Transdisciplinary Instruction: Implementing and Evaluating a Primary-School STEM Teaching Model

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Abstract

This article reports the implementation of a series of innovative STEM lessons, which were integrated into primary-school students' teaching and learning programs, and their evaluation using a mixed-methods approach. We provided 1095 grade 4-7 students in 36 classes from 10 schools with a series of STEM lessons modified from *Tryengineering* to fit local needs. Effectiveness was evaluated by administering a questionnaire to students before (pretest) and after (posttest) the STEM lessons. The questionnaire included two scales assessing student perceptions of their learning environment (Cooperation and Involvement), two scales assessing student attitudes (Enjoyment of Lessons and Career Interest in STEM) and two scales assessing student understanding of the work undertaken by people employed in engineering and technology. Also our evaluation involved qualitative information based on classroom observations and interviews. Statistically-significant improvements between pretest and posttest in career interest in STEM (0.70 standard deviations), understanding of engineering (0.81 standard deviations) and understanding of technology (0.74 standard deviations) supported the efficacy of the instructional activities, while lessons observations and student interviews further supported, explained and clarified the quantitative findings.

Introduction

The role of STEM (Science, Mathematics, Engineering and Technology) cannot be underestimated in preparing global citizens for the challenges of the future. Because innovation is the key to economic growth and STEM is a key driver of innovation, opportunities for engaging and supporting young people in pursuing their love of STEM, or even helping them to better understand what STEM entails, strengthens the future workforce and a country's international standing.

As an initial part of a long-term plan for STEM education and skills development, primary-school students were introduced to STEM lessons in an effort to lay a foundation for the future. In this paper, we report the development and implementation of these innovative STEM instructional materials and report their evaluation using quantitative methods (involving assessment of classroom environment, student attitudes and student understanding) and qualitative methods (involving classroom observations and interviews). In this introductory section, we (1) delineate the main purposes of this article, (2) provide some background context for STEM education and (3) briefly review the field of learning environments (because our evaluation drew constructs and methods from this field).

Aims

The two purposes of this article are to:

- Describe the development and implementation of primary-school instructional materials in STEM
- Report an evaluation of these STEM instructional materials in terms of students' perceptions of classroom environment, attitudes and understanding, as well as qualitative information based on observations and interviews.

Background context of STEM education

Challenges of the global economy and the move from the technology era to the information era require that educators transform students' classroom experiences to keep up with the opportunities and demands brought by the information era. Initiatives such as the integration of Science, Technology, Engineering and Mathematics subjects into STEM (Honey, Pearson, & Schweingruber, 2014; Zollman, 2012) and the Partnership for 21st Century Skills (http://www.p21.org/) reflect this transformation. Integration of the individual STEM subjects has the potential to prepare students for the workforce of the future by equipping them with 21st century skills such as problem-solving, innovation, creativity, collaboration and critical thinking, as explicated by the Australian Office of the Chief Scientist:

> *An education in STEM also fosters a range of generic and quantitative skills and ways of thinking that enable individuals to see and grasp opportunities. These capabilities – including deep knowledge of a subject, creativity, problem solving, critical thinking and communication skills – are relevant to an increasingly wide range of occupations. They will be part of the foundation of adaptive and nimble workplaces of the future. (2014, p. 7)*

The importance of STEM is highlighted by the shortfall in the global STEM workforce, gender gaps in both STEM-related occupations and STEM education, and disparities among education providers (Beede et al., 2011; Diekman & Benson-Greenwald, 2018; Engineers Australia, 2017; Kier, Blanchard, Osborne & Albert, 2014). These issues call for initiatives that can nurture and improve student retention and interest in STEM subjects. In order for these initiatives to be effective, factors that influence students' career choices need to be identified and addressed.

Honey et al. (2014, p. 33) identified five goals for students and two goals for educators in integrated STEM education:
Goals for students
- STEM literacy
- 21st century competencies
- STEM workforce readiness
- Interest and engagement
- Ability to make connections among STEM disciplines

Goals for educators
- Increased STEM content knowledge
- Increased pedagogical content knowledge.

