepancies between researchers

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in the coding process were discussed and resolved, leading to some final revisions.

Table 3 presents some example citations from the data from all participant stakeholder groups and countries, initial codes used in the first round of data analysis, and groupings of the initial codes into wider thematic groups in the final coding process. For instance, for the final coding, it was agreed to merge initial codes "learner's active agency," "learning by constructing or creating knowledge," and "no memorization" into a wider thematic group named "active knowledge construction." Additionally, citations related to "experiments," "inquiry/problem-based learning," and "science labs" were merged under "experiments and inquiry." In some cases, one fragment of the data was coded under different thematic groups. For instance, the expression, "teaching should include experimental and experiential teaching," by a Finnish male upper secondary school teacher was coded under "Experiments and inquiry" (see Table 3) and also under "Learning through experiences" (see Table 4).

Table 3.

Example Citations, Their Initial Codes, and Final Codes Created During the Data Analysis

Example citations	Initial codes	Final codes
"Pupils would have an important, active role." – a Finnish male primary school director "Students' active participation" – a Greek male lower secondary school teacher	Learner's active agency	
"Constructivist rather than teacher-centered learning" – a Greek female lower secondary school teacher "A place for constructing and interacting where students feel engaged" – a Spanish female lower secondary school student "Using building sets in maths" – a Spanish male primary school student	Learning by constructing or creating knowledge	Active knowledge construction
"No memorization of tricky texts" – a Greek female lower secondary school student "Applying knowledge not in the form of memorization" – a Belarussian male primary school director	No memorization	
"Various kinds of experiments" – a Greek mother of a lower secondary school student "That we do experiments" – a German female primary school student "Teaching should include experimental and experiential teaching" – a Finnish male upper secondary school teacher	Experiments	
"Solving general problems" – a German father of an upper secondary school student "More exploring by yourself" – a Finnish female primary school student	Inquiry/ problem-based learning	Experiments and inquiry
"Going to the laboratory" – a Finnish male lower secondary school student "Practical laboratory exercises" – a Spanish male upper secondary school student "Agreement with the laboratories at the university where it would be possible to do experiments" – a Belarussian mother of an upper secondary school student	Science lab	

While the open coding was made with no predetermined theoretical assumptions, during the final phase of the coding process, knowledge of existing learning theories and models was used to support the grouping and naming of the conceptual components into thematic groups. Example wishes for each theme were also collected to clarify what was meant by each code. The coded themes then served to name the design principles included in the pedagogical framework, which were

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grouped under four main categories: General principles, Socio-emotional aspects, Ways of teaching and learning, and Cross-curricular skills. At this phase of framework development, different themes were grouped under the category that they best suited thematically.

During the coding process, it was noticed that wishes expressed in sections (1) Teaching and learning, (2) STEM subjects, and (3) Cross-curricular skills as well as their subsections (see the Materials section) had a high degree of overlap. For this reason, a unified code list was created for all sections in the final phase of the analysis, instead of keeping a separate code list for each section. The frequency of wishes coded under one code could thus exceed the number of participants, as the same participant might mention the same wish under different FG sections. At this point, the analysis of the stakeholders' wishes related to cross-curricular skills was kept on a general level: only the frequency of wishes for fostering entrepreneurial skills, creativity, sustainability skills, professional skills, and transversal/cross-curricular skills expressed in sections 1–3 were coded and calculated.

FG2 Sessions

For the purpose of this paper, the number of each kind of response (4 = strongly agree, 3 = agree, 2 = disagree, or 1 = strongly disagree) related to the survey statement, "the presented pedagogical design principles foster learning and motivation toward STEM," was calculated, which served as a member check/validation for the framework and its design principles. In addition to the overall results, attention was paid to identifying possible differences between countries and stakeholder groups.

Results

FG1 Sessions

Table 4 presents the current version of the pedagogical framework and the titles of the pedagogical design principles. The design principles are based on the most frequent wishes identified in the data analysis of themes 1–3, ordered by the main categories created during the data analysis. The category "general principles" entails pedagogical design principles formulated from the participant stakeholders' wishes, which can be applied generally in the LE design. "Socio-emotional aspects" contains design principles identified in the data as referring to aspects that enhance interest, motivation, engagement, and wellbeing. "Ways of teaching and learning" includes pedagogical models and ways of teaching and learning mentioned by FG1 participants. Finally, "cross-curricular skills" represents competencies that are considered particularly relevant for the STIMEY LE. The design principles related to cross-curricular skills (theme 3) were already predefined based on the objectives of the STIMEY project, which provided the context for this study. However, wishes related to entrepreneurial and professional skills, creativity, and sustainability were also spontaneously expressed in wishes related to teaching and learning (theme 1) and STEM subjects (theme 2).

General Principles. "Connectedness" of studies to students' present and future lives was the most frequently commented wish of all (see Table 4). Participant stakeholders wished that students could perceive learning as useful to their future lives and careers. Furthermore, participants wished that assessments would be more connected with applying knowledge in practical situations. Creating connections with the local community through experts' visits to schools was also desirable. In relation to STEM subjects, in particular, participants wished that teaching was both connected with present scientific achievements and discoveries, and that it provided tools for students to improve STEM development for the global benefit.

Among the most frequently commented aspects were wishes related to "personalization", referring, for instance, to the importance of considering each learner's personal competency level, and their differences in knowledge, skills, rhythm, and ways of learning. According to participant stakeholders' views, the needs of both students with learning difficulties and gifted students should be considered. In addition to the competency level, participants gave importance to considering personal preferences and interests, and providing more freedom of choice. Participants also frequently referred to the importance of "teaching and learning aids". Teachers were expected, for

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example, to have tools and know-how for facilitating effective learning, teaching, and assessment, and to be able to use research know-how in teaching. Teachers were also expected to be able to motivate students using attractive, pleasant, and inspiring teaching methods and LEs that capture students' attention.

Table 4.
The Pedagogical Framework and Design Principles Based on the Most Frequent Wishes Identified in the Data Analysis (Participants, n = 132)

General principles	Ways of teaching and learning
Connectedness (f = 175)	Active knowledge construction (f = 85)
Personalization (f = 149)	Experiments and inquiry (f = 88)
Teaching and learning aids (f = 112)	ICT-enhanced learning (f = 70)
Novelty (f = 112)	Learning through experiences (f = 63)
Versatility (f = 91)	Participation and involvement (f = 60)
Conventionality (f = 33)	Learning outside the school (f = 56)
Socio-emotional aspects	Games and gamification (f = 49)
Joy of learning (f = 142)	Self-regulated learning (f = 43)
Extrinsic motivation (f = 88)	Collaborative methods (f = 40)
Intrinsic motivation (f = 53)	Reflective learning (f = 28)
Justice and equity (f = 27)	Multiple representations (f = 24)
	Project-based learning (f = 20)
Cross-curricular skills	
Entrepreneurial skills (f = 110)	Sustainability skills (f = 73)
Creativity (f = 98)	Professional skills (f = 67)

Another theme various participant stakeholders frequently commented on was the importance of "novelty" in both tools and methods. Under this theme, suggestions were grouped related to novel, creative, and innovative methods, such as learning by moving (i.e., doing physical exercise) or combining STEM learning innovatively with other activities, such as cooking, sports, and building different artefacts. Further, comments opposing the use of traditional materials, such as paper textbooks, were grouped under this topic. In relation to novel assessment, many participants requested either fewer exams or no exams or assessments at all. In addition, some participants opposed numeric grading. The importance of "versatility" in teaching, learning, and assessment to the participants was also evident throughout the data. Participants frequently referred to the importance of versatile and various methods, tools, and LEs. They asked for assessments based on various criteria, such as knowledge, skills, interests, attitudes, and behavior, and grading based on different activities completed during the learning process, instead of only a final examination. Furthermore, versatility was frequently mentioned in relation to aspects that would increase motivation in learning in general and learning STEM subjects (see also Socio-emotional aspects). In addition, some positive comments related to "conventionality" in tools and methods were identified. Participants commented, for example, that the use of books, pencils, and paper should not be abandoned.

Socio-emotional Aspects. The importance of "the joy of learning" was evident throughout the responses (Table 4). Participant stakeholders referred to the importance of enjoyment, learner satisfaction, and having fun. Some participants also commented that assessments should not cause negative consequences; rather, assessments should encourage students and contribute to a positive climate. Other participants expressed concern about long school days, homework, and extracurricular work at the expense of students' free time, thereby affecting their joy of learning. Some comments were related to the importance of a positive social climate for learning, fostered by good peer and teacher–student relations.

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Motivation was a frequent theme commented on not only in subsections directed to this topic but throughout all sections. Many of the participants' comments could be categorized as "extrinsic motivation". On the one hand, participants referred to the importance of positive and rewarding feedback, encouragement, and rewards, and on the other hand, they desired inspiring, comfortable, and good LEs, equipment, tools, and materials. Participants also referred to the importance of supporting "intrinsic motivation" (i.e., the inner need to learn), personal interests, desires, needs, and competencies. Finally, a considerable number of participants referred to the importance of "justice and equity", or equal treatment of all students, no discrimination, and fair assessment.

Ways of Teaching and Learning. Participants frequently referred to learning as "active knowledge construction" (see Table 4). Wishes related to the importance of considering learner's active agency, active learning, and constructivism or learning by constructing or creating knowledge were grouped under this theme. The theme also entailed comments criticizing frontal teacher-centered teaching or memorization. Specifically, in relation to STEM studies, participants frequently wished for more learning through "experiments and inquiry", entailing laboratory experiments, scientific inquiry in learning, discovery learning, and problem-based learning. Some participants highlighted the importance of having science labs at schools.

Wishes related to "ICT-enhanced learning" were frequent in all FG sessions. This theme included comments related to the use of technology, such as technical aids, mobile technology, virtual glasses, electronic measuring systems, platforms, robots, and digital assessment tools. The importance of "learning through experiences" (i.e., learning based on everyday or real-life examples), experiential learning, and learning by doing was also made evident in co-design sessions. Similar importance was given to the theme labelled "participation and involvement", where suggestions related to participatory, interactive, and conversational teaching-learning interaction were gathered. Some participants also referred to dialogical forms of assessment and co-designing learning with students. In addition, "learning outside the school", such as field trips and visits to workplaces, was suggested by many participants. A theme labelled "games and gamification" was created based on frequent comments on learning games and game-like elements, including non-digital components such as the use of play, stories, and narrative.

Furthermore, "self-regulated learning" (i.e., independent, autonomous, and self-directed learning), "collaborative methods" (i.e., teamwork, group work, cooperation, etc.), and "reflective learning" (i.e., reflection, deep thinking, creative thinking, and critical thinking), were raised as important concerns. Comments referring to various digital and non-digital forms of presenting information, including visuals, multimedia, audio, simulations, and animations, were gathered under the thematic group labelled "multiple representations". Finally, a considerable number of participants mentioned a desire for "project-based learning" (i.e., learning through cross-curricular or transversal projects), phenomenon-based learning, or linking different subjects.

Cross-curricular Skills. Fostering cross-curricular skills was considered important by the participating stakeholders (Table 4). Wishes related to promoting "entrepreneurial skills" entailed entrepreneurial games, tournaments, and simulations. Furthermore, participants considered that experts' visits to schools (also coded under a general principle named "connectedness") and visiting different working environments (also coded under ways of teaching and learning named "learning outside the school") would support the development of entrepreneurial skills. Entrepreneurial skills were also connected to creative problem solving, idea creation, and innovation. Some participants proposed that students could practice these skills by founding their own companies. In relation to "creativity", many participant stakeholders wished that all school subjects incorporated creative thinking. Participants referred to the importance of creating alternative solutions (i.e., "thinking outside the box") and solving problems together with others. They mentioned the importance of learning about and with new inventions and tools, something that was also coded under a general principle named "novelty." Mentions of using novel technological tools were also coded under ways of teaching and learning and named "ICT-enhanced learning." In some responses, the need for creativity was linked to societal and labor needs. For instance, the creation of new businesses was mentioned as an important long-term objective. "Sustainability skills" was also considered a vital topic to integrate into all school subjects and school life as a whole. Participant stakeholders wished that sustainability was promoted and considered in practical ways through activities of daily life. Some concrete actions, such as caring for animals and plants, recycling, and collecting waste, were proposed. Fostering "professional skills" overlapped somewhat with fostering entrepreneurial skills. For instance, participants wished for cooperation with representatives from professional life. Likewise, helping students identify work internship opportunities and future professions they might be interested in were considered important by many participants.

FG2 Sessions

Table 5 presents the responses to the statement, "the presented pedagogical design principles foster learning and motivation toward STEM." Among all the participants, 94.34% either agreed or strongly agreed with the statement, assuring the validity and usefulness of the pedagogical design principles for learning and motivation toward STEM from the participant stakeholders' perspectives. Oral comments received from participants confirmed that the design principles were seen as valuable in guiding the STEM LE design. The data did not reveal any clear differences in opinions between adult and learner participants, or between different age groups or genders. Only some male participants from Finland and Germany disagreed or strongly disagreed with this statement. Unfortunately, the disagreeing participants did not express their reasons for doing so.

Table 5.
The Percentages of Responses to the Statement, "The Presented Pedagogical Design Principles Foster Learning and Motivation Toward STEM" (Total of Participants, n = 137)

1. The presented pedagogical design principles foster learning and motivation toward STEM	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**
FINLAND	22.73%	72.73%	0	4.54%
GERMANY	29.42%	41.18%	11.76%	17.64%
GREECE	43.48%	56.52%	0	0
BELARUS	58.33%	41.67%	0	0
SPAIN	65.00%	35.00%	0	0
Total in all countries	44.34%	50.00%	1.89%	3.77%

Discussion

The current version of the pedagogical framework and design principles, which was developed based on the FG1 co-design sessions and validated in the FG2 sessions involving various stakeholders in five countries, is also strongly supported by both theoretical and empirical research literature. Of the theoretical considerations, the design principles are very much in line with Dewey's (1907, 1916) educational philosophy, which views learning as a learner-centered, active, experiential, and reflective pursuit. Further, they are in line with socio-cultural and socio-constructivist paradigms inspired particularly by the work of Vygotsky (1978), who viewed social environments and the mediating artefacts as essential for learning. Connections can also be found in Bronfenbrenner's (1979) ecological model, which views human development as taking place in reciprocal interactions with people, objects, and symbols, particularly through proximal processes in an individual's immediate environment.

General Principles

The first general design principle based on the empirical data collected in this study and supported by the research literature, "connectedness", draws attention to the importance of connecting LEs with real problems that are socially relevant (see Dewey, 1916), and with social and work-related activities (see Bronfenbrenner, 1979). Additionally, learning should be connected with learners' prior knowledge and experiences, and practices, and the transfer of learned knowledge or

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skills in new situations should be supported (Lee, 2003; Scardamalia et al., 2012).

In relation to "personalization", Dewey (1916) wrote about the importance of "flexible personal experiences" and the use of various methods according to each individual. Notions related to personalized learning are also in line with student-centered learning principles that draw attention to considering learners' prior knowledge and personal needs, presenting possibilities for choice (O'Neill & McMahon, 2005), and adapting teaching to individual needs (Cornelius-White, 2007).

With respect to the design principle named "teaching and learning aids", based on the results of FG sessions, it seems that teachers need support tools for their demanding task of guiding learners. Previous studies (Kokotsaki et al., 2016) have indicated, for example, that the success of constructivist, discovery, problem-based, experiential, and inquiry-based teaching (all of which are considered relevant ways of teaching and learning in this framework) is connected to teachers' competence to effectively scaffold students' learning and provide guidance and support. Thus, there needs to be a balance between didactic instruction and in-depth inquiry methods. Furthermore, this design principle is related to "pedagogical learning principles" named "scaffolding progressive inquiry," "supporting the active role of tutors," and "providing tools for structuring and coordinating activities," which were proposed for web-based collaborative LEs (Rubens et al., 2005).

The importance of "versatility" in tools and methods has also been highlighted both in theoretical considerations (e.g., Bronfenbrenner, 1979; Dewey, 1907, 1916) and in empirical studies (e.g., Mäkelä & Helfenstein, 2016). Based on Vygotsky's (e.g., 1978) theory of mediated learning, teachers are more commonly viewed as orchestrators of engaging and varying tasks, while learners interact with each other, the teacher, and mediating tools that connect them to the "highly supportive and stimulating learning environment" (UNESCO, 2012, p. 22).

With respect to "novelty", Dewey (1916) wrote, "Diversity of stimulation means novelty, and novelty means challenge to thought." The importance of novelty in tools (including but not limited to the use of ICT), methods, and spaces is also supported by recent studies (Mäkelä & Helfenstein, 2016). However, "conventionality" in methods, tools, and spaces can be supported by prior LE models that give importance to not only LEs' responsiveness to change but also their maintenance and stability (e.g., Fraser, 1998). Learners seem to, for instance, value combining the use of technology with the use of books and other traditional tools (Mäkelä & Helfenstein, 2016).

Socio-emotional Aspects

The importance of "the joy of learning" expressed in FG sessions can be supported by literature highlighting the need for satisfaction, joy, and happiness at school (UNESCO, 2012). Satisfaction and positive motivation have also been found to correlate with student-centered learning (Cornelius-White, 2007). Positive emotions, enjoyment, and interest toward learning, consisting of pleasant feelings and valuing learning, are also more likely to lead to autonomous motivational profiles such as intrinsic motivation (Loukomies et al., 2013).

According to the self-determination theory of motivation and its sub-theory named organismic integration theory (Deci & Ryan, 2002; Ryan & Deci, 2000), motivation orientations form a continuum. "Intrinsic motivation" is characterized by intrinsic regulation, autonomy, and self-determined behavior motivated by internal factors (see Ryan & Deci, 2000). Supporting intrinsic, autonomous motivation by creating LEs that provide learners with opportunities to fulfill their basic psychological needs may increase students' motivation toward science and science-related careers (Loukomies et al., 2013; Mäkelä et al., 2017). Intrinsically motivated people are also more likely to be satisfied by and enjoy schoolwork (MacLaren et al., 2017), thus contributing to the joy of learning.

In relation to "extrinsic motivation", students with the most extreme non-regulatory style, "amotivation," may fail to perceive the activity's value to be motivated to engage in it (Deci & Ryan, 2002; Ryan & Deci, 2000). External regulation may lead to performing the activity to receive the expected reward or to avoid punishment. Closer to intrinsic motivation are "identified regulation" (perceived personal importance, although not necessarily part of personal beliefs and values) and "integrated regulation" (perceived personal importance, which forms part of personal beliefs and values). Vainikainen et al. (2015) emphasized the role of situational interest, because interest is never entirely either intrinsically or extrinsically motivated, but it varies depending on the phase of interest development and the situation itself. They also underlined the distinction between individual and situational interest, as situational interest is largely dependent on the environment, for example, the ways in which the learning situation is organized (Vainikainen et al., 2015). Attention should be paid to inspiring and motivating environments that increase well-internalized forms of extrinsic motivation and may lead to the development of intrinsic motivation (Thuneberg et al., 2018). However, creative pedagogies and informal LEs are often faced with the challenge of enhancing situational motivation to support its transformation into intrinsic motivation and a deep-learning strategy (Thuneberg et al., 2017).

