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The earlySTEM Program: An Evaluation Through Teacher Perceptions

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Abstract Conceptually grounded curricular materials in the context of professional development programs facilitate teachers' adoption of new pedagogies. Even though science, technology, engineering, and mathematics (STEM) professional development opportunities for early grade level teachers continue to receive attention, one existing challenge is to support teachers further in implementing well-defined integrated STEM curricula. The earlySTEM program supports K–4 teachers with the systematically developed earlySTEM curriculum, its associated curricular materials, and year-long mentoring. The program was implemented in 26 schools. This mid-evaluation investigated teacher perceptions of the earlySTEM program with a focus on contributions and challenges. A total of 134 teachers from the 26 schools responded to a survey with open-ended questions. Survey data were analyzed using a descriptive approach. The findings indicated that the teachers had positive experiences with the earlySTEM program. The results revealed that the earlySTEM program is perceived to have contributed to (a) teachers' STEM teaching skills and STEM conceptualizations and (b) students' skills development and awareness on the connection of the curriculum content to real-world problems. The results also document the perceived challenge in implementing the earlySTEM curriculum: need for more classroom time. The conclusions offer insights for similar program designs.

Résumé Les instruments pédagogiques solidement fondés sur le plan conceptuel dans le contexte des programmes de perfectionnement professionnel facilitent l'adoption de nouvelles pédagogies par les enseignants. Même si les possibilités de développement professionnel en matière de sciences,

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de technologie, d'ingénierie et de mathématiques (STIM) pour les enseignants de la maternelle à la 4e année continuent de faire l'objet d'une attention particulière, l'un des défis actuels consiste à mieux soutenir les enseignants dans la mise en œuvre de programmes STIM intégrés et bien définis. Le programme appelé «earlySTEM» aide les enseignants de la maternelle à la 4e année en leur proposant un programme d'études «earlySTEM» qui a été élaboré de manière systématique ainsi que les outils d'apprentissage associés et un encadrement d'un an. Le programme a été mis en œuvre dans 26 écoles. Cette évaluation de mi-parcours a examiné les perceptions des enseignants en ce qui a trait au programme «earlySTEM» en mettant l'accent sur les aspects des contributions et des défis. Au total, 134 enseignants des 26 écoles ont répondu à un sondage comportant des questions à réponses libres. On a analysé les données issues du questionnaire selon une approche descriptive. Les résultats indiquent que les enseignants ont vécu des expériences positives avec le programme «earlySTEM». L'analyse révèle que le programme «earlySTEM» est perçu comme ayant contribué: a) aux compétences d'enseignement et aux conceptualisations STIM des enseignants et b) au développement des compétences des élèves et à leur prise de conscience du lien qui existe entre le contenu du programme et les problèmes concrets qui affectent notre du monde. Les résultats étayent également le fait qu'on perçoit dans la mise en œuvre du programme «earlySTEM» la nécessité d'y allouer plus de temps en classe. Les conclusions ouvrent des perspectives pour la conception de programmes similaires.

Keywords Elementary grades · Kindergarten · STEM education · Teacher professional development

In twenty-first century classrooms, learners are expected to be engaged in science and engineering practices as they develop their solutions to common global challenges (Schleicher et al., 2019). Science, technology, engineering, and mathematics (STEM) education has merit in accomplishing this goal by helping students think creatively and systematically (Altan & Tan, 2021; Bybee, 2018; Honey et al., 2014). The integration of STEM disciplines to solve real-world problems offers cognitive, procedural, and attitudinal benefits to students (Martín-Páez et al., 2019). Exposure to science and engineering practices at early grade levels is critical for students' skills development, providing evidence-based explanations, problem solving, critical thinking, collaboration, and learning STEM content (Cunningham et al., 2020). An increasing number of studies indicate that young children show readiness to be engaged in STEM practices with proper instruction and scaffolding (Li et al., 2021; McClure et al., 2017). Despite the consensus on the importance of STEM education for young learners, teacher perceptions reveal a need for more opportunities to practice integrated STEM teaching (Burrows et al., 2021; Estapa & Tank, 2017; Nesmith & Cooper, 2019). Intensive long-term programs to support teachers and students with curriculum and classroom practices at early grade levels align well with this need (Autenrieth et al., 2017; McClure et al., 2017). Nevertheless, increased active participation and autonomy of teachers, more focus on integration of the four STEM disciplines in the program tasks, and teaching STEM in structured school systems that typically segregate STEM subjects are issues that require attention (Huang et al., 2022; Nadelson & Seifert, 2017). In this study, earlySTEM, a year-long professional development (PD) program for K–4 teachers that address these issues, is described and evaluated through teacher perceptions.