The above five goals for students need to be introduced from an early age and aligned with the curriculum in high-quality STEM education programs that are reinforced and scaffolded for students (Goodrum & Rennie, 2007; Koul, Fraser, Maynard, Tade, & Henderson, 2016).

STEM education is important not only for promoting cognitive outcomes, but also for affective aspects of education. Students' attitude towards STEM was identified as one of the factors that determine whether or not students make career decisions in STEM (Bandura, Barbaranelli, Caprara, & Pastorelli, 2001; Osborne, Simon, & Collins, 2003; Tseng, Chang, Lou, & Chen, 2013). Hence, STEM education needs to create a rich and holistic learning experience that excites students, motivates them to pursue deeper understanding and stronger skillsets, and facilitates the attainment of 21st century skills.

Review of learning environment literature

Because students spend approximately 20,000 hours in classrooms by the time they complete a university degree, the quality of their classroom environments is highly important (Fraser, 2001). For this reason, Walberg and Anderson's (1968) evaluation of Harvard Project Physics included as process criteria of curricular effectiveness students' perceptions of the quality of their classroom learning environments, which were assessed by a multidimensional questionnaire called the Learning Environment Inventory (LEI). This pioneering research marked the beginning of the field of classroom learning environments.

Walberg and Anderson's (1968) work was pioneering not only because it introduced the use of learning environments dimensions as criteria of effectiveness in the evaluation of educational programs, but also because classroom processes were assessed through students' perceptions using the LEI questionnaire (in contrast to the prevailing domination of direct observational methods at the time). Therefore, this work in the US spawned much research around the world that involved the development and validation of new learning environment questionnaires and their use in curriculum/program evaluation.

However, the LEI has some limitations. It is uneconomical in terms of the time needed for students to respond to 105 items in 15 scales (e.g. Competitiveness, Goal Direction). Because the LEI was designed for the senior high-school level, some of its language is unsuitable for younger students. Importantly, the LEI was designed for teacher-centred classrooms that were the norm at the time. Later questionnaires overcame these shortcomings.

The first learning environment questionnaire with a specific focus of student-centred classrooms was the Individualised Classroom Environment Questionnaire (ICEQ), which has 50 items in the 5 scales of Personalisation, Participation, Independence, Investigation and Differentiation (Fraser, 1990; Rentoul & Fraser, 1979). The ICEQ's scales have been found to be significantly related to several types of student attitudes to science (Fraser & Butts, 1982).

The Constructivist Learning Environment Survey (CLES) contains 35 items in 5 scales (Personal Relevance, Uncertainty, Critical Voice, Shared Control and Student Negotiation) that assess the extent to which a classroom's environment is consistent with constructivism (Taylor, Fraser, & Fisher, 1977). The CLES has been useful in research involving a comparison of Australian and Taiwanese science classrooms (Aldridge, Fraser, Taylor, & Chen, 2000), an evaluation of science teacher professional development in the US (Nix, Fraser, & Ledbetter, 2005), and science teachers' action research aimed at improving classroom environments in South Africa (Aldridge, Fraser, & Sebela, 2004).

Because of the unique importance of the laboratory in science teaching, the Science Laboratory Environment Inventory (SLEI) was developed with 35 items assessing the 5 scales of Student Cohesiveness, Open-Endedness, Integration, Rule Clarity and Material Environment (Fraser,

Giddings, & McRobbie, 1995). Interestingly, the SLEI was field tested and validated simultaneously with 5447 students in 269 classes in six countries (US, England, Canada, Australia, Israel and Nigeria). The SLEI has been applied in investigating associations between the laboratory environment and student attitudes (Fraser & McRobbie, 1995), evaluating the use of anthropometric activities (Lightburn & Fraser, 2007) and identifying differences in the learning environments of science students in different streams (Fraser & Lee, 2009).