Finally, socio-emotional wellbeing may be fostered by following the principles of "justice and equity", inclusiveness, equality, and accessibility, which are also supported by the literature (UNESCO, 2012).

Ways of Teaching and Learning

In relation to the design principle named "collaborative methods", Dewey (1907, 1916) emphasized the importance of cooperation and joint activities. Interacting with people in one's environment and cooperating with peers is also central in Vygotsky's theories (1978). Further, Bronfenbrenner (1979) wrote about the importance of joint activities and participation. The importance of collaborative methods or teamwork has also been highlighted in various contemporary studies (see, e.g., Herrington & Oliver, 2000; Lowyck & Pöysä, 2001; Scardamalia et al., 2012). In digital environments, collaborative methods can be fostered by technologies that enable collaboration and sharing. Using discussion communities and peer tutoring has also been found to support student-centered learning (Cornelius-White, 2007). Further, the importance of LEs that foster "participation and involvement" is highlighted in constructivist and socio-constructivist theories, as well as in student-centered pedagogical principles (O'Neill & McMahon, 2005). Student-centered learning has also been found to correlate with participation (Cornelius-White, 2007).

"ICT-enhanced learning" and the use of technology can be considered a natural part of twenty-first century LEs (Mäkelä & Helfenstein, 2016). Vygotsky's (e.g., 1978) considerations of how "tools and technologies change the nature of tasks and the cognitive skills that are required to perform them" have been seen as especially valid in twenty-first century technology-enhanced LEs (Scardamalia et al., 2012, p. 25). Based on previous studies (Tseng et al., 2013), integrating technology studies and learning with technology into science and mathematics may be an effective way of raising young people's interest in STEM. The use of ICT in teaching and learning may support fostering novelty in tools and methods, which was also desired by the participants of this study.

The results of the FG discussions indicated that participants' wishes were generally in line with constructivist and socio-constructivist theories that view learning as student-centered "active knowledge construction" (O'Neill & McMahon, 2005; see also Herrington & Oliver, 2000; Rubens et al., 2005). FG session participants also wished for "learning through experiences". This design principle is connected to student-centered approaches such as experiential learning (O'Neill & McMahon, 2005). Learning through "experiments and inquiry", also desired by the participants in our study, can be seen as connected to student-centered approaches such as inquiry-based learning and problem-based learning (Hakkarainen & Sintonen, 2002; O'Neill & McMahon, 2005). In addition to physical laboratories, virtual laboratories can be employed for conducting experiments (Binkley et al., 2012).

The importance of "self-regulated learning" (Vygotsky, 1978) or learner's self-direction (Bronfenbrenner, 1979; Dewey, 1907; Scardamalia et al., 2012) is commonly present in research (Mäkelä & Helfenstein, 2016). Notions related to self-regulated learning are in line with student-centered learning principles that encompass responsibility, autonomy, and possibilities for choice (O'Neill & McMahon, 2005). Metacognitive skills such as learning to learn also require self-regulation (Binkley et al., 2012).

In FG sessions, "reflective learning" (i.e., reflection and deep thinking) was raised as an

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important concern. In the present analysis, wishes related to different ways of thinking, such as "critical thinking" and "creative thinking," were also coded under this theme, while at the same time acknowledging that they can also be considered cross-curricular skills. Creative thinking, in particular, was also coded under creativity. Reflection and awareness of one's own learning was already considered fundamental by Dewey (1907, 1916). It has been connected, for example, with problem recognition, critical thinking, and evaluation (Soodmand Afshar & Masoud Rahimi, 2016). Further, notions related to reflective learning are in line with student-centered learning principles that encourage a reflective approach, deep learning, and understanding (O'Neill & McMahon, 2005). Some aspects related to student-centered learning associated with positive learning outcomes are higher-order, critical, and creative thinking (Cornelius-White, 2007).

In FG discussions, participants also emphasized the use of "multiple representations". These may include auditory, visual, textual, and pictorial representations, including sound, video, simulations, animations, pictures, text, equations, diagrams, graphs, and tables (Ainsworth, 2006). Although previous studies have shown the benefits of multiple representations in supporting learning, it is vital to support learners in understanding, interpreting, and relating to different representations, as well as to consider learners' individual and age-dependent differences when using them (Ainsworth, 2006).

In relation to the design principle named "games and gamification", previous studies have indicated that games and game-like elements can be efficient, for instance, in increasing motivation and practicing problem-solving strategies (Gee, 2007). In this study, participant stakeholders also wished that there were games, tournaments, and simulations to promote entrepreneurial skills. Further, in line with participants' wishes for "learning outside the school", Scardamalia et al. (2012, p. 14) wrote about "finding productive connections between in- and out-of-school learning environments." This design principle is very much related to the connectedness of learning with present and future life. While the design principle named "connectedness" refers to relating learning with personal significance, meaningfulness, relevance, usefulness, or applicability, "learning outside the school" refers to connecting school learning with informal (e.g., hobbies) or non-formal (e.g., science center, museum) LEs (see also Eshach, 2007).

"Project-based learning" is a constructivist form of instruction, which shares some similarities with problem-based learning and experiential learning. It is characterized by elements such as students' autonomy and active involvement, collaboration, context-dependency, and reflection within real-world practices (Kokotsaki et al., 2016; Tseng et al., 2013). In the literature review of project-based learning (Kokotsaki et al., 2016), some positive results identified were high levels of student engagement due to the cognitive challenges and affective factors, improved self-regulated learning, intrinsic motivation, creative and deep thinking, and the understanding of scientific content. This approach has also been found to increase the effectiveness of studies, generate meaningful learning, influence future career pursuits, and make students feel that STEM is important to society's health and life (Tseng et al., 2013). Therefore, project-based learning can be seen as supportive of other design principles of this pedagogical framework, such as self-regulated learning, reflective learning, intrinsic motivation, creativity, and professional life. Notably, the use of modern digital technology (see the principle ICT-enhanced learning) is viewed as one facilitating factor in implementing project-based learning (Kokotsaki et al., 2016).

Cross-curricular Skills

The study confirmed that the participant stakeholders viewed the design principles related to the development of cross-curricular skills named "entrepreneurial skills", "creativity", "sustainability skills", and "professional skills" as important. The importance of these highly interrelated skills is also strongly supported by the literature.

In this study, the participants connected "entrepreneurial skills" mainly with creating businesses and self-employment opportunities. In the literature, however, entrepreneurial skills are often defined in a broad sense, covering also the detection of non-profit opportunities (Edwards-Schachter et al., 2015). Also in Key Competences for Lifelong Learning proposed by the European

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Commission (2018, pp. 58), entrepreneurial competence is understood in a wide sense as turning ideas into action and creating value, including social, commercial, and cultural processes and outcomes, as well as making "a positive contribution to individuals' lives and to the sustainable development of society as a whole." Furthermore, making informed decisions, being clear about the risks, coping with uncertainty, being perseverant, and having a sense of initiative and agency are seen to contribute to this competence.

The participants in this study also connected entrepreneurial skills with "creativity". This is in line with the literature that interrelates creativity and innovation with entrepreneurship and professional competences (Binkley et al., 2012; Edwards-Schachter et al., 2015). As described by Edwards-Schachter et al. (2015), fostering technological (inventions), economic (entrepreneurship), and artistic/cultural creativity in learning requires supporting learners' ability to generate ideas, experiment, and solve problems in novel ways. Fostering innovation, in turn, implies guiding the implementation of creative ideas to create economic or social value (Edwards-Schachter et al., 2015). Similarly, in the Framework for Key Competences for Lifelong Learning (European Commission, 2018), the development of creative and innovative ideas, approaches, or artefacts is seen to contribute to employability and entrepreneurship. The framework refers to specific skills (e.g., critical thinking) and attitudes (e.g., curiosity) that comprise creativity. It also connects STEM learning and digital competences with creativity. In this framework, creativity is presented as an integrated aspect, which underpins all the eight key competences.

In relation to the design principle named "sustainability skills", participants' wishes were very much in line with the literature on sustainability education referring to the importance of adopting different values, attitudes, habits, and behaviors related to environmental, social, and economic sustainability (Frisk & Larson, 2011). Sustainability education has also been connected to interdisciplinary approaches (see "project-based learning") and competences such as active engagement, cooperative group learning (see "collaborative methods"), connection with communities (see "connectedness"), and stakeholder perspectives (Frisk & Larson, 2011), which are all related to many other wishes collected from the participant stakeholders. As an example of how to foster sustainability, the education for sustainable development (ESD) framework involves its own set of transversal competencies related, for example, to individual and collective responsibility intertwined with genuine ESD competencies, such as fostering a sense of belonging to the environment, as well as special competencies in science education, such as "analyzing the impact of human activities on the environment and suggesting improvement actions" (Cebrián & Junyent, 2015). In Key Competences for Lifelong Learning (European Commission, 2018), sustainability is seen as an underlying concept connected with skills such as civic competences and entrepreneurship, participatory and collaborative skills, critical reflection, initiative taking and problem solving, as well as with STEM education.

Finally, "professional skills", also considered important by the participant stakeholders, can be seen as related to knowledge, skills, attitudes, values, and ethics needed for managing life and career as defined in the twenty-first century skills framework (Binkley et al., 2012). They include a need for being flexible and adapting to change, self-directedness and independent work (see the principle "self-regulated learning"), managing projects, goals, and time, working effectively with others in diverse teams (see "collaborative methods"), guiding and leading others, being responsible to others, and producing results. Based on the principles of situated learning (Herrington & Oliver, 2000), both professional and entrepreneurial skills can be fostered by providing authentic contexts that reflect the ways knowledge will be used in real-life, providing insights into expert performance and the modelling process, as well as promoting articulation to enable tacit knowledge to be made explicit, as is typical for situated learning.

Conclusions

The design principles selected for the current version of the pedagogical framework based on various stakeholders' views and supported by the theoretical and empirical literature are

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considered in the STIMEY LE design. In addition, some design principles, such as the importance of a sense of belonging, or considering local and global educational needs and challenges, did not emerge in the data analysis, but are considered relevant in the STIMEY LE design based on previous studies (Mäkelä, 2015; Mäkelä & Helfenstein, 2016). In the final phase of this study, the developed framework will be reviewed in FG3 sessions by experts in STEM, local curricula, educational policy, and educational technology. Additionally, the literature review will be extended to support the final framework version. This may still lead to some changes and improvements. However, the feedback received in FG2 as well as the support found in the literature already initially confirm both the practical usefulness and theoretical validity of this framework version in LE design, whereas final practical usefulness can then be proven after the framework has been applied in the STEM LE design.

Both the results of this study and previous literature suggest that many teaching and learning principles are highly interrelated. For instance, novel tools and methods, "collaborative methods", reflective learning, and entrepreneurial skills may support creativity and innovation, and vice versa. Instead of focusing on singular design principles, it is therefore recommended that LE designs take into account a wide range of design principles based on the assessment of stakeholders' wishes and the research literature. While this study has focused on analyzing the participants' wishes on a general level in order to formulate the pedagogical framework and design principles for the STIMEY LE, it should be noted that in the future, it would also be useful to compare differences between countries, stakeholder groups, genders, and age groups (primary, lower and upper secondary school students), as well as consider individual contributions that clearly differ from shared views. In this way, it would be possible to see how differing, critical, or minority views could be taken into account in both the LE design and use.

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RESEARCH REPORT

"My Picture is About Opening Up Students' Minds Beyond School Gates!" School Principals' Perceptions of STEM Learning Environments

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Abstract*: The provision of effective leadership in STEM education is essential to support teachers to consider approaches to STEM and to carry them out effectively. Principals' perceptions of STEM teaching and learning are, therefore, significant. In this paper we report on the perceptions of 21 primary and secondary school principals through their completion of the Draw a STEM Learning Environment Test (D-STEM), assessed through a customised rubric. Findings revealed that the participant principals maintained a diversity of interpretations of STEM learning environments primarily equated to the use of student-centred pedagogies in classrooms. Very few responses depicted and/or described teaching and learning practices anchored in realistic problems, which can enable the integration of individual STEM disciplines, and engage students in the translation of concepts across multiple representations. The use of representational tools remained implicit or was absent in most of the responses. Findings are discussed along with methodological issues, and implications and future research directions are suggested.*

Keywords: *STEM learning environments, school principals, drawings, STEM education*

Introduction

In Australia and internationally there is growing demand for graduates in science, technology, engineering and mathematics (STEM disciplines) to contribute to economic prosperity and productivity (Atkinson & Mayo, 2010; Office of the Chief Scientist, 2012; Science and Technology Policy Division of the OECD Directorate for Science, Technology and Innovation, 2016). Enrolments in senior secondary mathematics courses that prepare students for university studies in STEM fields, yet, have been declining (Australian Academy of Science, 2016; Barrington & Evans, 2014; Wienk, 2017). School students who are motivated towards and interested in STEM subjects are more likely to pursue STEM related careers (Stohlmann, Moore, & Roehrig, 2012). Enhancing the teaching of STEM subjects is therefore a priority. Research in STEM education field has grown, but there are several practical challenges to implementing effective STEM teaching and learning. Effective teaching of STEM, for instance, requires close collaboration among teachers, the commitment of teachers involved, and professional learning and administrative support (Zubrowski, 2002).

Although there has been little attention paid, to date, to the role that school principals might play in enhancing STEM teaching and learning (Likourezos, Beswick, Geiger, & Fraser, 2020), and hence supporting increased enrolments in STEM subjects, there is a substantial body of research on

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principals' instructional leadership (Aas & Paulsen, 2019; Robinson, 2007). From this work we know that school leaders have more influence on teaching practice when they are involved in the design and implementation of curriculum (Pietsch & Tulowitzki, 2017), and are more likely to influence student outcomes when the teaching and learning that happen in their schools is the central focus of their work (Robinson, 2007). It is reasonable to assume that these general findings apply also to STEM, and that the role that principals play in enhancing STEM teaching and learning would be dependent upon, among other things, the ways in which they believe STEM subjects should be taught and are best learned. In this study, therefore, we address the question: *What are school principals' perceptions of STEM learning environments?*

In doing so, this paper contributes to understanding the bases of instructional leadership in relation to STEM and presents implications for the kinds of supports that school leaders might need in order to build their capacity to exercise instructional leadership in this area. A further contribution is methodological and addresses the question: *How can established drawing-based techniques be adapted as a way of uncovering principals' perceptions of STEM learning environments?* In the sections that follow we review literature on STEM learning environments, including the principal's role in creating and maintaining them, and consider what is known about the use of drawings to study perceptions of learning environments.

We use the term learning environment as the diverse physical location, context and culture in which teaching and learning take place. Evans, Harvey, Buckley and Yan (2009) suggested three complementary components of a learning environment: (1) academic (the pedagogical and curricular elements); (2) management (the discipline styles for maintaining order); and (3) emotional (the affective interactions within the classroom). In this study, we focus on the first component, the pedagogical and curricular elements of the STEM learning environments. Importantly perceptions as to these components are likely to differ according to the participant in the environment who is consulted. That is, the teacher and individual students in a class may all have different perceptions of what goes on in the same learning environment (Beswick, 2007). Similarly, principals' perceptions are likely to be unique and hence worthy of particular study.

STEM Learning Environments

The acronym, STEM, is interpreted in a variety of ways and there is considerable confusion among what it means in school education (Bybee, 2010). It is used to refer to each of the four component disciplines – Science, Technology, Engineering, and Mathematics – separately, and also to the integrated teaching of two or more of them (Hobbs, Clark, & Plant, 2018). In this study, as in the larger project of which it is part, we did not mandate any specific conception of STEM teaching and learning or of STEM learning environments. Rather, we were interested in how our participants perceived these things. We used the literature on effective STEM teaching and learning to frame our analysis of participants' responses.

STEM Integration

When considered in terms of discretely taught disciplines, STEM has been interpreted as an impetus to enhance the teaching of the individual disciplines including by adopting approaches to teaching similar to those advocated by proponents of integrated STEM, such as the use of challenging problem in mathematics (Hobbs et al., 2018). When used in an integrated sense, STEM is often associated with pedagogical approaches such as inquiry or problem-based learning which have long been advocated for by science (e.g. Driver, Newton, & Osborne, 2000) and mathematics (e.g. Schroeder & Lester, 1989) education researchers. According to Kennedy and Odell (2014), effective STEM education requires teachers to move away from traditional one-way, direct instruction teaching practices to towards instructional strategies that better motivate students and support their learning. Hobbs et al. (2018) identified "skills and proficiencies that are common to STEM disciplines" (p. 142) along with pedagogies and practices. Namely, inquiry using multiple representations, problem-solving, design-based approaches and the incorporation of digital technologies, in their view, are essential to a program being a STEM program. Similarly, in their study of STEM education researchers' perceptions of STEM learning environments, Hatisaru, Beswick and Fraser (2019) found

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evidence that some participants seemed to equate STEM teaching and learning with pedagogies that involved group work.

In many countries, including Australia, teachers must report on individual STEM disciplines and this contributes to variation in the extent to which STEM subjects are integrated in schools (Timms, Moyle, Weldon, & Mitchell, 2018). Hobbs et al. (2018), for example, described five ways in which STEM was operationalised in the schools with which they worked. These were: (1) enhanced but separate teaching of the four disciplines; (2) teaching the four disciplines but with two emphasised and integrated; (3) integrating one discipline into the other three that are separately taught; (4) complete integration of the four disciplines by a single teacher; and (5) teaching integrated STEM but with individual and distinct contributions from teachers of the four disciplines. Hobbs et al. (2018) maintained that, by focussing on STEM pedagogies and practices, in any of these models, learning experiences can be created that are engaging for students and that maximise student learning through linking relevant concepts and processes from the individual STEM disciplines. Vasquez et al. (2013) also identified a set of practices inherent in the individual disciplines of science and engineering, technology, and mathematics that can support and strengthen each other in STEM teaching. Their list included asking questions, defining problems, developing and using models, planning and carrying out investigations, analysing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, and evaluating and communicating information. Vasquez et al. (2013) argued that these practices represent the capabilities that students are expected to gain in their years of schooling and that they are essential in today's knowledge-based and technological society.

Glancy and Moore (2014) presented a theoretical case for effective STEM classes being characterised by the integration of the four STEM subjects. They argued that "separating the disciplines sets up artificial divides that are not generally present outside of the classroom, while integration presents the disciplines in a more honest or realistic fashion" (p. 4). Similarly, Vasquez et al. (2013) argued that effective STEM teaching requires genuine connections to be made between subjects. They argued that this can lead to enhanced conceptual understanding as students apply their learning from individual STEM subjects. Part of this is understanding disciplinary representations, and sharing and communicating their understandings, enhances students' professional discourse proficiency (Vasquez et al., 2013).

Implicit in these arguments is that students study individual STEM subjects, or study them alongside integrated STEM. There is relative silence from STEM education researchers who advocate for integrated STEM teaching, on whether, how, and which, individual STEM subjects should be taught, beyond Hobbs et al.'s (2018) acknowledgement that current curricula considerations mean that the nature and extent of integration varies. Focussing on STEM as pedagogy avoids these questions to the extent that the practices advocated (e.g. by Hobbs et al., 2018 and Vasquez et al., 2013) can be applied to individual disciplines or in the context of any variant of integration. This fact can, of course, be used to argue against the imperative of integration.