Purpose of the Study

Research indicates the challenge teachers face in creating an integrated STEM curriculum as well as infusing STEM lessons into existing curricula (Christian et al., 2021; Margot & Kettler, 2019). The struggles of teachers are linked to typical school and curriculum structures and limited teacher knowledge of STEM education and STEM disciplines (Margot & Kettler, 2019). Teachers agree on a need for exemplary STEM curriculum, resources, and follow-up of their classroom implementations (Baker & Galanti, 2017; Margot & Kettler, 2019). Especially pre-school and elementary grade level teachers raise the difficulty to access STEM curricular materials (e.g., Estapa & Tank, 2017). Because teacher unpreparedness in the planning and enactment of STEM lessons remains a challenge, opportunities to experience STEM curricula have great value for the sustainability of STEM (Baker & Galanti, 2017; Estapa &Tank, 2017). Empirically grounded curricula can guide teachers in where to begin STEM teaching (Lamb et al., 2015; Ntuli & Ray, 2022; Wang, 2020).

A powerful indicator of program effectiveness, teacher perceptions, is commonly used for program evaluation purposes (Burton, 2022; Guskey, 2000). Teacher perceptions on a newly developed context such as a STEM training program or a STEM curriculum inform implications for fine-tuning and thus lead to a strengthening of the context (e.g., Ntuli & Ray, 2022). The revised contexts become more suitable for subsequent studies to gain an understanding of their impacts (Fraenkel et al., 2012). Grounded on these observations, the research questions of the study were as follows: (1) What are teachers' perceptions of the contributions of the earlySTEM program to their professional development? (2) What are teachers' perceptions of the contributions of the earlySTEM classroom implementations to their students' skills and knowledge development? (3) Do teachers perceive any challenges as they implement the earlySTEM curriculum?

Conceptual Framework

This section describes STEM education for young learners, supporting teachers, and the earlySTEM program.

STEM Education and Young Learners

Problems that individuals face in the twenty-first century have a complex structure, allowing for multiple solutions that can be created using concepts and practices of STEM disciplines (Corlu, 2017; Bybee, 2018). Exposure to these problem contexts at early ages has several benefits, e.g., academic achievement at later grade levels, improvement in learning science and mathematics (Kermani & Aldemir, 2015), and in interest, creativity, collaboration, critical thinking, innovation, and problem identification skills (Bybee, 2018; Counsell et al., 2015; Franz-Odendaal et al., 2016; Lamb et al., 2015; McClure et al., 2017). Even very young children can work on problems using science and engineering practices in the context of STEM-based learning experiences (Tippett & Milford, 2017). These conclusions collectively suggest encouraging early grade level teachers more often to facilitate their students' STEM engagement (McClure et al., 2017; Nesmith & Cooper, 2019).

Supporting Teachers with STEM Curriculum

For successful STEM integration in early grades, one essential component is teacher support in the form of exemplary STEM curricula (Brown & Bogiages, 2019; Graves et al., 2016; McClure, 2017). Long-term STEM education programs are usually structured to include (a) a face-to-face component to engage teachers in STEM activities and discussions and (b) a follow-up component where teachers prepare and/or enact STEM curriculum with ongoing on-site support (e.g., Brenneman et al., 2019; Çiftçi & Topçu, 2022; Kermani & Aldemir, 2015; Nesmith & Cooper, 2019). Program facilitators provide teachers with resources (e.g., activity books, Arduino kit) to enact exemplary curriculum (Brenneman et al., 2019; Graves et al., 2016). Thus, teachers experience well-defined and accessible STEM curricula (Counsell et al., 2015). Despite the success of these programs in supporting and empowering teachers, research evidence indicates limitations. The participating teachers need more support in producing lesson plans that integrate all STEM disciplines while showing the disciplinary connections to the learning standards (Boice et al., 2021). Considering form and contextual conditions, PD programs are recommended to benefit more from university-school partnerships, supportive teaching materials, higher teacher autonomy in implementing program tasks, interaction with experts and community, and space in the school curriculum for integrated STEM teaching (Chai, 2019; Huang et al., 2022). Previous work also shows insufficient research into elementary teachers' development in the context of STEM PD programs (Chai, 2019). The earlySTEM program addressed these constraints by targeting early grade levels, presenting a teacher's manual, activity books, story books, and a weekly STEM hour stemming from the university-school partnership among its other features.

STEM Professional Learning of Teachers

Elementary teachers have previously reported that intensive PD programs contribute to their conceptualizations of STEM and STEM integration, their STEM teaching skills, positive teacher and student attitudes towards STEM education, and student learning outcomes (e.g., Baker & Galanti, 2017; Erickson et al., 2020; Estapa & Tank, 2017; Graves et al., 2016; Havice et al., 2018; Lamberg & Trzynadlowski, 2015; Ring et al., 2017; Stieben et al., 2021). According to third grade teachers, their use of STEM curricular resources in the context of PD programs helps in developing a shared STEM mindset in their schools and a network among teachers (Ntuli & Ray, 2022). Teachers express the realization of their once-limited STEM definitions prior to participation in PD programs (Ntuli & Ray, 2022; Ring et al., 2017). Teacher perceptions of STEM program effectiveness also address an increase in student knowledge of STEM concepts, interest and motivation in learning, an awareness of real-world issues, hands-on skills, and science skills (Erickson et al., 2020; Stieben et al., 2021).