In the study reported in this article, selected scales were drawn from the 56-item What Is Happening In this Class? (WIHIC) questionnaire, which currently is the world's most-frequently used learning instrument and which assesses the 7 scales of Student Cohesiveness, Teacher Support, Independence, Investigation, Task Orientation, Cooperation and Equity (Aldridge, Fraser, & Huang, 1999). The WIHIC has been used as a source of criteria of effectiveness in the evaluation of many science programs, including a field-studies centre (Zaragoza & Fraser, 2017), an innovative university science course for prospective elementary teachers (Martin-Dunlop & Fraser, 2008) and the use of student response systems (Cohn & Fraser, 2016).

In the numerous studies reviewed above, learning environment variables have been used as dependent variables in evaluations of educational programs. When used as independent variables, learning environment scales were consistently, positively and strongly related to science students' outcomes in many studies reviewed by Fraser (2012, 2014, 2018). Therefore, having positive classroom environments should be seen not only as a worthwhile end in its own right, but also as a means for improving student outcomes.

Science teachers have used learning environment assessments in successful action-research attempts at improving their classrooms (Fraser & Aldridge, 2017). By assessing students' actual and preferred classroom environment perceptions and reflecting on gaps between the actual and the preferred, teachers have been guided in implementing classroom changes to reduce these gaps (Aldridge, Fraser, Bell, & Dorman, 2012; Aldridge, Fraser, & Sebela, 2004).

Our STEM education initiative

This project was motivated by the importance of providing high-quality STEM education in preparing the next generation for the future. The overarching aim was to promote interest and understanding among primary school students in STEM as potential career choices through creating engaging learning environments. The project addressed the teaching component in teaching and learning by providing support and experience for teachers, as well as the learning component by providing STEM learning experiences for students. Importantly, as described below, this initiative was evaluated quantitatively with a questionnaire assessing the learning environment, student attitudes and student understanding, as well as qualitatively based on reflections from students and teachers.

Students initially were given a lesson defining engineering and the importance of STEM. In addition, at least one engineering topic (two to three lessons, chosen by the class teachers) was taught in these classes. Researchers used lesson plans from *Tryengineering* (http://tryengineering.org/lesson-plans) as a guide and modified them to fit local needs. Teachers were given the lesson plans, materials and any other support needed for each topic. These lessons were observed by at least one researcher. The three engineering topics were:

- *Give Me a Brake* - lesson focused on brakes, force and friction, using bicycle rim brakes to demonstrate basic braking mechanisms to stop, slow or prevent motion. The topic was introduced using a short PowerPoint presentation that introduced science (friction), technology (bicycle brakes), engineering (design) and mathematics (measurement) ideas into the activity. This 45-minute activity aimed to teach students how simple rim brake systems work for bicycles. Teams of 3 students each explored how different materials react when used in a braking system to stop the motion and then evaluated the design and materials used in standard bicycle brakes. Students developed and presented a design for improved safety using words and sketches given in information sheets. Students were encouraged to make amendments to improve the design. The teams then were required present their ideas to the class.

- *Oil Spill Solutions* - lesson focused on the use of various techniques to provide speedy solutions for oil spills or other threats to natural water resources. Effort was made to integrate all the four streams of STEM by bringing in the science (environmental impact), technology (testing the system), engineering (design of system) and mathematics (measurement) in this activity. Students worked in teams of 3 to analyse an oil spill in the classroom and then to design, build and test a system that first contained and then removed the oil from the water. Students selected items from everyday use to build oil containment and clean-up systems, evaluate the effectiveness of their solution and those of other teams, and present their findings to the class.