Solving STEM Problems

According to Glancy and Moore (2014), STEM problems are ideally grounded in the real world; they are problems that are experienced by the community. Although students may draw upon subject knowledge of separate STEM disciplines, the problems are interdisciplinary. When problems arise from the local community context, students can relate to, engage with, and makes sense of them based on their own experiences (Glancy & Moore, 2014). A further benefit of working on real world problems is that students can see STEM as it is practised (Hobbs et al., 2018). In line with this, rather than being a solitary activity, solving STEM problems is necessarily collaborative. As in the real world, students work together and take on specific roles and responsibilities as interdisciplinary problems are tackled by teams consisting of members with differing knowledge and expertise (Glancy & Moore, 2014). In addition, students develop their understanding of the nature of evidence in different contexts through collecting data, using evidence to justify a solution or a decision, and making judgments about the reliability of the information they use or generate

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(Vasquez et al., 2013). In these sorts of environments teachers take on roles other than knowledge giver, including those of facilitator or guide, collaborator and learner (Crawford, 2000). Students take ownership of their learning and are active, taking on roles other than listener or knowledge receiver, such as those of collaborator, planner and experimenter (Crawford, 2000).

At the heart of the STEM practices proposed by Vasquez et al. (2013) and Hobbs et al. (2018) is the provision of opportunities for students to develop and interrogate their ideas. The conceptual, digital, and physical tools that teachers use in STEM classrooms are essential to learning that provides these opportunities. They might be representational and include graphs, maps, diagrams and tables (Goos, Geiger, & Dole, 2014); technologies that facilitate modelling or simulations (Kennedy & Odell, 2014), digital technologies (Hobbs et al., 2018), or physical tools such as those used in construction (e.g. saws, measuring devices, hammers), electronic materials (e.g. computers, design programs, robotics kits, calculators), and materials used in design (e.g. wood, cardboard, construction paper, glue) (Stohlmann et al., 2012). Students draw upon and develop their skills in using these tools as they collaboratively engage in a STEM inquiry, problem solution, or project. Finally, to facilitate concept development, generalization and abstraction, Glancy and Moore (2014) recommended that in STEM classrooms concepts be presented using multiple types of representations (written symbols, pictorial representations, real life situations, verbal symbols, and concrete representations or manipulatives), with the problems structured to require translations among these representational modes.

The proposed components of effective STEM teaching and learning environments described above, in fact, have been promoted for several decades as optimal ways of teaching both mathematics and science. For example, Pape and Tchoshanov (2001) discussed the importance of using multiple representations in mathematics in order to develop students' conceptual understanding. Many others, following social constructivist theories of learning, promoted collaboration among students. For mathematics, these sorts of approaches have central to reform movements in mathematics since the 1980s. They were, for example, promoted by the National Council of Teachers of Mathematics (NCTM) in their 1989 principles and standards and in subsequent updates of that internationally influential work (e.g. NCTM, 2000) and curricula that have embraced these principles to varying degrees (e.g. Common Core State Standards for Mathematics in the US, the Australian Curriculum: Mathematics in Australia (Australian Curriculum, Assessment and Reporting Authority)). More recently the NCTM (2014) have recommended that teaching and learning of mathematics includes using and connecting mathematical representations. The important difference between these subject specific attempts to reform teaching and more recent calls for integrated STEM teaching, could be that inherently interdisciplinary problems demand or require these kinds of practices or, at the very least, integrated STEM provides an impetus for promoting teaching and learning practices known to be effective in individual STEM subjects. At least in mathematics, calls for reformed pedagogy have achieved insufficient traction (Roesken, Pepin, & Törner, 2011).

The Role of Principals in STEM Teaching and Learning

Research on instructional leadership, not necessarily related to specific school subjects, has established that principals can positively influence student learning outcomes by enhancing the quality of teaching (Pietsch & Tulowitzki, 2017). We also know that transformational leadership styles allow principals to establish school environments in which teachers are motivated and inclined to be innovative in their pedagogy (Pietsch & Tulowitzki, 2017). It is reasonable to assume, therefore, that principals are key to instigating, supporting and sustaining the kinds of STEM learning environments described in the previous section. Also pertinent is Tulowitzki's (2019) finding that principals require professional development to build their capacity to respond to changing school and national priorities and aspirations, such as the recent and ongoing impetus to enhance STEM teaching and learning.

Some researchers have reported findings related to instructional leadership of individual STEM disciplines and noted a tendency for principals not to lead on instruction in science and technology (e.g. Gerard, Bowyer, & Linn, 2008). Similarly, Carpenter and Peake (2013) highlighted principals' relative lack of confidence in relation to their ability to provide instructional leadership in

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mathematics. Nevertheless, principals can exercise instructional leadership by facilitating teachers' contributions to decision making with an environment characterised by trust (Smetana, Wenner, Settlage, & McCoach, 2016). That is, deferring to the knowledge of specialist STEM teachers can be seen as an important part of principals' instructional leadership. In relation to science, Lewthwaite (2004) advocated instructional leadership in the form of establishing a coherent strategy for curriculum improvement that recognises the relationship between curricula and learning environments. Gerard et al. (2008) urged principals to consider the ways in which new curricula fit with their particular school goals, existing programs, and community connections. In the context of mathematics, Nelson (2010) described Leadership Content Knowledge (LCK) as comprising principals' knowledge of the subject matter and their beliefs about how it is learned and most effectively taught.

The ways in which principals perceive effective STEM learning environments is relevant to their capabilities and to the nature of the specific support that principals might need to enhance the STEM culture of their schools and support teachers to optimise the STEM learning environments that they create for students. In the next section, we turn to the methodological issues associated with researching perceptions of STEM learning environments that participant school principals held.

Perceptions of STEM Learning Environments

Learning environments research "provides one approach for conceptualizing, assessing, investigating, and improving what goes on in classrooms" (Fraser, 2014, p. 104). Although questionnaires have been used in learning environment research for some time, "there is considerable scope for the development of new methods and the wider use of established methods for qualitative studies" (Fraser, 2014, p. 116). In this study, we used drawings as well as writing as a mechanism for collecting information from the study sample.

Using Drawings to Study Learning Environments

There is a growing body of literature on the use of image-based methods in qualitative research (Matthews, 2012). One such method, using a particular image-based method, 'drawings', has been found to be a valid indicator of perceptions of classroom environments (Haney, Russell, & Bebell, 2004). Scientific interest in individual's drawings dates from the 1900s, with the drawings having been used in psychology, anthropology and ethnology (e.g. Goodenough, 1926) as well as in education research (e.g. Chambers, 1983). As a result, literature focusing on the use of drawings for research is extensive; our purpose here is to present a brief snapshot of the literature relevant to individual's perceptions in relation to the individual STEM subjects.

The research capturing students' perceptions on science education through drawings arose in mid-1950s, after the seminal work of Mead and Métraux (1957) examining the perceptions students held about scientists. Mead and Métraux asked approximately 35,000 high school students around the United States to write a short essay about their perspectives of science and scientists. Through the years Draw a Scientist Test (DAST) (Chambers, 1983) was patterned from Goodenough's (1926) the Draw a Man Test (now the Draw a Person Test). For facilitating ease of assessment, Finson, Beaver, and Crammond (1995) developed the Draw a Scientist Test Checklist (DAST-C). Thomas, Pedersen and Finson (2001) further modified the DAST-C to create the Draw a Science Teacher Test Checklist (DASTT-C) and used the DASTT-C to document the preservice elementary teachers' knowledge and beliefs about elementary science teaching methods. The authors also intended to provide preservice teachers with a reflective opportunity to picture themselves as future teachers and consider the ways in which they developed their own science teaching beliefs. Since interviewing each preservice teacher would be impractical, the authors added a written narrative component to the instrument which was found both to contribute some additional information and to confirm the researchers' interpretation of images in drawings. Later years, the DASTT was used for measuring the change in prospective science teachers' beliefs about science teaching after having science method and practicum courses (Ambusaidi & Al-Balushi, 2012).

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Researchers in mathematics education, such as Picker and Berry (2000), refocussed the DAST to enable students to draw a mathematician on a blank sheet of paper and to describe the images reflected in students' drawings of mathematicians. The instrument is entitled the Draw a Mathematician Test (DAMT) which also includes a section for students to describe elements of the drawings. Through a description, Picker and Berry (2000) assumed that students would give more information about their beliefs. Later years, the use of drawing tasks, with accompanying text has been found to add rigor to the instrument as the information provided in the writing reduces the subjectivity effect in coding the drawings (Murphy, Delli, & Edwards, 2004).

The DAMT or its modifications has been widely used to elicit data from students about their images of mathematics (e.g. Johansson & Sumpter, 2010; Rock & Show, 2000), mathematicians (e.g. Aguilar, Rosas, Zavaleta, & Romo-Vázquez, 2016; Hatisaru, 2019a; Picker & Berry, 2000), mathematics education with a focus on motivation (e.g. Johansson & Sumpter, 2010), assessment practices in mathematics classrooms (Remesal, 2009); or as a way to evaluate teaching in mathematics classrooms (e.g. Hatisaru, 2019b; Pehkonen, Ahtee, Tikkanen, & Laine, 2011), the kind of emotional atmosphere (Laine, Näveri, Ahtee, Hannula, & Pehkonen, 2013) and types of work experienced in mathematics lessons (Pehkonen, Ahtee, & Laine, 2016), and the teacher actions factor on the emotional atmosphere of mathematics classrooms (Laine, Ahtee, & Näveri, 2020).

Drawings have also been used to assist preservice teachers to become aware of their perspectives about the nature and learning of mathematics (Mewborn & Cross, 2007), whether their math-anxiety decrease as a result of completing their early childhood mathematics method course providing them opportunities for using and modelling manipulatives (Lake & Kelly, 2014), and to explore how they envision their future classroom and their own and students' actions within that classroom (Utley & Showalter, 2007). Additionally, researchers used drawings to examine preservice teachers' reflections on the way they had been taught, and the way they want to teach mathematics to their future students and found drawings to be a useful tool for enabling reflection upon past experiences and for planning future teaching (Lee & Zeppelin, 2014).

Over the years, the use of drawings in education as a measure of students' conceptions of teaching and learning school subjects (e.g. mathematics) (Johansson & Sumpter, 2010) have been found to be valid (Gulek, 1999; Laine et al., 2020; Losh, Wilke, & Pop, 2008; Murphy et al., 2004), reliable (Johansson & Sumpter, 2010; Remesal, 2009) and useful (Harris, Harnett, & Brown, 2009), as well as a cost-effective alternative to classroom observations (Haney et al., 2004). DAST, DAMT or DASTT studies have been conducted in many countries on different continents including Europe, the Middle East, Asia, and the United States from K-12 students to pre- or in-service teachers. The drawing task in our study has been adapted from these instruments to explore school principals' views about STEM learning environments.

The Study

The study reported here was part of a national project, *Principals as STEM Leaders – Building the Evidence Base for Improved STEM Learning* (PASL), aimed at developing research-based professional learning (PL) for principals to effectively lead STEM in their schools. While the project drew from various models of STEM (e.g. Hobbs et al., 2018) to inform the construction of its PL resources and activities, it did not promote any particular model of STEM education to principals as best practice. Rather the PASL project sought to support principals their understanding of leading the teaching and learning of STEM disciplines taught with any degree of integration.

The study is qualitative in which data were collected using the *Draw a STEM Learning Environment Test* (D-STEM), adapted from Thomas et al.'s (2001) DASTT and research on using drawings to document educational phenomena (Haney et al., 2004). The first page provides a rectangular area in which participants are asked to draw. Inspired by Haney et al. (2004), the following drawing prompt is given above the rectangle: "*Think about the teachers of STEM and kinds of things they do. Draw a STEM learning environment*." The second page provides an open-ended item borrowed from Thomas et al. (2001) and Picker and Berry (2000), which asks participants to explain

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their drawings: "*Look back at the drawing and explain your drawing so that anyone looking at it could understand what your drawing means. What does the teacher do? What do the students do? What tools do they use?*" This written narrative component contributes to gaining a deeper understanding of what participants are drawn and confirming the interpretations of input in their drawings.

Participants in the research were primary (*n*=10) and secondary (*n*=11) school principals from across Australia attending a 2-day face-to-face workshop as part of the PASL project. At the start of the workshop, the participants were presented with the D-STEM exercise and allocated 20 minutes to complete it. Of the 23 principals who completed the exercise, 21 agreed to their D-STEM response being used as data in the research.

Data Analysis

The drawings and associated text were subjected to content analysis by utilising a deductive approach (Elo & Kyngäs, 2008) with the coding categories determined on the basis of previous research. A D-STEM Rubric was developed, based on an extensive review of the literature related to STEM learning environments, and an analysis of initial drawing data generated earlier from a group of STEM education researchers (Hatisaru et al., 2019). The pictorial and written statement data were considered holistically, and the data were documented using excel spreadsheets.

The D-STEM Rubric includes elements of effective STEM learning environments identified by Glancy and Moore (2014), Hobbs et al. (2018) and Vasquez et al. (2013). Specifically, we looked for evidence of the indications of STEM integration, Realistic problems, the Collaborative nature of STEM, Personal experience, Multiple representations, Community-industry engagement, and the Teaching and learning of STEM (see Table 1). We coded the first six of these elements in a Likert fashion, with the extent to which each element seemed to be represented in drawings: '2- Strong indication', '1- Some indication' or '0- No indication'. The final element was coded in a dichotomous fashion, whether each sub-element seemed to be represented in drawings or not: '1- There is indication' or '0- No indication', due to the inability to discriminate further. Additionally, we critiqued each response thoroughly and noted which the teaching and learning practices of STEM (e.g. problem-solve, create, collect data) were present in the participants' pictures and their associated text. Participants are designated by codes (e.g. P1, P2 and so on).

The D-STEM Rubric continues to be refined based on the related literature. The latest version is provided in Table 1 representing the coding for each element and what constituted each of '2', '1' and '0' in relation to those elements. To illustrate the process, we described the coding of two responses. In Figures 1 and 2 we presented examples of two participants' drawings and their descriptions that represent elements of the D-STEM Rubric. Our judgements of the extent to which each of the elements of the Rubric are presented is shown in Table 2.

In Figure 1, there is an emphasis on learning tasks or activities that could require combining knowledge and skills from two or more disciplines (e.g. mathematics and technology) such as robotics, coding, programming with reference to designing and making, as well as science (E1: '1'). Real life issues are also referenced but no further details are provided (E2: '1'). It depicts a range of areas in which students work collaboratively on problems (E3: '1'). The mentioned real-life issues might be linked students' lives and elicit their interest (E4: '1'). The picture captures a context that could support multiple representations and includes a symbolic representation: "+xy~" (E5: '2'). No evidence of linking a content with the community (E6: '0').

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Table 1.
Elements of D-STEM Rubric and their descriptions

Element	Description and level of inclusion
	Drawing or writing includes:
STEM integration	2: reference to a context that might require students to use knowledge and skills from multiple STEM disciplines 1: reference to a context that might require students to use knowledge and skills from multiple STEM disciplines, but the nature of the problems or tasks is not explicit or not real-life based 0: no reference of such contexts or situations
Realistic problems	2: reference to interdisciplinary problems grounded in the real world 1: reference to problems that could involve realistic situations, but the nature of the problems is not explicit 0: no reference of realistic problems
Collaborative nature of STEM	2: reference to collaboration among students in which members have roles and responsibilities, i.e. teamwork 1: reference to collaboration/group work among students, but no explicit reference to the presence of teamwork 0: no reference of collaboration
Personal experience	2: reference to a context that problems or tasks are linked students' lives and tap into/elicit their interests 1: reference to a context that problems or tasks may be linked students' lives and tap into/elicit their interests, but the nature of the problems is not explicit 0: no evidence of personal relevance
Multiple representations	2: reference to a problem or context that could support multiple representation, and at least two representational models (e.g. symbols, visual diagrams, verbal statements) are explicit 1: reference to a problem or context that could support multiple representation, but representational models are not explicit 0: no evidence of multiple representations
Community-industry engagement	2: reference to linking content with industry, the community or families in a variety of ways (expert talks, joint works, using business/community contexts) 1: reference to linking content with industry, the community or families, but the ways of linking are not explicit 0: no reference of community engagement
Teaching and learning	Drawing or writing includes:
Teaching and learning practices	1: reference to open-ended student-centred instruction (e.g. inquiry, problem-based) 0: no reference of such student-centred instruction
Tools	1: reference to using a range of teaching and learning tools 0: no reference of tools
Roles of the teacher	1: reference to the teacher roles other than giving knowledge (e.g. facilitator, guide) 0: no reference of such teacher roles
Roles of the students	1: reference to the student roles other than receiving knowledge (e.g. planner, experimenter) 0: no reference of such student roles

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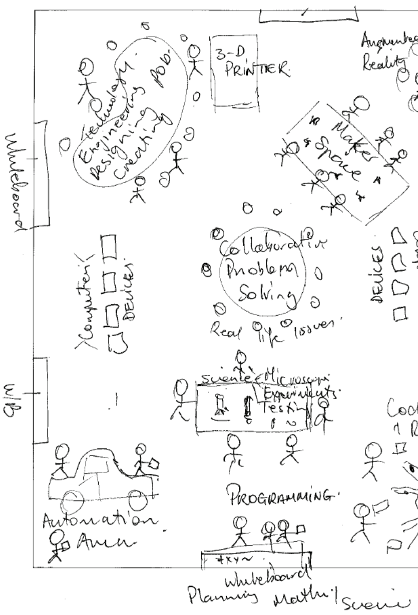
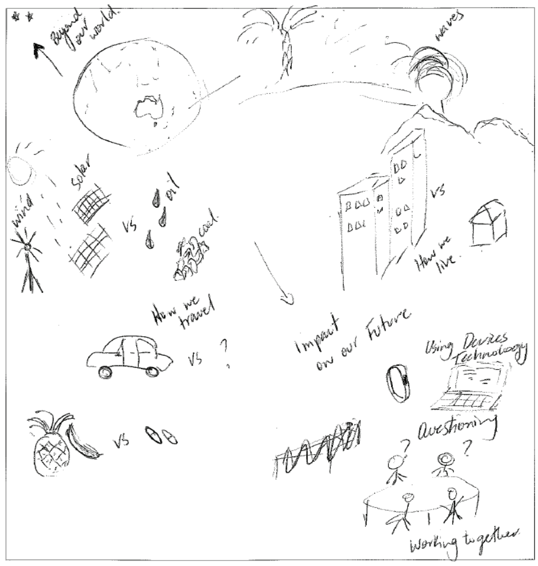


Student work: Collaborative environment for planning, designing, creating, problem solving and coming up with creative and innovative solutions. Teachers: Create provocation for students to engage & explore. Explicitly teach foundation skills in science, maths, literacy, technology, engineering (computational thinking). Provide the condition for collaboration. Scaffold student thinking to be creative problem solver. Tools: Range of tools/ devices to do the above.