The earlySTEM Program

Development of the earlySTEM Program As indicated by a review of the literature on K–12 STEM education, curriculum design, and teacher support are increasingly being researched (Li et al., 2020). The earlySTEM is a year-long curriculum-based program designed to support K–4 teachers. The program is composed of (1) face-to-face workshops where teachers experience the earlySTEM curriculum and (2) a follow-up where teachers implement the earlySTEM curriculum using the curricular materials and program facilitators' feedback through school visits and webinars. This research describes the perceptions of the teachers that implemented the earlySTEM curriculum embedded within the earlySTEM program.

The earlySTEM curriculum is based on the STEM integrated teaching framework (Corlu, 2017). Accordingly, integrated STEM teaching, shaped by the experiences and interests of the students and the teachers, is defined as teaching the unique concepts and methods of the central discipline integrated with at least two other STEM disciplines. As shown in Fig. 1, the framework is constructed on four broad principles: equity, relevance, interdisciplinarity, and rigor (Corlu, 2017; Bybee, 2018; Jackson et al., 2021). The first two principles center on providing an equal opportunity for each student in a classroom. This can be possible with equity, giving equal chances of participation, and with relevance, creating learning experiences that apply to real-world issues and students' interests and experiences. To continue with the horizontal axis, interdisciplinarity highlights meaningfully bringing together STEM disciplines. Rigor on the other hand stresses the unique contribution of each STEM discipline. These principles together provide a frame of reference for the earlySTEM curriculum.

The earlySTEM Curriculum The earlySTEM curriculum includes four themes that teachers implement throughout the school year: My Green World, My World of Machines, My Computational World, and My World of Imagination respectively (see Fig. 1). Each theme requires 8 weeks to complete.

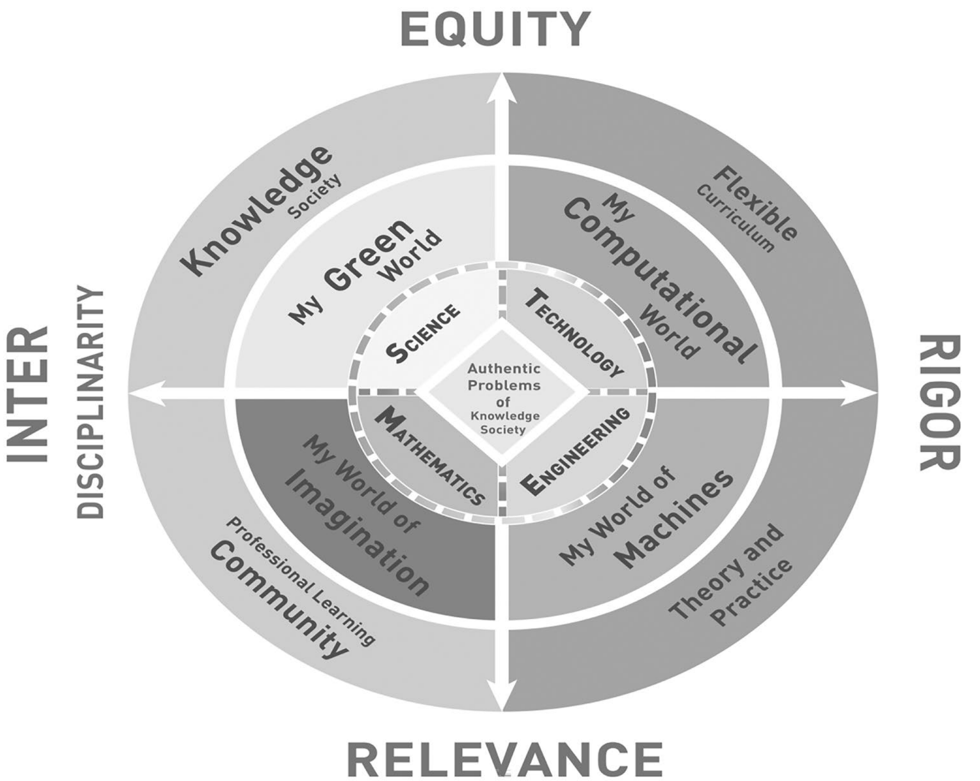

Fig. 1 Conceptual framework of the earlySTEM program (Corlu, 2017)

An authentic problem of the knowledge society (APKS) can be seen at the center of Fig. 1, a complex problem that represents real-world tasks with well-defined constraints. Each theme is built upon a different APKS. The learning objectives for each theme cover a central STEM discipline and at least two other STEM disciplines. The national learning standards and the Core Ideas of the Next Generation Science Standards, e.g., motion and stability, energy, and sustainability (NGSS Lead States, 2013), guided the formulation of the learning objectives.