- *Solar Structures* - lesson focused on how the sun energy can be used to heat and cool buildings. Teams of students were asked to design and build a one-bedroom model house, using passive solar heating techniques to warm up the house as much as possible. The house needed to be big enough to be able to place a thermometer inside the middle of the model with the door closed and be able to read the thermometer through the window. The passive solar houses were constructed from everyday materials and they were tested to determine how well they regulate temperature. In contrast to the first two activities, Solar Structures took a longer time (approximately 2 hours) to complete. Concepts of science (passive solar design convection, radiation and conduction), technology (regulating the temperature of the building with electronic devices such as thermostats or blinds), engineering (design in the form of cross ventilation, vegetation, colours used, windows direction) and mathematics (amount of heat generated, length and breadth of windows, angle of sun from the location, recording the temperature) were introduced.

Research methods

This study employed an explanatory-sequential mixed-method design (Creswell & Clark, 2007) within the pragmatic research paradigm (Mackenzie & Knipe, 2006). Because the aim of this study was to explore issues surrounding student and teacher experiences in primary classrooms involved in the STEM project, the pragmatic paradigm (in which the research aim is central) was considered appropriate. Quantitative and qualitative data collection and analysis were designed to contribute to understanding of students' and teachers' experiences during the STEM project. The quantitative data were used to identify changes in the learning environment, student attitudes and student understanding that occurred during the series of lessons, while the qualitative data were used to find possible explanations and clarification for the quantitative findings.

Ethics approval for the study was granted by the Human Ethics Research Committee of Curtin University.

Sample
Our sample comprised 1095 grade 4-7 students (570 male and 525 female) in 36 classes in 10 schools. Classes consisted of only grade 4, only grade 6 or a composite of grades 4/5, grades 5/6 or grades 6/7. Approximately 10% of participating students reported that one of their parents works or is qualified as an engineer. The study was carried out in a mix of private and public schools in suburban Perth, Western Australia. All schools were co-educational.

All 1095 students completed our questionnaires both as a pretest and a posttest. From these 1095 students, 265 students from five schools representing all grade levels were randomly selected to complete a reflection sheet to capture their learning experiences. Interviews were also conducted with 29 students from this group, as well as with their seven teachers.

Questionnaire
Salient aspects of the learning environment were assessed using scales from the widely-used and extensively-validated *What Is Happening In this Class?* (WIHIC) developed by (Aldridge, Fraser & Huang, 1999). According to Dorman (2008), the WIHIC is the most-frequently used classroom environment questionnaire around the world today. Two scales that were most appropriate for our study, namely, *Cooperation* and *Involvement*, were selected and modified. However, only 5 of the original 8 items in each scale were used because of the young age of students. Additionally, again because of student age, the original 5 response alternatives were reduced to only 3 (Disagree, Not Sure, Agree). Items in these two learning environment scales are listed in the Appendix.

Similarly, in order to measure student attitudes, the widely-used and -validated *Test of Science-Related Attitudes* (TOSRA) developed by Fraser (1981) was drawn upon. Two salient scales, namely, *Enjoyment of Lessons* and *Career Interest in STEM*, were selected and modified. Again, to minimise fatigue among young students, only five items per scale and only 3 response alternatives (Disagree, Not Sure, Agree) were used. Items in these two attitude scales are listed in the Appendix.

The validity and reliability of our four learning environment and attitude scales were found to be satisfactory for our sample. The 4-scale structure of the questionnaire was supported by principal axis factor analysis with varimax rotation and Kaiser normalisation, with the 4 scales together accounting for 52.46% of pretest variance and 60.55% of posttest variance. Eigenvalues ranged from 1.24 to 4.09 for the pretest and from 1.14 to 5.58 for the posttest. All items in the four scales could be retained. Cronbach alpha reliability coefficients for the four different scales ranged from 0.88 to 0.90 for the pretest and from 0.89 to 0.94 for the posttest.

Students' understanding of engineering and technology was measured with a questionnaire containing two questions: *What does an engineer do?* and *What is technology?* Prompts consisting of eight pictures for the engineering questions (e.g. design circuits, build houses, design machines) and six pictures for the technology questions (e.g. running shoes, spaceship and lightning) were used to help students relate to the context of these questions.