Figure 1. P1's drawing and description of a STEM learning environment



My picture is about opening up students' minds beyond our school gate looking at the impact that we are having our environment. Questioning our current practices and challenge them with new thinking. Teacher: provides a space/environment where they can question, learn new technologies/information, provide challenges/issues to explore. Students: working together in groups/ (collaboratively) (communicatively) working through issues, going and finding their own data perhaps working with experts in a special field. Tools-- whatever they need. They can be very resourceful.

Figure 2. P8's drawing and description of a STEM learning environment

Both the visual and written descriptions include indicators of an open-ended student-centred instruction (E7a: '1'), and teaching and learning practices such as planning, designing, creating, problem solving, exploring, developing creative and innovative solutions, and computational thinking are mentioned. Technologies such as TV/projector, 3-D printer, computer, augmented reality, google mask are included (E7b: '1'). The teacher is described in terms of their role in creating provocation for engaging students and making them to explore, as well as using the explicit teaching of foundational skills involving science, mathematics, literacy, technology and engineering (E7c: '1'), while students in solving problems and coming up with creative and innovative solutions (E7d: '1').

In Figure 2, the emphasis is on a context beyond the classroom. An open-ended realistic problem (the impact that human beings have been having on the environment) which could be required combining knowledge and skills from two or more disciplines, and could be linked students' lives is provided (E1, E2 and E4: '2'). The picture captures a context that could support multiple representations but includes no specific representation (E5: '1'). The emphasis in the response is, students are working collaboratively in collecting data to be able to question their current practices in relation to environmental issues (E3: '1') and possibly collaborate with experts in that field, though the nature of the collaboration with experts is not explicated (E6: '1').

Table 2.
Assessments of D-STEM responses shown in Figures 1 and 2

Element		Figure 1	Figure 2
E1	STEM integration	1	2
E2	Realistic problems	1	2
E3	Collaborative nature of STEM	1	1
E4	Personal experience	1	2
E5	Multiple representations	2	1
E6	Community-industry engagement	0	1
E7	Teaching and learning		
E7a	Teaching and learning practices	1	1
E7b	Tools	1	1
E7c	Roles of the teacher	1	1
E7d	Roles of the students	1	1

In like Figure 1, indicators of an open-ended student-centred instruction are evident (E7a: '1'). Perceived teaching and learning practices involve generating questions, learning new technologies, gaining information, collecting data and exploring. Students use technology, and at the same time, according to the creator, they can be very resourceful (E7b: '1'). The teacher's role is described as providing the environment, and the challenges or issues that students explore. Also references to expanding students' thinking, encouraging a critical orientation to current practice and self-reliance in terms of sourcing data (E7c: '1'). Students critique and are e.g. collaborator and experimenter (E7d: '1').

To ensure reliability of the results, the first and the second authors independently coded ten D-STEM responses achieving 87% agreement. Disagreements were resolved through discussion to reach consensus, which involved the examination of item descriptions which were unclear and/or needed modification. Throughout the coding process, they consistently discussed issues that required attention or needed resolution. The data from the drawings and writing were tallied and summarised. Both the participants' pictures and their own words were used in data analysis and reporting.

Results

Table 3 shows the frequency of visual and/or written descriptions scoring '2', '1' or '0' for each of first six elements of the STEM learning environments. In this section, we present findings of the participants' views with reference to these elements, giving examples from their pictures or text. Details about the final element, the Teaching and learning of STEM, are provided later in the section.

STEM integration

In general, it was difficult to interpret the extent to which the STEM subjects are integrated in participants' responses. While they did not indicate that the four STEM subjects are taught in an isolated manner, interpretation of the extent of integration was hampered by the nature of the problem or task in which students are engaged being unspecified or unclear. For example, in eight responses (P3, P9, P12, P15, P16, P18, P21 and P23) there was no reference to a problem or context (e.g. see Figure 3), and in a further three responses (P2, P6 and P10) the learning environment is described as students working on real life issues, STEM investigations or projects, but the nature of problem was not explicitly stated (e.g. see Figure 4).

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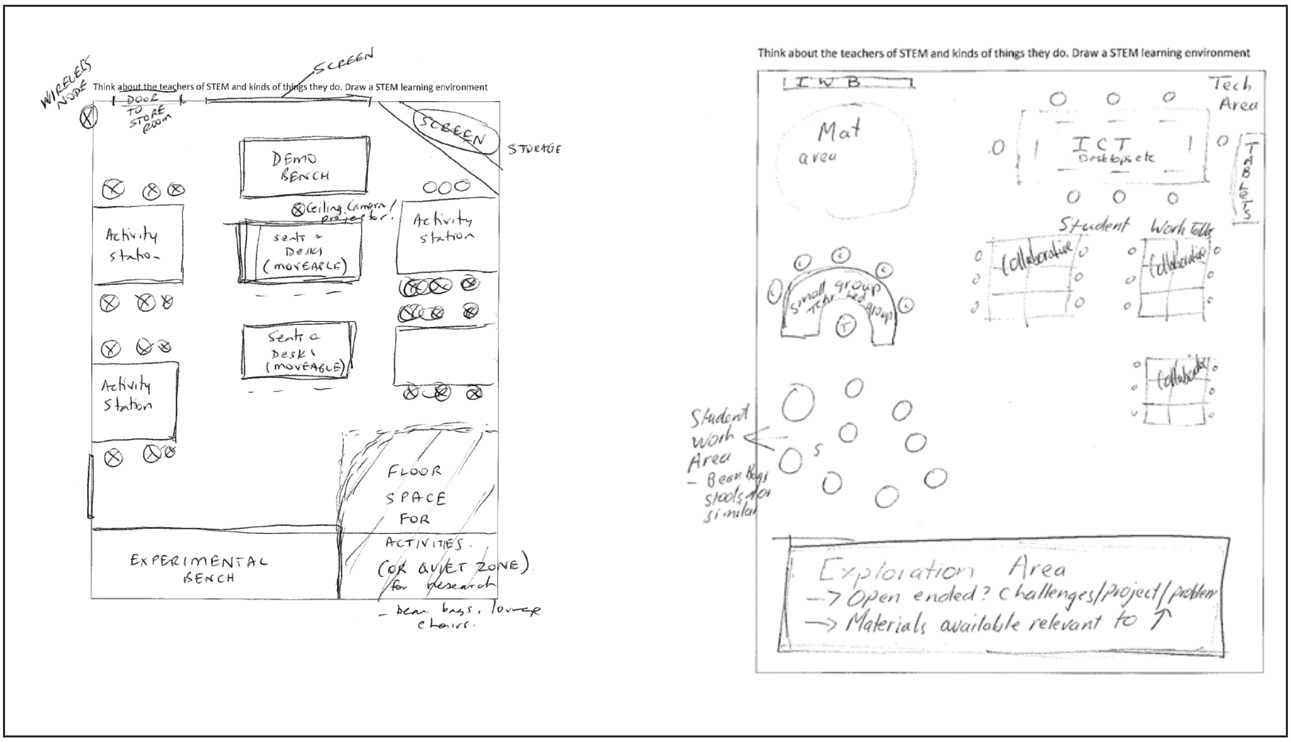
Table 3.
The frequency of D-STEM responses at each level for each element (N=21)

Element	Drawing/writing includes strong reference '2'	Drawing/writing includes reference '1'	Drawing/writing includes no reference '0'
STEM integration	3	11	8
Realistic problems	2	6	13
Collaborative nature of STEM	3	18	0
Personal experience	4	5	12
Multiple representations	3	9	9
Community-industry engagement	0	1	20

Based on the depicted and described contexts in the remaining eleven responses, there was evidence of a moderate or extensive degree of integration. In eight of them (P1, P4, P5, P7, P11, P13, P14 and P20) reference was made to learning tasks or activities that could require combining knowledge and skills from two or more areas such as Robotics (*f*=5), Coding (*f*=4), Programming (*f*=2), Cooking (*f*=2), Gardening (*f*=2), 3D Printing (*f*=1), Recycling (*f*=1), Construction (*f*=1), Manufacturing (*f*=1), Virtual Design (*f*=1) or Environmental Sciences (*f*=1). A STEM unit designed to incorporate these practices would combine knowledge and skills from two or more disciplines (e.g. science and mathematics or engineering) that are important for all students to learn. Planning the unit around common learning objectives across these disciplines would emphasise interdisciplinary knowledge or skills for students.



The idea is to create a semi-flexible, semi-permanent workspace where collaboration, experimentation and individual work can occur as needed. The design allows teachers to instruct as necessary allow supervision but provide opportunities for students to work at their own rate. Students use notebooks/ iPads and access online resources. They can use various equipment resources available to complete experiments. They have data loggers, robotics equipment etc. There is ceiling mounted camera to record the activities teleconference.	The area is designed to enable a combination of Teacher Led explicit instruction in two areas. Whole Group-Mat Area a small group at the U shaped table. Students have 3 Areas to work in. Collaborative Tables of 6 students ICT AREA- includes laptops/ tablets that can be used in other areas. Area where students can work at (non tables). A large area at back of the room is for exploration of problem/challenge/ investigation the class/students are undertaking. Materials, equipment in this area is there to support a compliment the STEM investigations may chance with the topic/area being investigated.
Figure 3. P9's drawing and description of a STEM learning environment	*Figure 4.* P6's drawing and description of a STEM learning environment

In the other three responses (P5, P8 and P19) the potential for extensive integration was apparent, as is evident in one of those responses described below:

> The teacher demonstrates how to do a 3D print of the Eiffel Tower. One student uses a drone to film this and project on a screen. Students are working independently/remotely on different aspects of STEM research, communication, investigation. A girl has programmed a new robot. In another scenario they are all working separately on aspects of one topic/ project (e.g. sustainability) to add the body of knowledge & learning. (P5)

In another, "STEM learning occurs outside of the classroom and within. It has a focus on the world outside of the school to create meaning within the school.", and an environment in which students are observing and measuring environmental conditions in field side with the use of STEM knowledge and resources at the school is pictured (P19). Although no more detail is given, we believe in the context of such a field work environment (P19) or in working on a project about "sustainability" (P5), students could apply their knowledge and skills from multiple disciplines to real world applications. In the image provided by P8 (see Figure 2), the goal was embedded in a real-world context: "... the impact that we are having our environment". In these responses, the focal points were the relevance of the students' learning and students' ability to use their knowledge in a real-world context. We understood that these contexts of the potential of an extensive level of integration, because students would apply their knowledge and skills in real-world situations.

Personal experience

As the responses of P5, P8 and P19 involved situations from real life, we assumed that students could relate and engage with the problems and make sense of them based on their own experiences and might encounter with the problems in their lives outside of school. In addition, P13 emphasised this personal experience aspect stating that:

> In my drawing there are a variety of STEM projects happening including robotics, computer coding/research. Maths learning which involved hands-on games [materials] and resources often applied to real-life, authentic purpose. Literacy is fundamental to STEM learning and quality literature, informational texts inform this. The environment features significantly including the outdoors. Construction cooking, other project-based activities, real life contexts ensure STEM learning is applied to the child's world.

In six responses (P1, P2, P10, P14 and P20) it was evident that the learning might be applicable or useful for students outside of the school. While real-world issues or problems were referred to, but the nature of the problem was not given in three responses (P1, P2 and P10), the other two responses (P14 and P20) included references to how new learning would be applicable and useful for students. P14's response indicated the importance of appealing to the curiosity of students through learning how or what make things work: "There is a makerspace with real tools as well as other materials to build prototypes. There is a breakerspace where students can pull apart old computers, bikes etc to learn how things work and then repurpose these parts". While P20's response highlighted the usefulness of "a kitchen/garden program" in which learning objectives could be embedded into: "A kitchen/garden program can also be part of a STEM space in which STEM activities are linked to the curriculum through cooking and growing" (P20). In the remaining responses no reference was made to the personal experience.

Collaborative nature of STEM

All responses included clear indications of students collaborating or working in groups. Almost all participants drew or described a context in which students are interacting and working together to find solutions to problems or running investigations or projects (e.g. Figure 1 and 2). A few responses (P2, P5 and P7), however, included more specific indications of the collaborative nature of STEM, that is, students working in teams, with each member taking on specific roles and responsibilities. P5's response was indicative: "[students] are all working separately on aspects of one topic/project (e.g. sustainability) to add the body of knowledge & learning". Although not explicitly stated, we inferred that P2 and P7 also referred to the collaborative nature of STEM. As can be seen in Figure 5, P2 stated: "[Students] Prepare design brief. Work in teams to provide ways of solving problems.". Similarly, as P7, wrote:

> STEM learning is about an inquiry-based approach to solving problems. There is a known methodology to apply but the STEM team work collaboratively to generate creative solutions to challenges. ... A STEM environment does not predetermine an outcome and allows individualism, collaboration to work together.

Multiple representations

In effective STEM learning environments learning activities are structured both to use different modes of representations (e.g. diagrams, concrete models, written symbols) and to translate between these representational modes. Identifying translation between modes from only drawings and text was difficult, so our analysis did not include a study of the extent to which there was a potential for translation. Rather we determined if a context was described in which students use representations and if some representations were pictured.

The analysis showed that the responses of nine participants (P3, P4, P5, P7, P8, P11, P14, P19 and P20) included reference to tasks or activities (e.g. programming, robotics type of work, an investigation about sustainability, virtual design, and a kitchen/garden program) through which concepts or ideas relevant to individual STEM subjects could be presented through different representational modes (e.g. spoken language, written symbols, diagrams, concreate models, metaphors). Usually, however, the representational modes were not made explicit. Only three participants (P1, P2 and P13) both depicted or described a context which is open to use multiple representations of a concept and gave clear indicators to one of the five distinct representation systems. It can be seen in both Figure 1 (P1) and Figure 5 (P2), that in addition to including a context open to using different representations, the participants included symbolic representations respectively: "+xy~" and "$x+y=3-3/41^3$". The third participant (P13) stated: "Maths learning which involved hands-on games [materials] and resources often applied to real-life, authentic purpose", and included "(dice, number charts, peg lines)" in the drawing and labelled them as "hands-on materials [manipulative models]".

Community-industry engagement

Community-industry engagement in the STEM learning environment was rarely evident in the drawings. P8's response, (see Figure 2), was the only one in which reference was made to community-industry engagement in the STEM learning environment. In this drawing, the participant represented students outside the classroom working on wicked problems relevant to the world in which they live (and beyond into outer space). The participant's supporting text highlighted her perspective when she considered a STEM learning environment: "[Students are] working together in groups/(collaboratively) (communicatively) working through issues, going and finding their own data perhaps working with experts in a special field" (P8). From this statement it was not clear how

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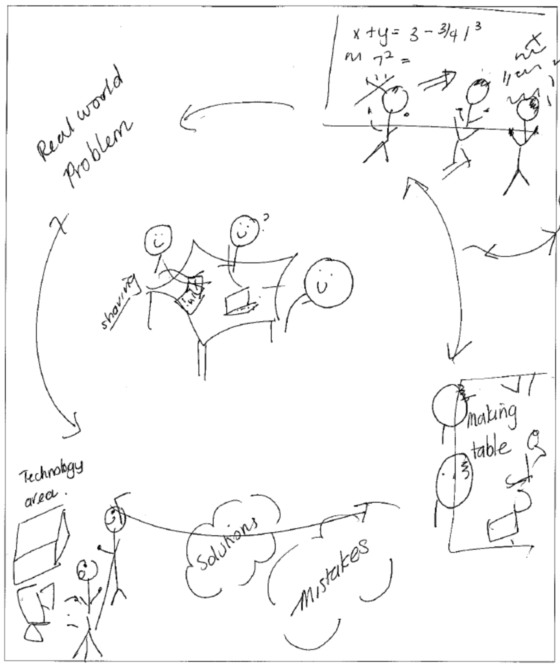
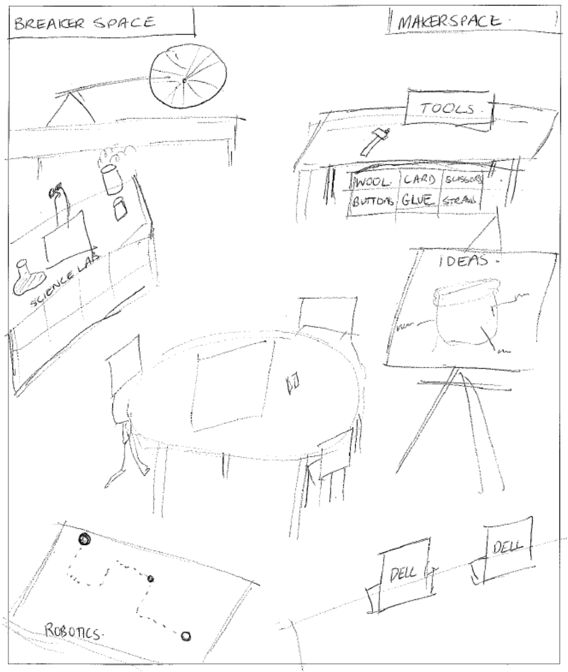
"experts in a special field" would be linked with learning objectives, but the participant might see the engagement of students with experts in a complex inquiry task to support and maximise the learning of STEM in students.



A real word problem. Teachers: Set the challenge/ design brief/problem. Guide the process. Students: Prepare design brief. Work in teams to provide ways of solving problems. Tools: Digital technologies- computers, - coding/robotics). Making tools- can be anything. Flexible learning environment.

Figure 5. P2's drawing and description of a STEM learning environment



Teachers use a range of materials to explore, invent and create. They have a space for collaboration and brainstorm their ideas. There are computers to research and also code, including with robotics devices. There is a makerspace with real tools as well as other materials to build prototypes. There is a breaker space where students can pull apart old computers, bikes etc to learn how things work and then repurpose these parts. There is a science lab for experimentation. These various sections can be used separately and/or in an integrated manner, depending on the project.

Figure 6. P14's drawing and description of a STEM learning environment

The teaching and learning of STEM

Table 4 provides the frequency of visual and/or written descriptions corresponding to the final element, the Teaching and learning of STEM. It was included separately as the drawings were analysed on a two-point scale (present/absent), rather than the three-point scale used in the other elements.

Table 4.
The frequency of D-STEM responses at each level for each element (N=21)

Element	Drawing/writing includes reference '1'	Drawing/writing includes no reference '0'
The teaching and learning of STEM		
Teaching and learning practices	18	3
Tools	20	1
Roles of the teacher	16	5
Roles of the students	18	3

The analysis showed that most responses (n=18) represented contexts in which experiential and open-ended approaches such as science inquiry, engineering design or problem-based learning (PBL) are implemented, and students investigate solutions to tasks or problems through designing, testing and revising their ideas. The drawing and text from P1 (see Figure 1) and the texts from P3 and P23 provided indicative responses:

> 21st C skills- resilience, asks questions, curious, being self-aware, collaborative. Inductive learning: Instead if here is the knowledge, now go practice it --- here are some objects, experience, data- what knowledge can we gain from it? (PBL/Inquiry learning). (P3)

> Problem identified-shared-ideas generated as group ⟶ Work can go to research or 'THINK TANK' to further develop or plan their solutions ⟶ Materials can be gathered to then ⟶ Test their solutions ⟶ Shared experience/group feedback/even better if. (P23)

These eighteen responses included explicit references to teaching and learning practices. The practices commonly identified were: making things (*f*=11), testing or experimenting (*f*=11), working with or using/learning different technologies or equipment (*f*=10), inquiring (*f*=9), solving problems (*f*=5) and developing/creating solutions (*f*=5), designing processes/products (*f*=3), asking/generating questions (*f*=3) and planning (*f*=3). Collecting information (*f*=4) or data (*f*=1) and interpreting (*f*=1) data, and computational thinking (*f*=1) were also evident.