A teacher's manual, activity books, and story books assist teachers in their classroom implementations and stimulate higher-order thinking addressing key STEM skills such as teamwork and scientific thinking (Beier et al., 2019). Separate for each theme, the manual presents the learning objectives; materials students can use with safety instructions for certain materials (e.g., water heater); professions and roles for student team members; useful online links; separate rubrics for presentation, collaboration, cognitive processes, science process skills, and self-evaluation; and an instructional plan for the eight classroom hours that includes examples of probing questions and tips for scaffolding. An example for the second week of the first theme, My Green World, from the teacher's manual states the following: "print and hang pictures of fruits and vegetables that students will use as materials in this theme." Part of the instructional suggestions is aligned with the activity and story books. An example would be the following statement from the teacher's manual: "students can complete the activity, what do I know, on page 3 of the Activity Book."

The core discipline of the first theme, My Green World, is science. Its APKS is associated with coloring clothes with natural dye (e.g., vegetables, herbs) to help a character named Tursu: "Tursu's clothes are devoid of colour. Tursu has allergies to artificially painted fabric. Please help Tursu in coloring her clothes while protecting the environment." Example problem constraints are as follows: produce at least three colors and in making patterns, choose materials that you use often in your daily life. The fourth grade science learning objectives with a focus on sustainability were the following: (a) realizes pollution in local environment, (b) gains awareness for environmental protection, and (c) creates methods for a sustainable environment. The theme also embraces, for example, learning objectives for technology; creates tables, mind maps, and flow charts, for engineering; gains awareness on constraints; identifies oneself as member of a team and for social skills; communicates findings in a fair; and realizes responsibility while working in a team. As explained, the first theme put science at the center and focused on sustainability and protecting the environment. The second theme was grounded on the learning objectives of its central discipline, engineering (e.g., gains awareness on constraints, lists steps of the design process), together with learning objectives of science, mathematics, and social skills. To continue, the third theme, with its central discipline technology, also addressed engineering, mathematics, and social skills. Finally, the fourth theme, grounded on the learning objectives of its central discipline, mathematics, addressed the learning objectives of all STEM disciplines.

The four themes are identical for each grade level; however, the APKS, constraints, associated learning objectives, and instructional strategies in the teacher's manual differ. This differentiation is facilitated by the four sub-principles shown in Fig. 1 (Corlu, 2017; Estapa & Tank, 2017; Margot & Kettler, 2019). The earlySTEM curriculum is flexible; the teachers are encouraged to make minor revisions considering accessible resources (e.g., everyday materials, a 3D printer, a lake close to the school). Next, the teachers are invited to tap on theory and practice, theoretical knowledge, and their prior teaching practices. The teachers become part of a professional learning community in their schools through regular meetings with the earlySTEM program developers. Finally, the earlySTEM curriculum aims to contribute to a knowledge society where education improves with reflection.

Method

Although providing teachers with PD programs has significant importance, evaluation can reveal insights into effectiveness and provide feedback to program designers and schools in making evidence-based decisions. Teacher perceptions are one of the helpful sources for evaluating the perceived impacts of a program (Guskey, 2000). This study investigated teacher perceptions of the earlySTEM program with a focus on potential contributions and challenges. A descriptive approach to program evaluation was adopted in identifying how the teachers perceived the program (Creswell, 2013; Spatz et al., 2021). Data collection in this study took place following the classroom implementations of the first two earlySTEM curriculum themes (see Fig. 1), My Green World and My World of Machines, approximately 6 months into the earlySTEM program.

Because results function as formative assessment for program designers, mid-evaluations of long-term programs and curriculum implementations are helpful for reflection and enhancement (e.g., Kigobe et al., 2021). It is also useful to conduct a mid-evaluation because the teachers implement different themes in the first and the second half of the program. Comparing and combining findings from a mid- and a final evaluation can result in a comprehensive view of teacher perceptions.

Data Source

A survey was developed to evaluate the earlySTEM program. The authors collaboratively worked on constructing and later revising the survey questions. Upon examination of similar open-ended questions to explore teacher beliefs who participated in STEM-focused trainings (Graves et al., 2016; Lamberg & Trzynadlowski, 2015; Ntuli & Ray, 2022), the researchers came up with a list of questions. The questions were formulated as semi-structured and open-ended to facilitate flexibility and thorough reflections. An

Table 1 Participant teacher demographics

Grade level	Pre-school (*23.13%*) 1st grade (*23.13%*) 2nd grade (*24.63%*) 3rd grade (*15.67%*) 4th grade (*13.43%*)	Education	Bachelor's degree (*93.85%*) Master's degree (*6.15%*)
Gender	Female (*83.08%*) Male (*16.92%*)	earlySTEM program experience	1 year (*69.40%*) 2 years (*30.60%*)
Age	22–30 (*46.92%*) 31–40 (*16.92%*) 41–50 (*7.69%*) 51 and above (*22.30%*)		

assistant professor of science and mathematics education and a STEM coordinator of a middle school provided expert reviews. A descriptive summary of expert recommendations was used to inform the clarity and consistency of the questions (Fraenkel et al., 2012). The survey included demographic questions followed by 15 questions on the earlySTEM program. It took half an hour on average for the teachers to complete the survey. The demographic questions and eight of the survey questions that focused on the perceived contributions and challenges constituted the data source (see Appendix). The demographics questions asked for teacher gender, grade level to teach earlySTEM, age, education level, and earlySTEM program experience. The following eight questions explored evaluation of the earlySTEM program in general, the earlySTEM curriculum, and its curricular materials. Although the questions did not require reflecting on factors that played a role in the perceived contributions, some teachers expressed their opinions. The remaining seven questions (e.g., what did you think when you were introduced to the teacher's manual at the beginning of the year?) fell outside the scope of this study. Mentoring was also not investigated with the questions. Teacher responses were collected through the online platform Qualtrics. Ethical approval was obtained from the university ethics committee. The teachers individually signed informed consent forms.