Qualitative data collection
In addition to quantitative data collection based on administering our questionnaire to 1095 students, a reflection sheet that was collected from a randomly-selected group of 265 students after the lessons. This reflection sheet contained five questions that were similar across topics and only slightly changed to reflect each particular topic. These five questions were designed to help students to reflect on the challenges which they encountered during the lessons, the interesting aspects of the lessons that they enjoyed, the changes that they would make to their designs and solutions, and suggestions for improving the lessons.

From these 265 students, 29 were selected and interviewed about their interest in their science class, their understanding of engineering and technology, the sources of information to which they have had access, their career choices and their parents' occupations. The purpose of these interviews was to collect information about factors that could influence students' career choices. Also interviews with seven teachers were conducted to gather information about their perceptions and experiences regarding STEM education. Observations were made by the researchers during the lessons.

Results

Quantitative questionnaire data
Our STEM teaching model was evaluated in terms of changes between pretest and posttest on each of the six constructs in our questionnaire described above: the learning environment scales of Cooperation and Involvement; the student attitude scales of Enjoyment of Lessons and Career Interest in STEM; and student Understanding of Engineering and Understanding of Technology. Koul, Fraser, Maynard and Tade (2018), reported on how 1095 students' questionnaire responses were analysed using one-way MANOVA with repeated measures with the six questionnaire scales as the set of dependent variables. Testing occasion (pretest/posttest) was the repeated-measures factor. Because pretest–posttest differences for the 6 scales as a whole (using Wilks' lambda criterion) were statistically significant, the one-way ANOVA was interpreted for each of the individual questionnaire scale.

Table 1 shows for each questionnaire scale, the mean and standard deviation (SD) separately for pretest and posttest, as well as the ANOVA results for the statistical significance of pretest–posttest changes. In addition to reporting the statistical significance of pretest–posttest changes, we also estimated their magnitude using Cohen's *d* effect size, which expresses a difference in standard deviation units. Table 1 reports effect sizes for those scales for which pretest–posttest changes were at least 0.2 SDs.

Results from Koul et al. (2018) in Table 1 show that pretest–posttest changes were small (less than 0.2 SDs) and statistically nonsignificant for both learning environment scales (Cooperation and Involvement) and for one of the two attitude scales (namely, Enjoyment of Lessons). On the other hand, pretest–posttest changes were both statistically significant and large for Career Interest in STEM (0.70 SDs), Understanding of Engineering (0.81 SDs) and Understanding of Technology (0.74 SDs). For individual Understanding items, statistically significant pretest–posttest improvements occurred for five Engineering items (make better food, works out ways to make tablets easier to take, build houses, drive machines and repair machines) and three Technology Understanding items (manufacturing plant, spaceship and lightning).

Table 1: **Descriptive statistics and ANOVA results and effect sizes for pretest–posttest changes in learning environment, attitude and understanding scales**

Scale	Mean		SD		Differences > 0.2 SDs	
	Pretest	Posttest	Pretest	Posttest	*d*	*F*
Learning Environment						
Cooperation	2.67	2.66	0.31	0.39		
Involvement	2.61	2.56	0.37	0.41		
Attitude						
Enjoyment of Lessons	2.43	2.38	0.57	0.68		
Career Interest	1.85	2.24	0.53	0.58	0.70	495.06**
Understanding						
Engineering	1.44	1.57	0.14	0.18	0.81	510.31**
Technology	1.66	1.76	0.13	0.14	0.74	414.94**

**$p<0.01$, $N = 1095$
Cohen's *d* effect size = Difference between means divided by pooled SD. Based on Koul et al. (2018)

It is noteworthy that, for the three scales for which pretest-postest changes were small and nonsignificant, the pretest mean out of a maximum of 3 was already high (ranging from 2.38 2.67). Because this suggests the presence of a possible ceiling effect for the three scales of Cooperation, Involvement and Enjoyment, the teaching and learning activities in the participating schools already were characterised by high levels of Cooperation, Involvement and enjoyment prior to our intervention.