Almost all responses (*n*=20) showed that an essential part of STEM learning environment is the integration of technology, digital tools and various equipment pertinent to the STEM practices depicted and discussed. For instance, in P18's response:

> Students collaborate together to work on questions/problems- utilising a range of tools+equip. The classroom/workshop provides: Space for collaboration/discussions/design, Space for building + assembling +experimenting, Space for whole class teaching and individual spaces for quite thinking. Computers/Technology access: Access to science habs + design spaces. Students use a range of equipment: including technology, scientific, building equipment tools Robotics/lego/3D printers laser cuttlers/Virtual reality programmes/mine craft/drones Design programs--- CAD, etc; coding.

P1 depicted electronic materials (TV/projector, Computer, 3D printer), science equipment, and digital tools (Augmented reality, Google mask) as being available to students for use in "collaboration problem solving" (see Figure 1). P14 described a context in which "a range of materials to explore, invent and create" including "computers to research and also code, including with robotics devices", a makerspace "with real tools as well as other materials to build prototypes" and "a science lab for experimentation" to be used "separately and/or in an integrated manners, depending on the project" (see Figure 6). What was less apparent in the responses was the presence of representational forms of ideas/concepts related to STEM subjects allowing these ideas/concepts to be communicated in e.g. graphs, tables or diagrams.

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In most responses the active role of the teacher (*n*=16) and students (*n*=18) in STEM teaching and learning environments was evident. The teacher and students were described or pictured as interacting in an environment in which the teacher is no longer just the knowledge giver, and students are no longer only knowledge receivers. Rather the teacher guides or facilitates the learning, and students are active, and take on roles other than listener or knowledge receiver including collaborator, maker and experimenter. As can be seen in Figure 2, the learning environment that P8 represented includes students working in groups to solve problems and appears to portray pedagogies that include students engaging thoroughly in the learning process and authentic inquiry. Similarly, P2 (see Figure 5) represented an environment in which creativity and student autonomy are encouraged and in which students link the knowledge they learn at school with the "External Environment".

Among the whole group, three participants indicated that the teacher is not an 'expert' anymore:

> The teacher is the facilitator to help students direct their learning journey--- helping guide the personal discovery linked to the outcomes to enhance their learning within the curriculum framework or beyond. Students can use a range of spaces and learning styles to gain the depth of understanding required. Students use the latest technology and teach the teacher this part as shared learners. The teacher is not expected to be the expert any more. Creative Critical Thinking Citizens. (P15)

> A hive of activity where students can engage in deep learning in an open learning environment. The space has flexibility and encourages collaboration, creativity, communication, critical thinking etc. The teacher collaborates with the students and is as much a learner as the students. They are not expert in the room. (P16)

> The teacher collaborates and acts as facilitator and guide mostly. Often the teacher is also the co-learner. ICT is a major tool used including traditional as well as new and innovative technologies. A kitchen/garden program can also be part of a STEM space in which STEM activities are linked to the curriculum through cooking and growing. (P20)

From these few responses it was not clear what the notion that the teacher is no longer 'expert' refers. It could refer to the fact that the problems are so diverse and draw from several STEM disciplines, that teachers can no longer have the level of expertise that the complexity of the problems requires, or it could be that STEM learning environments free the teacher from the need to be perceived as the expert.

Discussion, Implications, and Future Directions

The results reported here relate to perceptions of school principals with respect to STEM learning environments as revealed in their drawings and associated verbal statements. The study sought to answer the research question: *What are school principals' perceptions of effective STEM learning environments? A further contribution of the study is methodological in response to the question: How can established drawing-based techniques be adapted as a way of uncovering principals' perceptions of STEM learning environments?*

The drawing task elicited a wide variety of responses which varied in range and reflected a diversity of interpretations of STEM learning environments. The two elements most commonly depicted in participants' responses were: working collaboratively in groups, and using open-ended student-centred teaching and learning practices; while a focus on the opportunities that STEM learning environments provide to link content with industry and the community was almost absent. We were surprised that most of the responses reflected participants' perspectives about student-centred instruction. Very few responses depicted and/or described teaching and learning practices anchored in realistic problems, which can enable the integration of individual STEM disciplines, and engage students in the translation of concepts across multiple representations. This is interesting

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because it suggests that for most participant principals, the phrase 'STEM learning environment' equated to the use of student-centred pedagogies in classrooms, where students work collaboratively, and the teacher's main role is to motivate and facilitate their learning.

Adopting student-centred pedagogies does not reduce the teacher's responsibility for designing and overseeing student learning or their need to develop and apply specific expertise in the STEM learning environment (Keiler, 2018). Consequently, the three participant principals' statements that describe the teacher as a 'co-learner', or that the teacher is no longer expected to be the 'expert', warrant further investigation. The extent to which an individual teacher needs to be knowledgeable about all science, technology, engineering and mathematics practices in STEM learning environments, described by Vasquez et al. (2013) is as yet unexplored (see exceptions e.g. Chan, Yeh, & Hsu, 2019; Srikoom, Faikhamta, & Hanuscin, 2018), but the fact that expertise is required is clear (Allen, Webb, & Matthews, 2016).

Principals' drawings and text indicated that they placed more emphasis on science, engineering and technology practices (e.g. making/designing, testing or experimenting, and working with or using/learning different technologies) than mathematical practices in the drawings and descriptions. While of concern, this outcome is useful for mathematics educators, as the D-STEM instrument reveals its potential to draw attention to the presence or otherwise of mathematics in an integrated environment and to confirm or assuage fears that mathematics may be neglected in such contexts (Fitzallen, 2015). In addition, it has the potential to highlight the ways in which mathematics is portrayed in these environments. The latter offers an opportunity to re-emphasise the value of research-based approaches to mathematics teaching (e.g. Sullivan, 2011) and STEM education more broadly.

As discussed, the literature emphasises the importance of incorporating opportunities for students to work with different modes of representations as they learn STEM concepts. Data analysis of principals' drawings and text revealed that only a small number of participants incorporated different modes of representations in their learning environments or referenced tasks or activities that could draw from different representational modes. In most of their diagrams and text, the use of representational tools remains implicit or is absent altogether. In order to determine the real extent to which multiple representations are incorporated into STEM learning environments and the problems/projects that students engage in, this element would need to be the focus of observation in classroom settings.

Principals treated the drawing-based technique, designed to elicit their perceptions of STEM learning environments as a serious task, taking some considerable amount of time to capture their responses. In addition, it is our observation that drawings contain rich information relating to understanding of STEM learning environments in educators active in STEM education (Hatisaru et al., 2019). We take these as evidence of the success of the drawing method as a means of investigating individual views about STEM learning environments. As anticipated, it was methodologically very useful to include the prompt requesting participants to look back at the drawing and explain it so that anyone looking at it could understand it. This addition enabled us to clarify the information contained in the drawings and to enhance our interpretation of the STEM learning environments depicted.

The D-STEM Rubric continues to be refined based on the related literature and the ongoing collection of additional data. The D-STEM Rubric reported on here is the second version and points to the need to hone it further, through trialling both it and the D-STEM instrument with larger groups of participants including teachers of STEM disciplines and their students. However, our research confirms that drawings have the potential to "provide a valuable catalyst to document, change, and improve what goes on in schools" (Haney et al., 2004, p. 243). Importantly, this research has revealed the usefulness of the D-STEM instrument and its rubric as a methodology for unearthing the ways in which principals think about STEM learning environments. Making their thinking visible in this way, enables a discussion of the presence and absence of elements in learning environments revealed as being essential for effective STEM learning. Participating in such an activity both challenges conceptions and stimulates thinking about how such learning environments could be constructed

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as well as the dispositions and skills that they, and both teachers and students need to possess or develop in order to engage in rich STEM learning. The data reported here points to the need for professional development in STEM education designed specifically for principals, aimed at building their capacity to both understand the need for effective instructional leadership in relation to the pedagogical and curricular elements of STEM teaching that the D-STEM Rubric involves and to enact it in their schools.

While the D-STEM instrument and its associated rubric have enabled an understanding of principals' conceptions of STEM learning environments, data analysis revealed that the instrument itself could be further improved. In our development of the D-STEM instrument for use with principals, we acknowledged that not all principals teach or if they do, STEM subjects may not be their area of expertise. Hence, in order to explore their thinking about STEM learning environments, we provided them with the prompt: "*Think about the teachers of STEM and kinds of things they do. Draw a STEM learning environment*." We acknowledge that the prompt itself may have influenced the type of drawings and responses we obtained. For example, direct reference to the teacher in the prompt may influence their being in the image, and the absence of any reference to learning objectives may diminish the importance of student learning in their thinking.

While acknowledging that the D-STEM instrument and its rubric will benefit from further evaluation and enhancement, this research suggests several other lines of inquiry for the future. As discussed earlier, drawing methodology is a powerful approach to unearthing perceptions about phenomena but it is limited. When something is absent from a drawing and text, does that mean that it is absent from perceptions or just the response? A case in point is the near absence of reference to representational tools (e.g. diagrams, graphs, written symbols) in principals' drawings. Understandings about both of this element (multiple representations) and others (e.g. realistic problems) (see Table 1) recognised as being important for STEM learning, would benefit from classroom observation guided by the D-STEM Rubric elements in Table 1. Similarly, the extent to which these elements are present in learning environments could be assessed with respect to student performance and learning outcomes and/or teacher professional knowledge and dispositions. Indeed, using the D-STEM methodology to interrogate the outcomes of professional learning on the latter aspects of teacher practice could prove useful in measuring change.

Conclusion

The version of the D-STEM Rubric presented here emerged from analysis of the responses of school principals and initiates a new area of research concerning the ways in which these school leaders perceive STEM learning environments. It enables consistent messaging about, as discussed Bybee (2013), what STEM looks like in the classroom, and whether anything and everything in relation to the individual STEM subjects are STEM.

The D-STEM instrument and its rubric were developed based on an extensive literature review and initial empirical data from researchers active in STEM education (Hatisaru et al., 2019). Given that STEM education, undertaken either as separate disciplines or integrated to a greater or lesser extent, is positioned as a key strategy for fostering economic development and prosperity. The D-STEM Rubric represents an initial contribution to providing STEM educators and researchers with a tool for considering the breadth and quality of STEM learning environments.

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RESEARCH REPORT

How Parents Support Children's Informal Learning Experiences with Robots

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Abstract: *Coding and robotic technologies are becoming more prominent in early childhood STEM education. Parents, who are key facilitators of children's early educational experiences, are increasingly invited to engage with their children in collaborative robotics activities. Few studies have focused on the ways in which parents support young children's informal learning experiences involving robots. This paper presents two different approaches to exploring how parents support young children's engagement. Both studies involve KIBO, a screen-free robot programmed with tangible wooden blocks. The first approach brought together children ages 5-7 with their parents in small groups for 1-2-hour "KIBO Family Day" workshops. Findings from parent surveys (N = 51) indicated that these workshops significantly enhanced families' interest in coding. Parents also reported engaging as coaches, whereas children engaged as playmates and planners. To further explore the role of parents as coaches, three parent-child dyads were invited to participate in a 20-minute videotaped KIBO play session. Findings indicated that parents predominantly used cognitive scaffolding strategies, such as asking questions, offering suggestions, and verbally acknowledging their child's actions. Affective and technical scaffolding strategies were used less frequently. Study limitations and implications for practice and future research are discussed.*

Keywords: *Early childhood, robotics, collaborative learning, parents, scaffolding*

Introduction

Coding and robotic technologies are becoming more prominent in early childhood STEM education as a reflection of the importance of computer skills in today's society (Bers, 2018; K-12 Computer Science Framework Steering Committee, 2016). Programmable robots that are developmentally appropriate, such as the KIBO robotics kit, are well-suited to introducing young children to coding in both formal and informal learning settings (Albo-Canals et al., 2018; Bers 2018; Lee, Sullivan, & Bers, 2013).

Prior work has shown that parents are important facilitators of young children's learning in informal settings (Parker, Boak, Griffin, Ripple, & Peay, 1999). For example, parent-child reading interventions and home reading programs have been shown to improve children's linguistic and cognitive development (National Early Literacy Panel, 2008; Taylor, 1983). However, in contrast with family literacy initiatives, parents may have little or no experience with coding and may not have access to educational robotics tools. Thus, they may feel ill-prepared to introduce robotics to their children on their own (Dell'Antonia, 2014; The Toy Association, 2017). To address these issues, initiatives to bring families together to engage in creative coding and robotics activities have risen in popularity in the last several decades (Beals & Bers, 2006; Bers, 2007; Govind, Relkin, & Bers, 2020; Cuellar, Penaloza, & Kato, 2013; Feng, Lin, & Liu, 2011; Lin & Liu, 2012; Pearce & Borba, 2017;

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Roque, 2016). Findings from these family coding events have demonstrated the benefits of parents and children engaging in collaborative computing activities. However, few studies have focused on young children and the ways in which parents support their informal learning experiences with robots.

This paper presents two different studies that brought parents and their young children together to engage collaboratively with the KIBO robotics kit, a screen-free robot programmed using tangible wooden blocks. The first study reports on findings from a series of five "KIBO Family Day" workshops that took place outside of school hours and enabled families to interact in semi-structured play sessions with the KIBO robot. The purpose of this study was to understand parents' views on how these workshops impacted families' interest in coding, as well as the kinds of roles assumed by children versus parents during the robotics activities. A second observational study examined the specific strategies used by parents to support children's engagement with KIBO. Three parent-child dyads were videotaped during a 20-minute semi-structured play session with the KIBO robot. Together, findings from the two studies were used to answer the following research questions:

1. How did participating in a KIBO Family Day workshop impact parents' views on their families' interest in coding?
2. What kinds of roles did parents perceive themselves and their children engaging in while working together with KIBO?
3. What kinds of strategies do parents use to support children's engagement with KIBO?

Related Work

There is some evidence that family coding events foster greater interest in coding among children and adults. These events have largely been conducted in informal community-oriented settings with multiple families. For example, Family Code Night (Pearce & Borba, 2017) provides event kits for schools to host large-scale family coding workshops using Code.org and unplugged activities. The Family Creative Learning model (Roque, 2016; Roque, Lin, & Liuzzi, 2014, 2016) brings together school-age children and families to create projects using the Makey Makey invention kit and the Scratch programming language. Another example is the organization Startups for Kids, which hosts free workshops to teach children and their families about coding in preparation for careers in tech (https://startupforkids.fr). Findings indicate that parents and children find programming more enjoyable after these family-oriented events and show increased interest in creative problem solving and project-based learning.

Furthermore, these opportunities enable parents and children to assume and develop a variety of roles as they collaborate and learn from one another. Unlike traditional roles of child as novice and parent as expert, new technologies often bring about varying role dynamics and interactions (Barron, Martin, Takeuchi, & Fithian, 2009; Roque, Lin, & Liuzzi, 2016). For example, parents may serve as learning brokers and non-technical consultants (Barron et al., 2009) or become their children's co-designers and assistants (Armon, 1997; Feng, Lin, & Liu, 2011; Lin and Liu, 2012; Roque, Lin & Liuzzi, 2016). In addition, museum studies involving young children and their parents and grandparents have found participants engaging in similar roles such as planner, observer, teacher, coach, and playmate (Sanford, Knutson, & Crowley, 2007; Swartz & Crowley, 2004). Although the role names differ slightly across disciplines, the strategies that parents use to peripherally assist children and encourage them to drive their own learning are best summarized by the literature on scaffolding.

Scaffolding is defined as the "process that enables a child or a novice to solve a problem, carry out a task, or achieve a goal which would be beyond [her] unassisted efforts" (Wood, Bruner, & Ross, 1976). Research on scaffolding indicates that parents assume a variety of positive supportive behaviors that promote children's early learning (Neumann, 2017; Wood et al., 2016). Yelland and Masters (2007) identified three types of scaffolding behaviors used by teachers to encourage student learning within computer-based environments. The first, cognitive scaffolding, denoted behaviors that promoted conceptual and procedural understandings, such as asking questions, assisting with making plans, and encouraging collaboration (i.e., social cognition). The second, affective scaffolding, consisted of behaviors that promoted staying on task and using positive encouragement to promote

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higher levels of thinking. Lastly, technical scaffolding referred to features of the computer technology that teachers could highlight to facilitate learning.

In this paper we use this classification scheme to understand the types of strategies parents use to promote children's engagement with robotics, specifically the KIBO robotics kit. The KIBO robotics kit (Bers, 2018) is a developmentally appropriate platform designed to teach coding to children between four and seven years of age. It has been subjected to extensive testing and use in a variety of educational settings. Prior research has found KIBO not only effective for teaching young children foundational coding and computational thinking concepts, but also for encouraging problem solving, creativity, and social interactions (Elkin, Sullivan, & Bers, 2016; Sullivan, Bers, & Mihm, 2017).

The screen-free KIBO robot (see Figure 1) is programmed using tangible wooden blocks. Children connect wooden programming blocks into a syntactically correct sequence and then scan the blocks using a barcode scanner contained within the robot. Each block represents one instruction step. KIBO was designed with a "low floor, high ceiling" (Resnick & Silverman, 2005) principle, meaning the robot is simple enough for a novice to use but sufficiently adaptable to challenge a more advanced child programmer. The KIBO robotics kit has sensors, modules, and extensions that attach to the KIBO body and enable children to artistically design and personalize their robot creatively, as well as respond to stimuli from the environment, such as light, sound, and distance.

Figure 1. KIBO Robotics Kit.
The left image shows the KIBO robot, programming blocks, and add-on parts, and the right image shows the robot sensors and other modules.

This paper, which presents two different studies involving parents and children co-engaging with the KIBO robotics kit, builds upon prior work in several ways. First, we add to the existing literature on family coding, specifically focusing on young children in order to fill the early childhood gap. Educational robotics kits are increasingly popular play tools for young children, so this work will prove useful for understanding how parents and children interact when co-engaging with these tangible tools. Second, this work was conducted in two different types of settings using different methodologies. The first study, KIBO Family Days, involved community-oriented events that took place in informal settings, and data were collected directly from parents in order to understand their perspectives. The second study, Parent-Child Interactions, involved a more experimental approach and took place in a lab setting. Data were collected through close observation of parent-child dyads and analysis of parent behaviors. Taken together, both studies provide insight into how parents support young children's informal learning experiences with the KIBO robotics kit.

Method

Study 1: KIBO Family Days

Recruitment. Five KIBO Family Day events took place between October 2017 and July 2018.

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As part of the recruitment and outreach plan, two additional events were hosted by individuals who were not part of the research team. Because data from parent attendees were not collected during these two events, we have not included these events in our analyses. We recruited families using our research group's mailing lists and social media platforms, event flyers, and word-of-mouth. The event was advertised as a free family coding workshop for children ages 5-7 and any of their family members. Although recruitment methods reached individuals around the world, all five events were conducted in the New England area and facilitated by one or more of the authors of this paper.