Participants and Context

The earlySTEM program was implemented in 26 schools in its second year with the participation of 161 teachers. Of all program teachers, 134 participated in this research by completing the survey questions on a voluntary basis. Table 1 illustrates the teachers' personal information obtained with the demographic questions on the survey.

Each school had 1 h in their weekly schedules to implement the earlySTEM curriculum, 8 weeks for each theme, where teachers use the teacher's manual, activity books, and story books. Figure 2 outlines the phases students experience separately for each theme. The process starts with the introduction of the APKS. During the first 3 to 4 weeks (the teacher can decide), students engage in fact finding and ideation in relation to the given APKS and constraints. For the first theme My Green World, for example, students do research into allergies and artificial paint during fact finding. Students are encouraged to use the library and digital sources as well as talk to people with information. During ideation, student teams are expected to create multiple solutions reflecting the use of different color sources and different methods to extract the colors. As the students move to product development, they test their potential solutions and arrive at final decisions and products. The product is defined as an experiment design for the first theme, an algorithm for the second theme, a working prototype for the third theme, and an abstract model that shows relations among variables for the fourth theme (Corlu, 2017). The remaining weeks

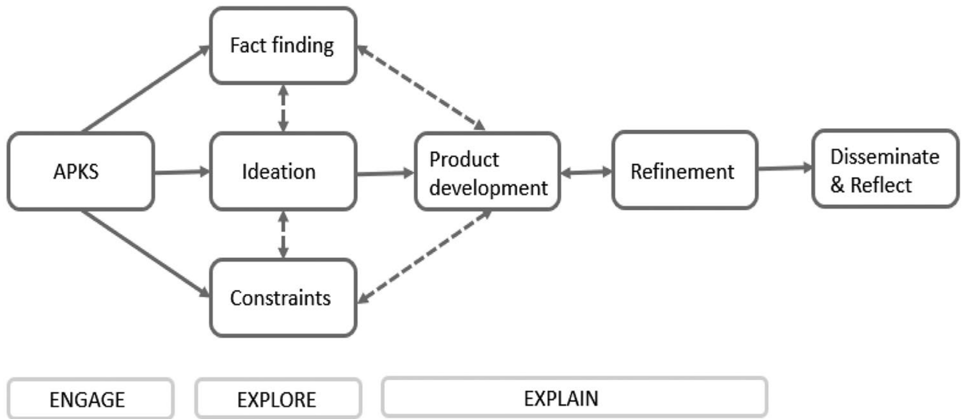

Fig. 2 STEM cycline (Corlu, 2017)

are for refinement: revising the product based on test results and new research, and for dissemination and reflection: finalizing the portfolios, preparing for the fair, and taking part at the fair (Corlu, 2017).

Data Analysis

This study adopted the five-phased cycle by Yin (2016) to analyze the qualitative survey data using a descriptive lens: (1) compiling, (2) disassembling, (3) reassembling, (4) interpreting, and (5) concluding. Compiling included bringing together teacher responses in three separate response collections: (a) responses to the questions that focused on teachers' professional development, (b) responses to the questions that focused on student outcomes, and (c) responses to the question on challenges and suggestions (see Appendix). Teacher responses to the question asking for the general impacts of the earlySTEM program were selectively distributed to the first two response collections. Following this arrangement, the researchers read the data to break down teacher responses into smaller pieces during disassembling. The researchers individually and iteratively created lists of emerging codes for the separate response collections. During reassembling, first, the researchers shared their lists of emerging codes with each other. Following discussions to try different groupings and sequences to organize the interpretation of the data, codebooks were created, as illustrated in Tables 2, 3, and 4. Using the codebooks, the categories, and their underlying codes for perceived contributions of the earlySTEM program could be graphically represented.

During the fourth phase, interpreting, accompanied by the codebooks, the researchers calculated the percentages representing the appearances of the codes. This resulted in a narrative to understand the findings. Codes were assigned to a complete response or the fragment of a response a teacher provided to a question. There were cases where different codes were assigned to a complete response to one survey question. On the contrary, it was never the case that a code was assigned within a complete response more than once. To further illustrate, the frequency of a code equaled the number of teachers that the code was assigned to. Finally, concluding resulted in an interpretation of the findings. The percentages of frequencies for the codes in the codebooks were used to summarize the findings.