In addition to the overall effectiveness of the instructional materials for the whole sample (as reported in Table 1), the possible differential effectiveness of the materials for male and female students was important. We explored differential effectiveness by comparing males and females in terms of the magnitudes of their pretest–posttest changes in learning environment, attitude and understanding scores. Because the magnitudes of these pretest-posttest changes were found to be quite similar for males and females, it appears that the instructional materials were equally effective for students of different sexes.

Qualitative student reflection
Qualitative data from student reflection also reflected the effectiveness of the STEM lessons, with students reporting their engagement and enjoyment with responses such as:
 I was enjoying it, *It was prepared well and everyone had a lot of fun and learned lots of new things about engineering*, and *It was fun and interesting*. Comments for all three activities also reflected students' design thinking and ability to evaluate their activities and methods: *I would have a sensor instead of a button* (Give Me a Brake) and *If I were to do this again, I would put Glad Wrap under the rice: this way, when the rice absorbs the oil, we can lift it up* (Oil Spill). The design component of the lessons *Give Me a Brake* and *Oil Spill Solutions* was reported to be challenging but also interesting while, for Solar Structures, the creation part was found to be more difficult than the design component.

Regarding the changes that students would like, most students who undertook *Give Me a Brake* wanted to spend more time in thinking and designing to arrive on a better solution. Almost all students who undertook *Oil Spill Solutions* commented on different materials that they think

would work best, including cotton buds and Glad Wrap while, for *Solar Structures,* most students considered location and isolation to be the most important factors in heat retention.

When asked about which elements of the activities they enjoyed most, students who undertook *Give Me a Brake* identified the design process, collaboration, observing other students' designs, learning about the system, experiments and the presentation. For *Oil Spill Solutions,* in addition to these elements, most students enjoyed the activity most when their experiments worked. In contrast, for *Solar Structures,* students most enjoyed the building and temperature-measuring elements.

With regards to how the activities could be improved, many students expressed their satisfaction with the activities, but several students suggested more tangible approaches and technologies such as by working on a real bike, using more materials, or using their computers to draw their design.

Qualitative interviews with students
All students who were interviewed reported experiments as being an interesting aspect of their science class. They enjoyed science most when: they could relate the topic to real life and the environment; the topic was relevant, useful and exciting; and when they could design, build and manipulate different materials.

When asked about their understanding of what engineers do, most students were hesitant, except students whose parent was an engineer or who were interested in becoming an engineer. They defined an engineer as a designer, maker, builder or repairer. The skills and traits that they associated with engineers included being intelligent, creative, innovative, good in science and mathematics, helpful, resourceful, calm, strong, patient and hard- working.

Students' source of understanding of engineering and what engineers do included books, school, friends, parents, television and the internet, as well as the lessons in which they had just participated. Most students had never considered a career in engineering but several reported that they had started to think about the possibility.

Qualitative interviews with teachers
Teacher interviews about each of the three STEM activities reflected overall satisfaction. The chosen activities were within the framework of their science curriculum, were well planned and catered for the needs of the children. All seven teachers recognised the connection between the STEM activities and the curriculum being covered during the term and generally appreciated the support provided by the researchers. Teacher responses reflected that activities involved:
- the curriculum-related topic being chosen;
- discussions, communication and team work;
- problem-solving and critical thinking;
- relevance to real life; and
- fun and motivational elements.

While all teachers reported that they and their students were satisfied with the activities, teacher confidence in engaging their students in similar STEM activities varied. Their responses ranged from *I think I can incorporate this activity easily* to *because I have no science background, I rely heavily on resources provided.* Lack of resources and time to organise them were also mentioned as concerns.

Discussion

The STEM lessons were considered effective by students and teachers reported their satisfaction. There were large and statistically-significant pretest-postest improvements in students' career interest and understanding related to STEM, and students' reflections showed engagement in both the activities and design thinking. STEM activities were identified by students as developing skills and positive attitudes such as curiosity, innovation, collaboration, critical thinking and problem-solving. The alignment to the curriculum was also found to contribute to the effectiveness of the STEM lessons.