Participants. The five KIBO Family Day events attracted a total of 70 parents, who consented to participate in research surveys before and after the event, along with a total of 99 children. We present in this paper the findings from N = 51 survey participants who completed both pre- and post-surveys (see Figure 2 for study flow diagram). No significant family demographic differences were found between parents who completed one survey versus parents who completed both. All 51 survey participants identified as the parents of the children that attended the event.

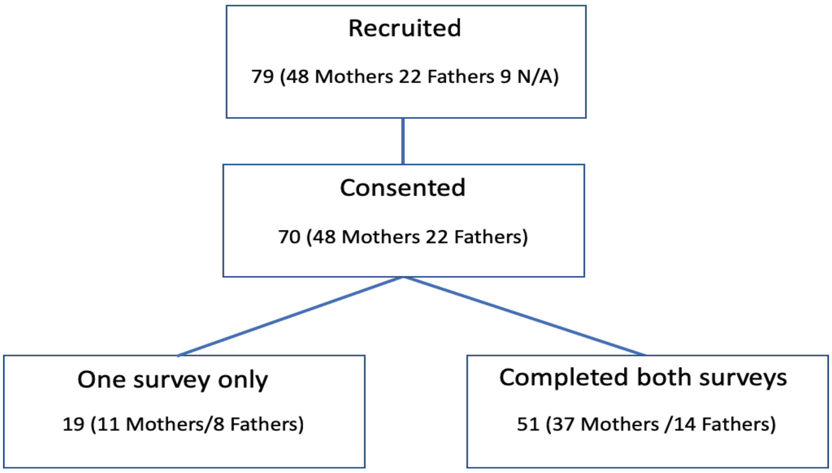

Figure 2. Study Flow Diagram for KIBO Family Day

Of the 51 parents, 37 (73%) identified as female, and 14 (27%) identified as male. These participants brought a total of N = 56 children with them. The mean age of all children was five years. 45% of parents reported that their children had prior coding experience before the event (31% ScratchJr, 24% KIBO, 8% Scratch, 5% LEGO WeDo, 21% other). Parents' educational attainment varied, but the majority of participants (90%) held at least a bachelor's degree (37% bachelor's degree, 33% master's degree, 20% professional degree). In addition, 29.4% of parents in this sample reported their profession was related to STEM (Science, Technology, Engineering, and Math). Examples of reported STEM professions included software engineering, healthcare, and graphic design. Examples of non-STEM professions included merchandising, architecture, and compliance. 29% of parents reported that they had some level of coding experience themselves prior to this event. 16% of parents identified as "coding frequently and being a coding expert."

Procedure. Facilitators followed a step-by-step KIBO Family Day protocol. The protocol included a facilitator script, sample agendas, suggested coding activities, parent tip sheet, and activity sheets for children. Depending on the number of families who signed up, each event was led by 2-4 facilitators. All five events lasted between 1.5-2 hours and involved a maximum of 25 children and their families at a time. The events took place during after-school hours in two adjacent classrooms. The first large classroom had ample floor space and contained the KIBO robotics kits and decorative craft materials. In the second classroom, facilitators set up tablets with surveys for parents to complete before and after the workshop. All adults provided informed consent under the terms approved by the university's institutional review board.

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Each event followed a similar agenda. For the first part of the event, children engaged in interactive games and a hands-on introduction to the KIBO robot while parents completed consent forms and pre-surveys. After 20-30 minutes, parents joined their children to work together on a creative coding project with KIBO. Families either followed the provided activity prompts ("create a robot dance" or "create a robot animal") or came up with an idea of their own. While families worked on their projects, facilitators monitored the room and encouraged families to share tips and ideas with one another. At the end of the workshop, families gathered in a circle to share their coding projects with one another. Parents completed post-surveys as children assisted the facilitators with cleaning up.

Data collection and analysis. Parents/legal guardians were asked to complete optional research surveys before and after the event. Surveys consisted of multiple-choice, Likert-type scale items, and open-ended responses. Some items such as coding interest were included in pre- and post-surveys in order to assess the impact of the KIBO Family Day event. Other items such as parents' views of roles assumed by children and parents were included only in the post-survey.

To answer the first research question, "How did participating in a KIBO Family Day workshop impact parents' views on their families' interest in coding?", we analyzed parents' responses to the coding interest items in the pre- and post-surveys. Parents reported on their own level of coding interest, as well as their perceptions of children's coding interest, on a 5-point Likert-type scale. Related samples t-tests were used to test the significance of differences between coding interest before and after the event.

To answer the second research question, "What kinds of roles did parents perceive themselves and their children engaging in while working collaboratively with KIBO?", we analyzed parents' responses to the post-survey items pertaining to parent and child role engagement. We used the five major roles (planner, observer, teacher, coach, and playmate) identified from the literature and asked parents to rate the extent to which they and their child engaged in each role on a 5-point Likert-type scale. Related samples t-tests were used to test the significance of differences between parent and child roles. Due to running multiple comparison tests, which increases the risk of Type I error, the Bonferroni correction was applied, and the resulting alpha value for determining statistical significance was determined to be .007.

A brief description was provided for each of the five roles:

- Planner: planned out project topic and delegated tasks to others
- Observer: let others guide project creation and did not contribute to coding activities
- Teacher: explained some of the coding topics to the group
- Coach: encouraged and supported the group and offered suggestions
- Playmate: shared the fun, enjoyable parts of the coding activities

Parents were also asked about the extent to which their experience was collaborative (meaning that the majority of discussion and activities were shared) or predominantly led by either an adult or child. Chi-square tests were used to compare differences in the frequencies of responses.

Study 2: Parent-child interactions

Recruitment. For the second observational study, we recruited families via mailing lists, word-of-mouth advertising, and prior KIBO Family Day event attendance lists. Inclusion criteria for study participation were that the child must be between five and seven years old, the parent must be able to complete surveys in English, and both the child and parent should be able to converse comfortably in English.

Participants. This sample consisted of three parent-child dyads, all consisting of a child who participated with their mother. Each participant's name has been replaced by a pseudonym to maintain confidentiality. The first parent-child dyad included Thomas (age 6), who had no prior experience with KIBO, and his mother Maria (age 40), who worked in a STEM profession, held a master's degree, and had coding experience using statistical software. The second dyad included Sarah (age 6), who had prior experience with KIBO, and her mother Andrea (age 42), who worked in a non-STEM profession, held a master's degree, and had no prior coding experience. The third dyad

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included Jordan (age 5), who had prior experience with KIBO, and his mother, Caroline (age 50), who worked in a non-STEM profession, held a master's degree, and had no prior coding experience. We acknowledge that these three case studies are not fully representative of all families who previously attended KIBO Family Day workshops or have co-engaged with KIBO in other informal settings. However, these case studies were still meaningful in unpacking the specific strategies used by parents to support their children during collaborative robotics activities.

Procedure. We conducted this study in a closed room connected to an observation booth, separated by a one-way-view mirror. The room included a center table with four surrounding chairs, a sofa on the back wall, a side table for displaying a visual timer and decorative craft materials (e.g., construction paper, tape, scissors, and markers). One KIBO robotics kit was placed on top of the center table. The adjacent observation booth had a built-in audio and video system, and an additional tripod was set up inside the room. In addition to videotaping play sessions, 1-2 researchers observed and took live field notes from the observation booth.

The parent-child dyad first entered the testing room with the primary researcher and was permitted to sit anywhere they felt comfortable. The parent then completed a brief demographic survey while the researcher allowed the child to freely explore KIBO. After the parent completed the survey, the researcher provided a brief interface tutorial and explained to the dyad that they would have 20 minutes to play with the interface and create their own coding project. The prompts for the coding project were similar to those provided during the KIBO Family Day events. In order to make the setting feel as naturalistic as possible, the researcher asked parents to engage with their child as they would during any other activity. If the parent or child needed any assistance during the KIBO play session, a researcher would be outside the room and could assist them at any point. After 20 minutes, the researcher came back into the testing room, and the dyad shared their coding project. Parents also participated in a semi-structured interview and post-survey about the joint programming experience; however, these data are not presented in this paper.

Data collection and analysis. To answer the third research question, "What kinds of strategies do parents use to support children's engagement with KIBO?", we transcribed the three 20-minute play sessions and identified the total number of talk turns for each parent. We defined a parental talk turn as a full statement or set of statements that expressed a complete thought or action. If the researcher came into the room to assist the dyad during the 20-minute play session, we omitted from our analysis parental talk turns that took place during the researcher's presence in the room.

After identifying the parental talk turns, we coded every talk turn using the cognitive, affective, and technical scaffolding (CATs) coding system and sub-categorized the talk turns by specific behaviors. Eleven codes were identified in total (see Table 1 for code descriptions). After one researcher coded all of the talk turns for the three dyads, a second trained researcher coded a randomly selected 25% of the transcripts to establish inter-coder reliability. Initial percentage agreement was 77%. After discussing discrepancies, both coders collaboratively refined the coding system for greater clarity and came to 96-98% percentage agreement per dyad. The second coder then re-analyzed the other 75% of the transcripts using the refined codebook.

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Table 1.
Codebook for parental scaffolding strategies

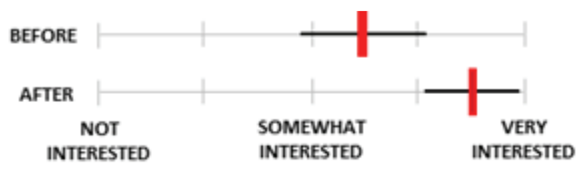
Code	Description
Cognitive scaffolding	
Asking questions	Parent asks the child a question about the project or about KIBO
Modeling	Parent provides an example to help child come up with an idea or demonstrates effective design thinking
Offering suggestions	Parent suggests ideas to the child or offers an idea as a statement or question
Encouraging collaboration	Parent asks or encourages child to work together
Verbal acknowledgement	Parent either verbalizes part of the code or KIBO's action, or parent repeats something the child says
Affective scaffolding	
Encouraging or praising	Parent encourages or praises child
Relieving stress/frustration	Parent provides encouragement if child is stressed or frustrated
Redirecting to task	Parent redirects child to stay on task
Being playful	Parent acts playfully with child
Technical scaffolding	
Physically assisting	Parent physically helps operate KIBO
Verbally instructing	Parent provides verbal instructions on how to use KIBO

Results

Study 1: KIBO Family Days

Coding interest. Parents reported that their interest in coding and that of their children increased significantly following the KIBO Family Day events (see Table 2). Children's coding interest started at a mean of 3.52/5, SD =1.15 and increased to 4.41/5 SD=.805. Adult coding interest averaged 3.38/5 SD=1.18 initially and increased to 4.39/5 SD=.75 after the coding event.

Table 2.
Parent-reported coding interest before and after KIBO Family Day

Survey Question	Responses: Mean (red) +/- SD (black)	Significance
Child Coding Interest n = 44 "Please rate your child(ren)'s level of interest in coding:"		t(43) = 4.65, p < .001
Adult Coding Interest n = 42 "Please rate your level of interest in coding:"		t(41) = 6.53, p < .001

Collaboration. The majority of parents considered the event to be collaborative (n = 28, 54.9%),

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some thought it was child-directed (n = 18, 35.3%) and only a few parents (n = 5, 9.8%) reported the experience was adult-directed. Prior experience with KIBO did not significantly affect parents' ratings of the collaborative nature of the Family Days activities. Mothers were more likely to report that the activity was collaborative, whereas fathers were more likely to report the event as child-directed. The relation between parent gender and nature of collaboration was significant, X2(2) = 8.99, p = .011 (see Table 3).

Table 3.
Classification of coding experience stratified by parent gender in Study 1

	Adult-directed	**Child-directed**	**Collaborative**
Mother (n = 38)	4 (10.5%)	9 (23.7%)	25 (65.8%)
Father (n = 13)	1 (7.7%)	9 (69.2%)	3 (23%)

Parent versus child role engagement. Parents reported engaging more as coaches compared to their children, $t(77.15) = 2.99$, $p = .004$. Children engaged more as planners, $t(85) = 6.60$, $p < .001$, and as playmates, $t(62.90) = 2.95$, $p = .004$ (see Figure 3).

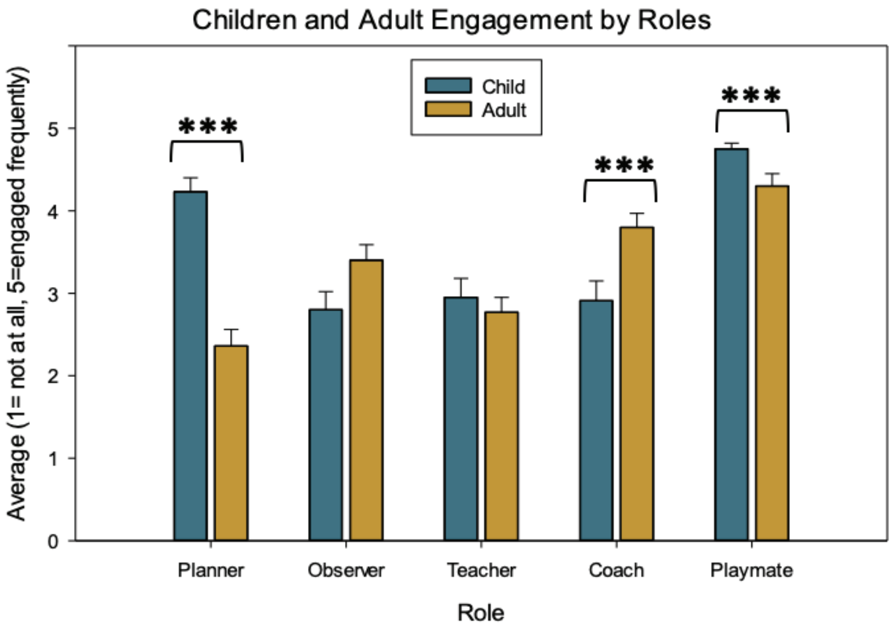

Figure 3. Parent-Reported Role Engagement during KIBO Family Day.
Parents reported engaging more as coaches, whereas they reported children engaging more as playmates and planners.

Study 2: Parent-child interactions

We first present a summary description of our three case studies and the KIBO projects they co-created. Then, in order to ground the quantitative findings from Study 1 and further explore parents' perceived roles as coaches, we describe the specific strategies we observed parents in our three case studies using to support their children's engagement with KIBO.

Dyad 1: Thomas (child) and Maria (parent). In this play session, Thomas creates a "KIBO hotel" project, beginning by showing his mother, Maria, how to scan the blocks. After testing the program together and realizing that KIBO is not performing all of the actions in the program, Thomas calls the researcher in to help. Thomas and Maria figure out that they probably missed some blocks while they were scanning and that they forgot to record a sound using KIBO's Sound Recorder module. Maria continues to encourage Thomas to explore KIBO and helps Thomas scan the new program he

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has made. The program runs successfully this time, and Thomas eagerly calls the researcher back in to showcase the new program. The dyad starts to make a new project, and Thomas decides to let his mother take a turn to make her own project. Thomas allows Maria to plan the project by herself, while remaining fully engaged in helping her assemble the blocks and offering encouraging words.

Dyad 2: Sarah (child) and Andrea (parent). Sarah, having had extensive experience with KIBO, immediately starts assembling a KIBO program. After testing it once, Sarah asks Andrea if she wants to change the program. Andrea replies by asking for assistance with creating the program and Sarah teaches her mother about start and end blocks. While Andrea begins to create a program, Sarah abruptly shifts her attention to decorating KIBO and asks to make a rainbow. Sarah decides that she will make the "baby rainbow," then gives Andrea instructions on how to cut out the "momma rainbow." Andrea offers Sarah assistance with taping the rainbow onto the platform piece several times, but Sarah refuses each time. Andrea cuts out a pink heart after Sarah tells her to make something else for the project. Andrea watches and worries about Sarah's safety as Sarah insists on independently cutting out holes in the heart using the scissors. After finishing the decorations, Sarah and Andrea only have five minutes remaining and return to programming.

Dyad 3: Jordan (child) and Caroline (parent). Jordan decides that he wants to program KIBO as a tiger and Caroline lets him take the lead, beginning with the decorations. Caroline starts drawing a face on the tiger and prompts Jordan with questions to tell her about what the tiger should look like. Jordan becomes more engaged as Caroline draws and works with his mother to tape the orange paper around KIBO. Jordan and Caroline bounce ideas off of each other to make the decorations more sturdy. They begin to program KIBO after they run out of tape and Caroline asks Jordan for suggestions on what to make for their program. Jordan is distracted at first, but then becomes engaged. He purposefully chooses blocks, records tiger growling sounds, and scans the whole program independently. Caroline shows her excitement when they finally run their program.

Table 4 displays the frequencies of parental scaffolding behaviors for the three dyads. On average, parents exhibited 71.8% cognitive, 22.8% affective, and 5.5% technical scaffolding behaviors. We next describe qualitative examples of these behaviors.

Table 4.
Frequencies of parental scaffolding behaviors in Study 2

Dyad	1	2	3
Child has prior experience with KIBO	no	yes	yes
Cognitive scaffolding	**48**	**48**	**49**
1. Asking questions	22	20	17
2. Modeling	8	1	3
3. Offering suggestions	4	13	15
4. Encouraging collaboration	2	9	5
5. Verbal acknowledgement	12	5	9
Affective scaffolding	**13**	**15**	**18**
6. Encouraging or praising	8	3	5
7. Relieving stress/frustration	0	8	0
8. Redirecting to task	0	2	10
9. Being playful	5	2	3
Technical scaffolding	**10**	**1**	**0**
10. Physically assisting	6	0	0
11. Verbally instructing	4	1	0

Cognitive Scaffolding Behaviors. Among the three categories of scaffolding behaviors, cognitive was most prevalent, with asking questions and offering suggestions as the most common types of cognitive scaffolding. Parents asked questions in an effort to understand their child's design process, figure out how they could assist, and move the project along towards completion. If children were stuck or indecisive, parents would assist by reading aloud the character or block names. For example,

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when Thomas (Dyad 1) was deciding which blocks to use for their KIBO program, his mother Maria offered to read aloud the names of the different blocks, asking, "Do you want me to explain what all the blocks say on them? That way, you can understand your options."

Affective Scaffolding Behaviors. All three parents provided words of encouragement or praise throughout the play session. For instance, parents complimented their children for thinking creatively ("Your ideas are so original") and for problem-solving ("I knew you'd figure it out"). Parents would also often praise or encourage their child's effort to complete a task ("Nicely done" or "Good job"). This type of praise was particularly evident when a task was completed solely by the child. A parent would also redirect their child's attention back to the project if the child was distracted by other things in the room (e.g., the automated lights turning off, the mirror covering the one-way-view, the crafting materials, etc.). Redirection strategies included asking the child to look at the KIBO blocks together, reminding the child of behavioral expectations, or noting how much time they had left to work on their project.