A cut-off percentage of 20% was used; categories and codes with percentages that indicated less than three out of 10 teachers were eliminated (Vattøy, 2020). One example was the code "student content knowledge" with a frequency of 14%. For reliability purposes, two researchers assigned the codes to randomly selected pages of the survey responses. Next, the proportion of the times that the researchers

Table 2 Codebook for teacher professional development

Contributions to teaching practice (58%)	
Teaching skills (40%)	Remarks concerning improvement and experience in STEM teaching
Quotation	"I realized that I used my teaching skills and teaching experiences now in a new context."
Understanding and knowledge (32%)	Reported improvement in disciplinary knowledge, conceptualizations of STEM education, and knowledge about interdisciplinary approaches
Quotation	Knowledge about: "…science and engineering," "…how disciplinary knowledge can be integrated," and "…how STEM is implemented in pre-college settings."
Teacher roles (29%)	Comments concerning teacher roles and continuous professional development
Quotation	"The earlySTEM program addressed the importance of making investigations continuously as a teacher, looking for contemporary knowledge and new experiences."
Social contributions (34%)	
Collaboration with colleagues (55%)	Remarks related to improved teacher collaboration, working towards mutual goals, exchange of ideas
Quotation	"…I can recognize the increase in how we support each other in giving feedback and exchanging knowledge," "…we as teachers experienced the benefits of presenting professional ideas to one another."
Social relations (45%)	Comments about social interaction and positive communication between teachers, school administration, students, and parents
Quotation	"…we started to interact with our colleagues in other school campuses," "this program helped me adapt to my school very quickly due to the positive communication I had with my colleagues, students, and their parents during the program tasks."

assigned the same code to the same teacher response was calculated. This resulted in a sufficient inter-rater reliability value of 0.78 (Fraenkel et al., 2012).

Results

The results are presented in three parts in line with the research questions of the study. Tables 2, 3, and 4 display the results with illustrative quotations.

Influence of earlySTEM Program for Teachers' Professional Development

Teacher responses regarding the influence of the earlySTEM program on their personal development were divided into two categories: (a) contributions to teaching practice and (b) social contributions (see Table 2). The most frequent code spoken for the first category was teaching skills. Two illustrative teacher responses were as follows: "I used to prioritize traditional teaching strategies…I gained experience in adapting innovative teaching methods while supporting creativity" and "I learnt how to transfer my science disciplinary knowledge to interdisciplinary teaching." Several teachers noted that asking more questions to their students as they used the teaching materials and more frequently getting open-ended questions from their students facilitated the change in their teaching skills. Two teachers commented: "My students asking more questions made me do further research on the content and new teaching strategies…with everyone asking more questions to each other, I could use this to facilitate

Table 3 Codebook for student outcomes

Skills development (53%)	
Teamwork (60%)	Comments about progress in collaboration, share of responsibilities, expressing ideas, making presentations, improved social relations with classmates
Quotation	"I observed my students to show improvement in helping each other as team members, showing willingness to be part of their team."
Science and math skills (21%)	Perceived benefits in science skills (e.g., making investigations, observations, classifying) and math skills (e.g., measurement, operations)
Quotation	"Their math skills improved as they use their creativity in the tasks," "…spatial relations, experimenting, making observations…"
Awareness of connection to real-world problems (25%)	Reported recognition of appreciating local environment and of connecting earlySTEM tasks to daily life issues and problems
Quotation	"…my students used the school garden as a knowledge source, they realized how their environment is related to what we do in earlySTEM tasks."

learning more effectively" and "Using the creative responses my students provided, I learnt to think of my instruction from their perspective."

Next, teachers perceived an improvement in their knowledge and conceptualization of STEM education. A teacher expressed, for example: "I used to think STEM education only uses and contributes to science knowledge and practices. Now I see it creates changes and is informed by multiple disciplinary aspects." Although most teacher accounts addressed an improvement in their science disciplinary knowledge, a few of the responses reflected engineering: "…engineering was very intimidating for me at the beginning, but now I learnt how engineers might work and what methods they follow…." Many teachers mentioned the workshops, where they experienced the curriculum themes prior to classroom implementations, to be useful for improving their STEM conceptualizations.

The teachers also reflected on how the earlySTEM program led to a revised image of a teacher who embraces the search for new knowledge and keeps oneself updated. Several teachers noted contacting parents as a factor that contributed to this image of themselves. Although collaborating with parents was not part of the earlySTEM program tasks, some of the teachers explained that they asked parents who were engineers to visit some of the class hours to give students feedback.

Comments on social contributions were distributed to (a) collaboration with colleagues and (b) social relations. Collaboration with colleagues demonstrated teachers' exchange of professional opinions and their learning from each other.

Findings revealed that the teachers were perceived to benefit from the earlySTEM program in different aspects. More so, it was discovered that factors such as exchanging questions in the classroom, participating in the teacher workshops, and contacting parents played a role in the perceived contributions of the program on teachers' professional development.