Students' engagement with STEM activities is likely to create positive attitudes towards further study and future career in STEM. In this study, all students reported interest and enjoyment when lessons were tangible, contextual, useful and relatable. The lack of pretest-postest improvement for two learning environment scales and an enjoyment scale could suggest that student engagement with STEM activities needs to be better facilitated (but also could be explained by a ceiling effect in which scores were already high at pretesting). Creating positive classroom environments that emphasise cooperation, involvement and enjoyment is likely to further engage students in STEM activities and develop their 21st century skills.

Shortages in STEM-related occupations have made it vital for educators to prepare students for the future workforce. Studies show that students' career interests are affected by factors such as self-efficacy, positive experience, early exposure, peer influence and the availability of role models (Bandura et al., 2001; Diekman, Brown, Johnston & Clark, 2010; Kier, Blanchard, Osborne, & Albert, 2014). Similar to these findings, our study revealed that students' career interest was influenced by parents as role models, information from various sources, and positive experiences during STEM activities. If education is to prepare students for a future in STEM, educators need to tap into these factors and provide sufficient information and experience in STEM.

Contrary to most research findings on gender gaps in STEM (Beede et al., 2011; Diekman et al., 2010), this study revealed that the STEM lessons were relatively comparable in their effectiveness for boys and girls in terms of pretest–posttest changes in learning environment, attitudes and understanding. Research also shows that early exposure to STEM activities and scaffolded learning could bridge gender gaps in STEM (Kier et al., 2014; Reilly, Neumann, & Andrews, 2017; Sadler, Sonnert, Hazari, & Tai, 2012) and that students' level of interest in STEM subjects in the early high-school years strongly influences their career choices at the end of high school (Sadler et al., 2012). By exposing students to exciting and engaging STEM activities during early schooling, gender disparity in STEM occupations could be reduced.

Approaches for building STEM capabilities involve both students and teachers (Honey et al., 2014. As learning facilitators, teachers have a very important role in creating a STEM-proficient workforce. All three components measured by the questionnaire in our study (learning environment, attitudes and understanding) are shaped by teachers. Therefore, factors that help teachers, from teacher training programs to professional learning communities, need to be strengthened. Teachers need training, support, resources, professional learning programs and professional learning communities in order to keep abreast with current developments and technologies and to enable them to create constructive STEM learning environments. Support for primary-school teachers is especially vital because, although students start to develop their STEM interests and abilities at an early age, many primary school teachers are not well-

equipped to facilitate STEM learning. This calls for frequent initiatives to support primary-school teachers in their STEM teaching.

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Appendix

Listing of all items in four learning environment and attitude scales

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Working Together
1. I cooperate with other students when doing science work.
2. I share my books and resources with other students when doing work in science.
3. I work with other students on projects in this class.
4. I learn from other students in this class.
5. Students work with me to achieve class goals.

Involvement
6. I discuss ideas in class.
7. The teacher asks me questions.
8. My ideas are used during classroom discussions.
9. I ask the teacher questions.
10. Other students in the class discuss problems with me.

Enjoyment
11. Science lessons are fun.
12. School should have more science lessons each week.
13. Science is one of the most interesting school subjects.
14. I enjoy going to science lessons.
15. I look forward to science lessons.

Career Interest in Engineering
16. When I leave school, I would like to work with engineers.
17. Working as an engineer would be an interesting way to earn a living.
18. I would like to teach engineering when I leave school.
19. A job as an engineer would be interesting.
20. I would like to be an engineer when I leave school.

Footnotes
The first two learning environment scales (Items 1-10) were adapted from the What Is Happening In this Class? (WIHIC, Aldridge, Fraser & Huang, 1999) and next two attitude scales (Items 11-20) were adapted from the Test of Science Related Attitudes (TOSRA, Fraser, 1981). Items are scored 1, 2 and 3, respectively, for the responses Disagree, Not sure, and Agree.