Technical Scaffolding Behaviors. The level of parental technical support varied depending on whether the child had previous experience with KIBO. For instance, Jordan (Dyad 3) had extensive classroom experience with KIBO and thus required no technical assistance or parental instruction. Conversely, Thomas (Dyad 1) had no prior coding experience and was struggling to scan the blocks using the KIBO robot's embedded barcode scanner. His mother suggested holding the KIBO robot from different angles and positions, which improved his scanning accuracy.

Discussion

Coding is being introduced into early elementary school curricula in the United States and elsewhere in the world with increasing frequency (Code.org, 2020). However, there has been relatively little attention paid to family-inclusive coding experiences for young children. This study examined two approaches for bringing family members together in an informal environment designed to make learning to code with the KIBO robotics kit an enriching and collaborative experience. Although technology training in the classroom is invaluable, the involvement of parents and other family members in an extracurricular learning setting can potentially amplify benefits. The interaction of a parent and child can foster a higher level of engagement than may come about from a child's interaction with an unrelated individual (Piazza et al., 2020). By the age of eight, children's thoughts and perceptions about robotics are already heavily influenced by their parents (Druga, 2018). Our findings suggest that KIBO Family Day events provide open-ended and collaborative opportunities for families to learn about and become interested in robotics together.

Parents reported an overall high level of engagement and interest in coding after participating in KIBO Family Day events. This finding is consistent with previous studies that highlight the success of collaborative coding experiences for children and families (Pearce & Borba, 2017; Roque, 2016; Roque, Lin, & Liuzzi, 2014, 2016). In addition, children were observed to take the initiative to a considerable degree in planning their coding projects, whereas adults more frequently saw themselves in a coaching role. This finding reinforces the respective child and parent roles of "driver" and "reviewer" described by Lin and Liu (2012).

The significant gender difference in parents' classification of the event as collaborative, adult-directed, or child-directed is an interesting finding that was not anticipated prior to the study. The source of this difference is not clear but could reflect a generic difference in how mothers and fathers view play with their children rather than a specific outcome of the coding event. For instance, Bers (2007) found that fathers tended to be more controlling as compared to mothers when collaboratively coding using LEGO Mindstorms.

The participants in this study had varied educational attainment, occupations, and levels of past coding experience. It seems noteworthy that regardless of these differences in backgrounds, almost all participants reported high engagement during the event and expressed an increased interest in coding in the aftermath. In fact, no adult participants reported less interest in coding after taking part in the event. Three out of 43 children were reported to show less interest after the event. However, no further information was provided to explain reasoning for the decline in those cases. The overall high satisfaction level of adults and children participating in this event suggests that Family Day Coding events may be an effective way to enhance interest in coding in young children and their family members.

Findings from our second study showed that cognitive scaffolding was the most prevalent type across the three dyads, with asking questions and offering suggestions as the most frequently coded behaviors. This finding is not surprising considering that we identified five categories of cognitive scaffolding compared to only four affective and two technical scaffolding categories. However, this finding may still prove useful for understanding the relative importance parents place on cognitive development with educational robotics, as opposed to socio-emotional learning or fine motor skills. In addition, it may be likely that parents use similar strategies in other types of play-based learning activities with their children and have transferred those behaviors into this coding activity. For instance, one parent commented in the post-interview, "[We] do everything together. We play together, we grocery shop together...so this was no different."

Affective and technical scaffolding behaviors were observed less frequently. Affective scaffolding behaviors were present in roughly equal frequencies across the three play sessions. Parents used affective scaffolding to encourage their child in various ways, such as helping their child stay on task ("Alright before we do that, we should complete the program, no?") and praising their child's actions ("Oh there you go! Knew you'd figure it out"). Technical scaffolding was used by parents to physically assist or instruct their child in creating their program. For example, in a KIBO session, the parent pointed out to the child, "Yeah so that's light. It seems like these are all like different sounds KIBO can make...this is singing, this is a beep beep, this is play one." The relatively low frequency of technical scaffolding may relate to two of the three children being familiar with KIBO and thus requiring little technical support from parents.

Limitations and Future Directions

The data in Study 1 were collected exclusively from parent surveys. A strong correlation between levels of interest of the adult and child was observed, raising the possibility that the parent projected their own level of interest on the child. However, past studies focusing on parent reports of children's engagement suggest that parent assessments tend to be accurate (Hughes, Wikeley, & Nash, 1994). Prior work has shown that the KIBO robot can foster a high level of interest and excitement about programming and robotics in young children (Sullivan & Bers, 2018; Bers, 2018). We found that parents also report a significant increase in both their children's and their own coding interest after engaging with KIBO.

In order to maintain an informal, naturalistic environment, we did not interview, formally observe, or directly survey the participating children during KIBO Family Day workshops. Some studies have shown that lab-based play can provide a reasonable model of behaviors in more naturalistic environments (Rideout, 2017). Thus, we used a closed laboratory setting for the second observational study. However, we acknowledge that families may interact differently in laboratory settings as opposed to natural home environments and informal learning spaces such as museums and afterschool programs.

Likewise, families were not formally evaluated on their coding abilities after attending this event. Although assessment may be helpful in understanding what kinds of learning children and adults gain from these collaborative coding experiences, a brief intervention such as a single KIBO Family Day event only introduces families to basic coding principles. A series of such events combined with classroom instruction may be more likely to yield measurable improvements in coding ability. As such, this study focused specifically on parents' perceptions of children's coding interest rather than objective skill measures.

Despite the use of a protocol designed to standardize events, each KIBO Family Day was conducted slightly differently. The number of KIBO kits and participants at each event were not identical, and the need to share robots may have impacted (positively or negatively) the nature of

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collaboration and other outcomes. Available space may also have influenced study outcomes, as space was limited at some of the events and participants were confined to relatively small work spaces that may have detracted from their enjoyment of the experience.

We originally intended to have educators from outside of our research program collect survey data. Although we received over 60 inquiries from educators around the world expressing interest, no outside facilitators contributed survey data. The event required at least two facilitators to collect survey data in accordance with the protocol, which may have created too much of a burden on outside facilitators. Future studies of family coding events might employ simplified protocols that reduce personnel requirements.

Both studies also utilized convenience sampling techniques. In Study 1, approximately 30% of participants reported a background in STEM-related areas, and many had high levels of educational attainment. Study 2 included a small number of families within the network of recruitment efforts who self-selected to participate. The three dyads consisted of mothers who were highly educated from middle-to-high socioeconomic backgrounds. Future research should employ a larger and more diverse sample size and explore the possible effects of parent and child gender, age, prior coding experience, and socioeconomic status to increase generalizability.

Conclusion

This work explored how parents support children's informal learning experiences with the KIBO robotics kit. Overall, KIBO Family Day events were well-regarded by parents, who reported that the events increased coding interest in their children and themselves. Most parents reported that the event provided a collaborative experience in which adults and children took on different roles. Parents supported their young children's exploration of new technologies by the use of cognitive, affective, and technical scaffolding strategies. The model of using programmable robots in informal group settings that include parents and other family members has merit as a means of introducing young children to the valuable skill of coding.

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RESEARCH REPORT

STEM Integration for High School Mathematics Teachers

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Abstract: *The discipline of mathematics in science, technology, engineering, and mathematics (STEM) integration has not yet been consistently connected in a clear way for a large amount of high school mathematics teacher to implement STEM integration well. In response to this I have proposed a focus on integrated steM education; the integration of STEM subjects with an explicit focus on mathematics. There are benefits to integrated steM education in a mathematics classroom including increased motivation, interest, and achievement for students. Integrated steM integration can also prepare students with the needed proficiencies and knowledge bases to be productive and impactful members of society. This article discusses three methods that high school mathematics teachers can utilize for integrated steM education. By focusing on open-ended problems through engineering design challenges, mathematical modeling, and mathematics integrated with technology high school students are more likely to see mathematics as meaningful and valuable. Examples of each method are discussed along with common instructional elements among the methods.*

Keywords: *High School Mathematics Teachers, STEM Integration*

Introduction

The technologically based data driven world in which we live in has made science, technology, engineering, and mathematics (STEM) education and STEM careers of great importance. In everyday life and careers people often solve problems that require knowledge from multiple subjects. Too often though in school, the STEM disciplines are taught within silos independent of each other and when integration has occurred mathematics has often had a diminished role (English, 2016; Fitzallen, 2015; Shaughnessy, 2013). In prior STEM integration research it seems that mathematics learning benefits less than the other disciplines (English, 2016). This necessitates the need for future research and discussion on how mathematics can receive focus in well-designed STEM integration curricula. Along these lines I have researched and proposed more work done with integrated steM education. I use the acronym steM to mean integrated STEM education that has an explicit focus on mathematics (Stohlmann, 2018). High school mathematics teachers can implement integrated steM education through open-ended problems in three main ways: engineering design challenges, mathematical modeling, and mathematics integrated with technology through game-based learning (Stohlmann, 2019a). In recent years it was found that 45% of STEM jobs were connected to computers, and engineering jobs made up an additional 19% of the STEM workforce (Fayer, Lacey, & Watson, 2017). In addition mathematical modeling often has connections to technology and engineering (Zawojewski, Hjalmarson, Bowman, & Lesh, 2008). If high school mathematics teachers implement integrated steM education it can not only develop mathematical understanding and interest in mathematics, but also expose students to possible careers in STEM fields with job availabilities.

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In the United States, there is currently a shortage of STEM majors and graduates (National Science Board, 2015). These shortages of STEM education qualified workers include the fields of engineering, computer science, web and app developers, cybersecurity, and manufacturing jobs (Maiorca, Stohlmann, & Driessen, 2019). In order to fill the pipeline of STEM professionals it is important that students are properly prepared to have the opportunity to pursue a STEM career if they desire. Research has shown that students who perform well in calculus, pre-calculus, trigonometry, physics, and chemistry in high school are more likely to be successful in college STEM gatekeeper courses (Redmond- Sanogo, Angle, & Davis, 2016). These gatekeeper courses can be STEM content courses that students are not able to be successful in and hinder them from completing a STEM degree. There is work to do at the high school level to ensure that students are prepared for college level STEM courses. Only 26% of students who indicated an interest in STEM majors or careers met or surpassed the ACT College Readiness Benchmark in STEM (ACT, 2017). An integrated steM education approach has the potential to keep more students engaged in mathematics at the high school level to be better prepared for college-level mathematics.

As society becomes increasingly more dependent on STEM knowledge it is vital for those who do not plan on pursuing a career in a STEM field to receive integrated STEM education instruction as well (Surr, Loney, Goldston, Rasmussen, & Anderson, 2016). An authentic integrated STEM learning experience is important for all students because it encourages students to use teamwork and problem solving; skills they need to be successful in life regardless of their chosen profession (National Academy of Science, 2014). Whether students end up in a STEM career or not, learning through an integrated steM education approach will benefit students. I will now provide more detail on integrated steM education and then discuss the three main methods for high school mathematics teachers.

Definition of Integrated steM

Integrated steM education is an effort to combine mathematics with at least one other STEM discipline into a unit or lesson that is based on connections between the subjects and socially relevant problems. It involves a focus on grade level mathematics through content integration while being supported and enhanced by science, technology, and/or engineering (Stohlmann, 2019a). This is important because in the past mathematics teachers have noticed that integrated STEM lessons do not always align with grade-level mathematics content standards (Lesseig et al., 2016). There are not specific combinations of STEM subjects that are inherently better than others. The subjects that are integrated should depend on the natural connections between the subjects that are aided by the real-world contexts. Further, integrated steM education is an approach that builds on natural connections between STEM subjects for the purpose of (a) developing student understanding of each discipline by building on students' prior knowledge; (b) broadening student understanding of each discipline through exposure to socially relevant STEM contexts; and (c) making STEM disciplines and careers more accessible and intriguing for students (Wang, Moore, Roehrig, & Park, 2011).

There are varying levels of integration of STEM concepts. Table 1 provides four different levels described by Vasquez, Sneider, & Comer (2013). The goal for integrated steM education for high school mathematics teachers is to be at the Transdisciplinary level by drawing either on their own knowledge bases, their students' knowledge from other STEM classes, or the knowledge of other STEM disciplinary teachers at a school. STEM content knowledge is certainly a concern for implementation but the idea that integrated steM education can be implemented into mathematics classes once or twice a chapter will make it more likely for gradual implementation that can be successful.

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Table 1
Levels of integration

Forms of integration	Features
1. Disciplinary	Concepts and skills are learned separately in each discipline.
2. Multidisciplinary	Concepts and skills are learned separately in each discipline but within a common theme.
3. Interdisciplinary	Closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills.
4. Transdisciplinary	Knowledge and skills learned from two or more disciplines are applied to real-world problems and/or projects.

Within the levels of integration there are different approaches that high school mathematics teachers can use for integrated steM education including team planning and individual implementation (Roehrig, Moore, Wang, and Park, 2012). Team planning is where a group of teachers might plan a lesson or unit together and then implement this in their own classroom. This team planning would be more likely to occur within STEM subjects; for example, a team of mathematics teachers meeting together to plan, but could also involve seeking feedback from teachers outside of a team's subject area. Another structure, individual planning and implementation, involves one teacher working by him or herself to implement integrated STEM which could involve seeking advice from teachers in other disciplines. This paper will focus on what high school mathematics teachers can accomplish using the team planning or individual implementation structure of steM integration. These are the structures that are most likely to be able to implemented by high school mathematics teachers due to time, planning, and topic sequencing restrictions.

There are three main ways that high school mathematics teachers can implement integrated steM in their classroom. This can be done by focusing on open-ended problems through engineering design challenges, mathematical modeling, and mathematics integrated with technology. The three modes of integrated steM make implementation more likely because each mode implements mathematics with a different STE subject so teachers can begin with integration they are more comfortable with. Each of the three modes will now be discussed.

Integrated steM Through Engineering Design

When students get to high school, it is becoming more likely that they have had experiences with engineering design. In the U.S., twenty states have adopted the Next Generation Science Standards (NGSS, 2013), which include engineering design at the elementary, middle, and high school levels. There are several additional states that also include engineering design in their science standards (Carr, Bennett, & Strobel, 2012). Even if students have not had engineering design experience by the time they enter high school, the types of activities that high school mathematics teachers can use, Model-Eliciting Activities (MEAs), have a strong research and practice tradition in mathematics education.

MEAs are student-centered, open-ended, team-based, realistic problems that enable students to solve complex problems (Lesh & Doerr, 2003). MEAs were designed explicitly to focus on mathematical knowledge and competencies that are needed for success beyond school. There are many more complex systems in the world and the people that can make sense of these systems will be more successful (Lesh and Doerr, 2003). The engineering design process is incorporated in the activities as students express, test, and revise their ideas (English, 2010). MEAs enable students to see that most engineering problems do not have a single, correct solution, and highlight how engineering is a creative endeavor. MEAs can be used as a formative assessment or as a way for students to apply the mathematics they have learned in previous lessons.

The general format of MEAs involves students reading an article or watching a video to provide background information on the problem that will be solved. Then students answer a few readiness questions and there is a whole-class discussion. Students then have time to work on the problem. The teacher can monitor students working and then select and sequence groups that will share. The format of MEAs and integrated steM education in general ties in nicely with the 5 practices for orchestrating productive discussion (Smith, Hughes, Engle, & Stein, 2009) for how teachers can implement these lessons.

1. *Anticipating* likely student responses to challenging mathematical tasks;
2. *monitoring* students' actual responses to the tasks (while students work on the tasks in pairs or small groups);
3. *selecting* particular students to present their mathematical work during the whole-class discussion;
4. *sequencing* the student responses that will be displayed in a specific order; and
5. *connecting* different students' responses and connecting the responses to key mathematical ideas (Smith & Stein, 2008, p.11).

The rocket MEA (Maiorca, 2016) is an example of an MEA that could be implemented as way for students to apply understanding of trigonometric ratios in right triangles. The background article talks about how commercial spaceflight has been receiving more attention. The problem statement asks students to design a rocket that will go the highest. The context is that the rocket could be used to provide supplies to the international space station.

Before students begin designing their 2-liter bottle rocket, they use a 2-liter bottle rocket launch simulator to begin to develop their ideas. In the simulator students conduct multiple tests of a rocket by changing cone style, nose weight, body weight, tail weight, the amount of water in the rocket, and pressure. The simulator provides the altitude, velocity, and time in flight of the rocket (Figure 1).

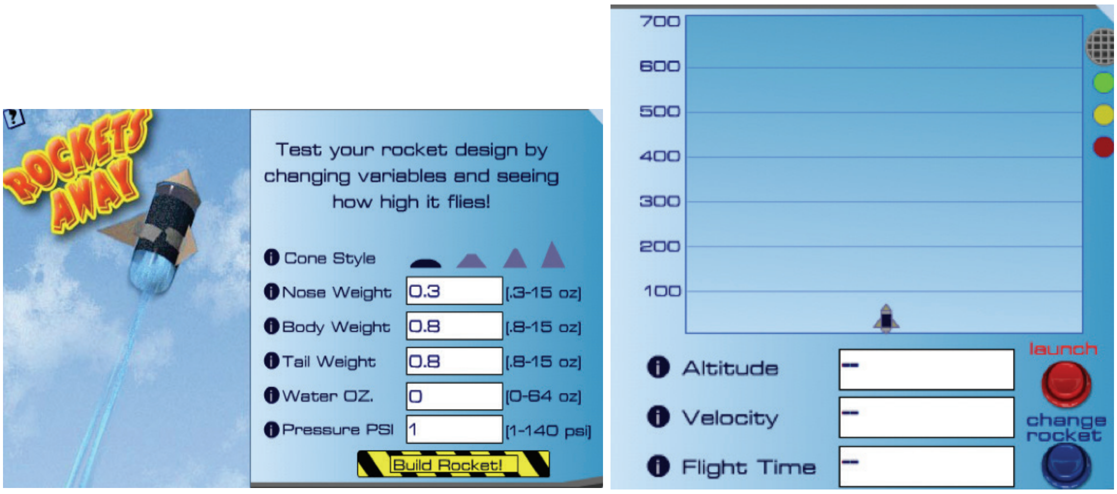

Figure 1. *Rocket simulator* (Ohio4H, 2017)

Around 640 feet is the highest the rocket can fly. This is accomplished with the following conditions: cone style (4th option), nose weight (8 oz), body weight (0.8 oz), tail weight (0.8 oz), water (30 oz), and pressure (140 psi). The cone that is closest to a triangle is the most aerodynamic of the choices. For the cone weight, too much can decrease height but too little would cause the rocket to spin over the top. Less is better for the body and tail weights. Since force equals mass times acceleration the goal is to push out the most mass (water and air) in the shortest amount of time. Too much water, and the air pressure is not strong enough to push it out fast enough. Too little water and the mass that is expelled is smaller which decreases the force. The simulator provides a good opportunity to have discussion with students with connections to force and Newton's laws of motion.

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Students are then given materials they can use including 2-liter soda bottles, tennis balls, foam floral cones, Styrofoam, cardstock, and duct tape to build their rocket. Before students test their rockets, it can be discussed how the height will be estimated. Students can be provided a diagram of the situation to see if they can see how the height could be estimated (Figure 2). Once students have recognized that tangent can be used to determine the height, it can be shown how the angle will be measured. A clinometer can be used by attaching a straw to a protractor and then tying a piece of string that can hang down with a weight attached.