Table 4 Codebook for perceived challenges

Limited time (28%)	Comments about the need for more hours in the weekly schedule
Quotation	"…I could observe that the students were unhappy with limited time."
Problem constraints (21%)	Remarks on the problem constrains limiting students' progress towards solutions
Quotation	"Some of the constraints were too structured…this limited student teams' imagination and thinking towards multiple solutions," "…too many"

Benefits of Implementing the earlySTEM Program on Students' Outcomes

Teacher accounts on perceived student outcomes fell into two categories detailed in Table 3: (a) skills development and (b) awareness of connection to real-world problems (see Table 3). More than half of the teachers indicated an observed improvement in skills development, teamwork, and science and mathematics skills. The teachers underlined how students worked together towards a common goal, sharing group responsibilities, and described an improvement in expressing oneself, appreciating different opinions, and positive social relations: "…our students experienced contacting people outside our campus; parents and experts" and "…speaking in front of an audience, expressing personal opinions and experiences, especially during the STEM fair to people of multiple age groups…."

The students are also reported to have gained an awareness of the connection of the earlySTEM curriculum content to real-world problems. Results revealed a recognition of environmental issues; for example, many students are reported to describe the need to keep the school building and garden clean. Another pattern in the results is the acknowledgment of a connection between mathematics and science concepts and daily life problems. A teacher stated that one of his students started to show more appreciation of her classmate with a health condition: "…one of my students has allergies to certain food…another student in my class explained a connection between his health condition and the first earlySTEM curriculum theme."

Many teachers mentioned that having a fair with students across grade levels was important for student development. Two teachers, for example, reported: "…students had the opportunity to observe the products of student teams of upper grade levels, which contributed to their development" and "…because students of different grade levels work on the same theme at the same eight weeks, students share and learn from each other in ways that exceed their regular class hours."

Notably, the earlySTEM program is perceived to benefit students in terms of skills development and making real-world connections. The teachers also stressed the role of taking part in fairs in bringing students of different grade levels together.

Challenges of Implementing the earlySTEM Curriculum

Results showed that many teachers could not think of situations that were of concern to them. For the teachers who commented on challenges that came with implementing the earlySTEM curriculum, two categories surfaced (see Table 4). Many teachers discussed the weekly class hour failing to fully address the curriculum tasks, especially with regard to responding to students' questions and giving feedback. A second challenge was associated with the constraints given in relation to each APKS. Some teachers perceived some of the constraints as a barrier for students' progress through formulating alternative solutions.

The next section discusses the findings with the literature and aims to translate the findings into improvement points.

Discussion

This study investigated teachers' perceptions of implementing a STEM curriculum. Our findings indicated that practicing STEM curriculum in a program context is perceived to benefit teachers primarily in their teaching skills and in conceptualizing STEM education (e.g., Autenrieth et al., 2017; Havice et al., 2018; Ring et al., 2017). Teachers who believe that they have the necessary knowledge and skills to teach STEM have a higher tendency to modify their instructional practices and achieve greater self-efficacy toward STEM teaching (Margot & Kettler, 2019; Thibaut et al., 2018). Insufficient knowledge of STEM education and incompetency in teaching STEM are significant barriers to the effective implementation of STEM practices (Honey et al., 2014). Guided by these conclusions, the findings are promising for the long-term adoption of STEM in early grade levels.

This mid-evaluation of the earlySTEM program showed that teachers' conceptualizations of STEM education evolved from presuming science as the main context to embracing integration of multiple disciplines. This might have stemmed from supporting teachers with themes that integrate all STEM disciplines with connections to the learning standards (Boice et al., 2021). This improvement might facilitate teachers' adoption of STEM experiences in their future practices (e.g., Lamberg & Trzynadlowski, 2015; Ring et al., 2017). Highlighting knowledge of engineering can be explained by the fact that the core discipline of the second theme My World of Machines was engineering. Because teachers receive little or no training on engineering during their formal education, especially teaching engineering for early grade levels can be intimidating. Successful PD programs with exemplary curricula help teachers understand the engineering design process and increase the likelihood that teachers approach engineering more positively (Graves et al., 2016).

Teacher perceptions of professional development also stressed a recognition of a school culture of collaboration, positive communication, and a teacher image who continuously strives to improve. Previous research also stressed a professional teacher mindset that embraces life-long learning to play a role in adopting integrated STEM teaching (Nadelson & Seifert, 2017). The findings together can lead to schools with a shared STEM philosophy (Margot & Kettler, 2019; Ntuli & Ray, 2022). Transformation into a progressive teacher can more strongly highlight collaboration, teachers who support each other, and thus shared conceptualizations of STEM education (Autenrieth et al., 2017; Lamberg & Trzynadlowski, 2015). Teachers of the same grade levels of the same school campuses had participated as a group in the program which might have contributed to perceiving social contributions (Ntuli & Ray, 2022).