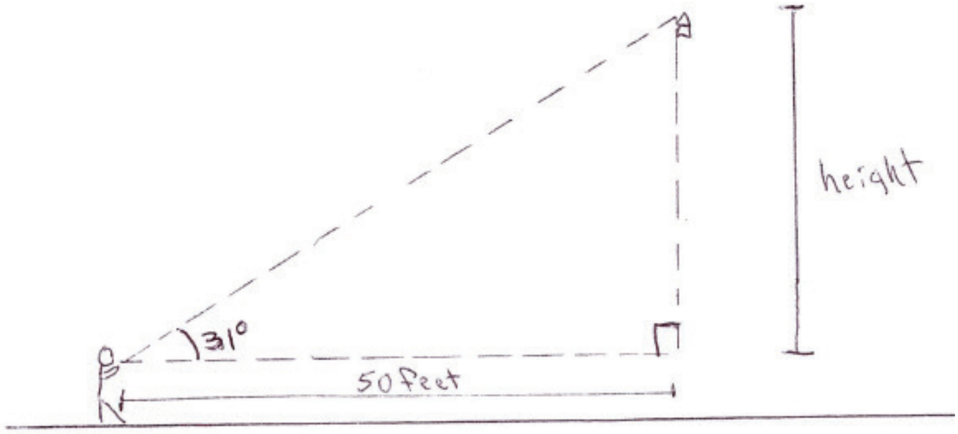

Figure 2. *Right triangle diagram*

A GeoGebra app can be used to have students see how the clinometer will work (Figure 3). In implementing this activity with students I have found that this is an important part as students may record the incorrect angle. The angle that students should use is the compliment of the acute angle. Through this MEA, students are able to apply their mathematical knowledge through an engaging design challenge.

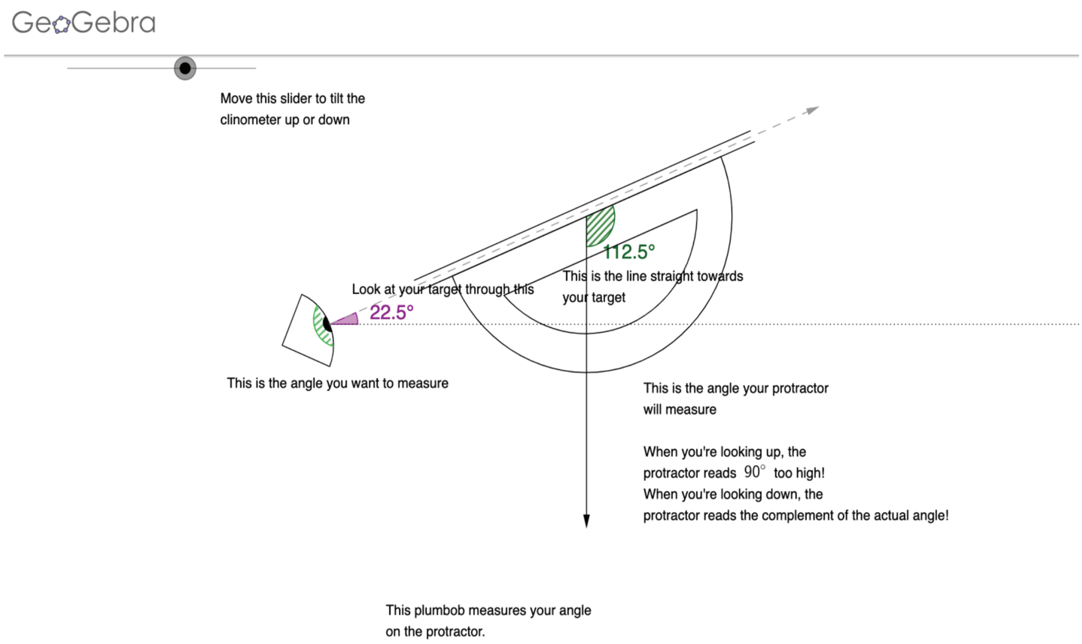

Figure 3. *Clinometer GeoGebra applet (Sdickson, 2019)*

Another example of engineering design with a mathematics focus done at the high school level is for students to design and test catapults. A study done with twenty students that used surveys found that students were highly engaged and became more interested in STEM careers after participating in integrated steM lessons (John, Bettye, Ezra, & Robert, 2016). Similarly, Bray and

Tangney (2016) reported students had increased engagement in mathematics after participating in several integrated steM lessons including catapult design.

Integrated steM Through Mathematical Modeling with Science Contexts

Mathematical modeling is garnering national and international focus due to the many benefits that it can provide to students including increased engagement, understanding through multiple representations, and discourse (Stohlmann & Albarracin, 2016). Mathematical modeling is one of the Standards for Mathematical Practice in the U.S. Common Core State Standards for Mathematics (National Governors Association, 2010). Additionally, sixteen content standards are highlighted as modeling standards at the high school level. My definition of mathematical modeling is that "mathematical modeling is an iterative process that involves open-ended, real world, practical problems that students make sense of with mathematics using assumptions, approximations, and multiple representations" (Stohlmann & Albarracin, 2016, p.2). This definition is aligned with the description of mathematical modeling in the Common Core State Standards for Mathematics (CCSSM). Mathematical modeling is becoming more common in high school mathematics and implementing mathematical modeling in science contexts enables high school mathematics teachers to implement integrated steM education. I will describe two example activities that I have implemented with teachers and students that integrates mathematical content standards that are highlighted as modeling standards in the CCSSM.

The first activity is connected to health science and an event held in Las Vegas sponsored by the American Lung Association, whose mission is to save lives by improving lung health. Each year at the Stratosphere Tower people climb up 108 floors of the tower consisting of 1,455 stairs to raise money for the American Lung Association. Shaun Stephens-Wale has the fastest time running up the stairs in 7 minutes and 3 seconds. At the start of this problem a video is shown about the event. The question is then posed if Stephens-Wale would beat someone in an elevator to the top of the tower. Students realized that someone in an elevator should arrive at the top first.

The question for the problem is then posed. How many floors would someone in an elevator have to be stopped at in order to tie Stephens-Wale running up the stairs? (Stohlmann, 2019b). This problem is connected to creating equations that describe numbers or relationships. In figuring out this problem students make different assumptions and approximations including if the elevator is being used by guests of the casino or staff, the speed of the elevator, and the time it takes for people to get on or off the elevator at each stop. Students have also used the Internet to help develop their solution. An example solution involves making an assumption that the elevator takes 1.5 seconds to go up each floor and approximately 17 seconds of wait time for each floor it stops at. This takes into account people getting on and off the elevator. The equation would be the following then: $423 = 108 (1.5) + 17x$ which when solved gives about 15 floors with stops. In this activity the importance of choices and assumptions are highlighted for mathematical modeling.

A second example mathematical modeling activity is connected to physics and is based on a video of a basketball being dropped off the top of the Cotter Ranch Tower building in Oklahoma City (Dude Perfect, 2016). Students are asked to figure out how long it will take the basketball to reach the basketball hoop, which is at the bottom of the building. Students apply their knowledge of quadratics and use an equation and/or graph to determine a solution. $y = -16t^2 + h$

After students come up with their solution, the video is then watched to see the real answer. It is then found that the actual time is longer than was predicted. Students are asked to explain why this was the case. There are several short YouTube videos that can be integrated into the discussion after students have shared their ideas, which focus on information related to dropped objects (Stohlmann, 2019b). In brief, the basketball takes longer than predicted to reach the basketball hoop because of air resistance. Students may think that if you drop two similar shaped objects from the same height that they will hit the ground at the same time, but this is not always the case. Mathematical modeling in science contexts can engage students in interesting problems. These problems provide the opportunity for rich discourse and for students to draw on knowledge from multiple disciplines.

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Research studies have shown the benefits of this approach with high school students with different science contexts. MEAs and follow-up activities related to light intensity and decay rate of a fully charged capacitor helped students develop their reasoning about average rate of change (Arleback, Doerr, & O'Neil, 2013). In another study, students were motivated by the context of looking at global oil consumption and predicting when oil reserves may run out (Busse & Kaiser, 2003). High school students in Australia demonstrated higher order thinking with the ability to apply mathematical knowledge in the context of analyzing animal populations (Brown & Edwards, 2011). The mathematical content of functions, data analysis, and creating equations have quality connections with mathematical modeling at the high school level. Mathematics teachers can integrate mathematical modeling with science contexts to help students see the many areas that mathematics can be applied.

Integrated steM Through Mathematics Integrated with Technology

In this section I refer to integrated steM education integrated with technology in regards to open-ended game based learning. Game-based learning has drawn international interest and has been suggested as an effective educational method that can improve students' motivation and performance in mathematics (Byun & Joung, 2018; Foster & Shah, 2015; Wang, Chang, Hwang, & Chen, 2018). Students often play technology-based games whether it is video games or apps on their phones. However, when used in the mathematics classroom, game-based learning is often not implemented in the most effective way. For example, most of the games used in prior research in mathematics classrooms involved drill and practice (Byun & Joung, 2018).

My definition of integrated steM education through game-based learning has several important features that help ensure quality implementation. First, the technology integration should allow for the creation of new tasks that would not be possible without the technology or for significant task redesign (Puentedura, 2006). Second, the tasks used should be worthwhile tasks. These tasks have no prescribed rules or methods and there is no perception that there is a specific "correct" solution method (Hiebert et al., 1997). Third, the tasks should be aligned with grade-level standards. Fourth, the tasks should enable students to work with multiple representations. Fifth, the technology should provide students feedback. Finally, the tasks should be open-ended and allow for discussion and multiple solutions (Stohlmann, 2019c). When structured well, technology-based mathematics games can engage students in mathematics and help develop their conceptual understanding.

One example of game-based learning that high school mathematics teachers can implement is through the use of programming and robotics. There is a movement for states to require computer science courses for students in high school (Computer Science Teachers Association, 2018). As students' knowledge of computer science increases the potential for mathematics teachers to integrate programming and game-based learning also increases. Current technologies for programming are becoming more user-friendly as well, which can make it more likely for mathematics teachers to feel comfortable integrating programming. Exposing students to this work is essential as applications software developers is the largest STEM occupation (Fayer et al., 2017). There is a need for more qualified workers in this area.

Kim and Tjoe (2019) describe how mathematics can be integrated with game-based learning, programming, and robotics. They used the Sphero SPRK+ robotic ball that can be programmed through the Sphero Edu app. The app is user-friendly and compatible with various operating systems and devices. Programming can be done through simply drawing and driving, block-based coding, and JavaScript text programming. The heading, the speed, and the duration can be programmed with the app.

Students programmed the robotic ball with different speeds to travel in a straight line for three seconds and measured the distance traveled. They recorded this information in a table and then worked to come up with a method to predict the distance traveled given a speed. Various ideas were used by groups including proportional reasoning and a line of best fit or linear regression. Students were able to make connections between tables, graphs, equations, and the situation in which the data was collected. The students considered friction between the ball and the floor for

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why the ball might not have traveled as far as they initially thought.

Along with this task, various games can be incorporated with the robotic balls in which students can use their knowledge from the previous task. A track can be setup and students can program the balls to race each other around the track. Mini golf holes can be drawn on paper or setup with blocks and students can program the balls to end up in the hole. Bowling pins can also be setup as another game to be incorporated with the programming.

Another example of technology game-based learning that is open-ended is through the use of Desmos activities. Desmos is an online graphing calculator, but also has a suite of free classroom activities available with some of the activities being game-based. Little research has been conducted on these activities, but they have the potential to enable teachers to develop students' conceptual understanding through multiple representations.

In my research, I did two studies with middle school students using Desmos in teaching experiments (English, 2003). Theses Desmos game-based activities would be appropriate for high school students as well. In the studies I collected the student work in Desmos, audio recordings, and researcher field notes. In the first study I investigated the use of the Desmos online graphing calculator for students to play the game Battleship. Students used linear equation with restricted domains or ranges for the ships and they used equations of circles to take turns seeing if they could hit their opponents' ships. Students cannot see where their opponent had placed the ships and needed to decide where to place the circles to try to hit the ships. Students were actively engaged in the game, and the activity assisted students in making connections between representations of linear equations and circles (Stohlmann, 2017a).

Another example of game-based learning in Desmos is the activity Polygraph lines. I analyzed the data in this study with an interpretative approach by looking at the ways in which students used mathematical vocabulary in the game. In this game, sixteen linear graphs are given. One student selects one of the graphs and the other student asked yes or no questions to determine which graph had been selected. After playing the game several times, the students discussed what are quality questions to ask and strategies for asking the least amount of questions. Through playing the game and subsequent discussions, students were able to make use of mathematical vocabulary including slope, positive slope, negative slope, horizontal line, vertical lines, origin, and quadrants (Stohlmann, 2019a).

Discussion

In this article I have described three main ways that high school mathematics teachers can implement integrated steM education through open-ended problems: engineering design challenges, mathematical modeling with science contexts, and mathematics integrated with technology through game-based learning. The goal of implementing these methods is to prepare students for the demands of the 21st century with 21st century competencies, while also addressing future workforce needs. Students can be engaged to learn mathematics and increase their understanding through integrated steM education. In general, STEM education disciplines need to have more of a focus on integration (English, 2016). Also, mathematics integration has not received adequate focus in STEM education and future research is needed on how to best support mathematics teachers for this approach (Stohlmann, 2019a; English, 2016; Shaughnessy, 2013). When teachers have received professional development for integrating STEM subjects they grow more confident in their implementation and are more willing to continue integrating STEM subjects (Mayes et al., 2017).

Table 2 provides a summary of important instructional elements for integrated steM education. A focus on student-centered pedagogies, multiple representations, integration of STEM subjects, and open-ended problems can engage students and possibly lead to interest in a STEM career. With these elements, students are more willing to share and discuss their mathematical thinking and learn from each other (Stohlmann, 2017b). The Next Generation Science Standards (NGSS, 2013) at the high school level provide quality connections for integrated steM education. Matter and its interactions, motion, forces, ecosystems and animal populations, and natural resources provide

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good opportunities for high school mathematics teachers to make learning more connected and to integrate science knowledge into mathematics. When mathematics is learned through relevant contexts students can be engaged to continue to put forth effort in learning mathematics. This can lead to possible STEM careers and doing well in college level mathematics classes. High school mathematics teachers can also implement integrated steM education to further show the benefit of mathematical understanding through multiple representations.

Table 2
Instructional elements for integrated steM and future research

Instructional elements for integrated steM curricula

- Open-ended (multiple solutions and tasks are worthwhile tasks (Hiebert et al., 1997).
- Integrated assessment (Assessment is not merely summative but is woven seamlessly into the tasks with students receiving feedback from the technology, other students, the Internet, and the teacher).
- Transdisciplinary perspective (Students make use of knowledge bases from multiple disciplines).
- Collaboration (Students work in teams with the goal of clear communication).
- Real world or social relevance based on students' interest or popular culture.
- Grade level mathematics integrated.
- Multiple representations incorporated.
- 5 practices of orchestrating productive mathematical discussion are implemented (Smith & Stein, 2011).

Future research

- Further development of integrated steM curricula.
- Further research on the impact of integrated steM approaches on high school students' mathematical achievement, development of mathematical understanding, mindsets, motivation, and interest in STEM careers.
- Further research on what support teachers need to implement more student-centered learning through integrated steM.

A great benefit of an integrated steM education approach is that teachers will be implementing best practices for teaching mathematics. This can challenge teachers to build on students' ideas and prior knowledge to have a more student-centered approach (Stohlmann, Moore, & Roehrig, 2012). Effective mathematics teaching practices detailed by the National Council of Teachers of Mathematics (NCTM, 2014) are aligned with an integrated steM education approach. NCTM describes the vision of these practices in that,

> "students are active learners, constructing their knowledge of mathematics through exploration, discussion, and reflection. The tasks in which students engage are both challenging and interesting, and students cannot quickly complete them by applying a known rule or procedure. Students must reason about and make sense of a situation and persevere when a pathway is not immediately evident. Students use a range of tools to support their thinking and collaborate with their peers to test and refine their ideas" (NCTM, 2017, p. 2).

In implementing integrated steM education, teachers are more likely to implement effective teaching practices in their other lessons as well by seeing the benefits of these practices.

Current standards support the implementation of integrated steM education at the high school level. In the U.S., the Next Generation Science Standards (2013) and the Common Core State Standards for Mathematical Practice (National Governors Association, 2010) provide science, engineering, and mathematical practices. These practices include mathematical modeling, integrating mathematics and computational thinking into science, planning and carrying out investigations of real world problems, analyzing and interpreting data, and designing solutions. A primary goal of integrated STEM education is to provide students with the opportunity to engage in real-world problem solving through hands-on experimentation, research, modeling, and design challenges (Mayes, Rittschof, Gallant, & Martin, 2017).

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Integrated steM education has many benefits for students. It can develop students' mathematical understanding through different representations, students' interest in STEM fields and positive perceptions of STEM, and develop students' 21st century competencies that will help students in their current lives and any future career (Stohlmann, 2018). It can also help increase students' mathematical achievement which is important given that the number of students in remedial non-credit bearing mathematics courses has been increasing (Lee, 2012). Remedial mathematics classes can cause financial strain for students and delay or even prevent them from completing their degrees.

Integrated steM education is receiving more focus at the elementary and middle school level as well which will help students be more used to learning mathematics through this approach when they enter high school. In my prior work I detailed a vision for how middle school teachers can implement integrated steM education (Stohlmann, 2019a) and also have analyzed how elementary teachers implemented this approach after receiving professional development (Stohlmann, Maiorca, & DeVaul, 2017). This prior work has demonstrated that teachers want further resources and classroom-tested curriculum for integrated steM education. Teachers have seen the benefits of this approach and want further support to implement it well.

Further work on integrated steM education can expand the curricular resources available for teachers. In studies done on integrated steM education at the high school level the mathematics has focused mainly on measurement, data analysis, functions, and creating equations (Stohlmann, 2018). Future research can look at further development of integrated steM curricula to expand the mathematical content that can be integrated. This curricula can then be researched to determine the impact of its implementation on various outcomes of high school students. High school mathematics teachers may need support for implementing open-ended problems so there is a need for professional development for teachers to be comfortable and effective with this approach.

Depending on a teacher's content knowledge of other subjects or the possibility to collaborate with teachers in other subjects, other subjects beyond the STEM subjects can be integrated as well. I integrated art with a study done with students and the Robot Art MEA. In this MEA students work in groups to determine the best method to communicate to one of the students how to draw a picture. The student who is the drawer pretends to be a robot and can only draw based on the directions that are given. Students learned the importance of clear programming directions for robotics and also more about the creativity of artists (Stohlmann, 2017c).

There are many benefits to integrated steM education for students. In this article I have shown ways in which these benefits can be realized with an integrated steM education approach with high school mathematics teachers. Integrated steM education is a dynamic and important topic to ensure that students are prepared to be successful in their current and future lives. With an increased emphasis on MEAs, mathematical modeling, and mathematics integrated with technology through game-based learning I believe it will be more likely for high school mathematics teachers to implement integrated steM education effectively.

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