The study also showed that the workshops for teachers, interaction with parents, and asking more questions in the classroom play roles in teachers benefitting from the program. Reaching out to parents which reflects the flexibility principle of the earlySTEM program also responds to the need for increased autonomy and active participation of teachers in STEM program contexts (Huang et al., 2022). The role of STEM education in inspiring students and teachers to ask more questions is described by numerous other studies (e.g., Bybee, 2018). Our finding can be attributed to the success of the driving problem, APKS, and to the teacher's manual that guided classroom practices. Considering ways to increase the weekly earlySTEM hour in the school curriculum can further support exchanging questions (Nadelson & Seifert, 2017). For younger students, our results also showed concerns with respect to the problem constraints. Keeping in mind their essential role in engineering design, the constraints of the first two themes might benefit from other age-appropriate budgetary, dimension, or material constraints (Honey et al., 2014). Fewer constraints, solution examples of similar problems, and using storyboards can also lead to children's improved understanding of problem constraints. Teachers can be reminded to pose the example questions in the teacher's manual to facilitate students' creation of multiple solutions.

The results evidenced teacher perceptions on improved student skills and real-world connections. These findings are consistent with previous research that reported on the perceived impacts of STEM curricula on students' teamwork skills, problem solving, science skills, learning science and mathematics concepts, and making real-world connections (e.g., Erickson et al., 2020; Stieben et al., 2021). The connection of the APKS to a familiar issue such as having allergies might have facilitated students' capabilities in making connections to daily live occurrences (Martín-Páez et al., 2019). Graves et al. (2016) asserted that integrating the school garden into the STEM curriculum in a teacher PD context inspires activities relevant to students' personal lives while addressing science standards. The importance of these findings is certain considering the benefits of exposing students to real-life problem contexts at early ages (Corlu, 2017; Bybee, 2018). Students' awareness on connections beyond the classroom aligns well with student-centered learning (Jeter et al., 2019). Including teachers in formulating ideas for

APKS based on their school context and their student profile might be beneficial for the improvement of the earlySTEM curriculum.

The findings collectively address the potential of supporting early grade level teachers in enacting well-designed STEM curricula. The initial positive results of teacher perceptions suggest more often engaging K–4 teachers and students in systematically developed STEM curricula.

Limitations of the Study

This research did not include data to present teacher and student actions during the weekly earlySTEM hours, for example, classroom observations or logs (Huang et al., 2022). Using teacher self-reports, no claims on the actual impacts of the earlySTEM program can be made. For some of the identified codes, the percentages representing the number of teachers were not at a desirable level. Results of final evaluations can lead to conclusions on an overview of the program and a comparison across different curriculum themes.

Conclusion

The study contributed to the literature by introducing a sustained STEM education program executed with input from a university research center and K–12 schools. Because early grade level teachers have difficulty accessing STEM curricular materials, professional development opportunities that model STEM integration need to be more accessible (Baker & Galanti, 2017; Brown & Bogiages, 2019; McClure, 2017). This mid-evaluation suggested that providing early grade level teachers with well-developed and accessible STEM curricula might lead to teacher and student gains (Brenneman et al., 2019; Brown & Bogiages, 2019). Descriptions of the earlySTEM program together with the findings of an evaluation present an informed template for similar program designs. Designers that aim to improve the positive impacts of similar programs and to contribute to research in early grade STEM education can consider our program and findings.

Teacher perceptions offered guidelines to strengthen the earlySTEM program. Based on the findings from this mid-evaluation, the following recommendations can be helpful for the continuation of the earlySTEM program and designers of STEM curricula:

- Using unique local conditions, like the case of the character with allergies, wherein teacher reflections on their students' experiences or their local school condition might be used as a source in further sharpening a real-world connection,
- Extending the shared STEM mindset in schools, continuing with the recruitment of teachers of the same school campus while improving staff communication through platforms such as online channels, supporting teachers in making presentations in external events communicating the program implementation, and involving school administrators in the process,
- Certain elements of the program concerning the first two themes are supported by teacher perceptions to be useful such as workshops, campus fairs, and weekly STEM hours,
- Even though the APKS for the first two themes supports students' open-ended questions, attention might be given to the constraints, and
- The program might include parental involvement.

This research demonstrates an example case of a university-school partnership in supporting early grade level teachers and students with long-term STEM programs. Further research to capture data on classroom practices can provide more insights into evaluating the program.

Declarations

Competing Interests The authors declare no competing interests.

Appendix

earlySTEM Program Evaluation Survey Questions

1. What do you think about the impacts of the earlySTEM program considering your perception of the teaching profession?
2. What do you think about the impacts of the earlySTEM program considering your professional development?
3. What do you think about the impacts of the earlySTEM curriculum on your students' knowledge, skills, and attitudes about mathematics?
4. What do you think about the impacts of the earlySTEM curriculum on your students' knowledge, skills, and attitudes about science?
5. What do you think about the contributions of the earlySTEM curriculum to your students' knowledge, skills, and attitudes considering other STEM disciplines?
6. What do you think about the contributions of the earlySTEM curriculum to your students' non-academic knowledge, skills, and attitudes?
7. Please discuss any other comments on the impacts of the earlySTEM program.
8. Please discuss any challenges and aspects that may require improvements.

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