Learning to Teach and Teaching to Learn STEM Through a Makerspace Approach

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Abstract This chapter outlines the implementation of a STEMinist Makerspace Project with a group of female primary pre-service teachers in India. The STEMinist project had previously been enacted in Australia, Indonesia and Malaysia, and targeted female pre-service teachers focusing on building their science, technology and mathematical knowledge and engineering process skills, empowering them to become more confident and competent STEM educators. Using a *Makerspace Approach* pre-service teachers participated in a series of activities: first, as 'students' in a Makerspace creating their own artefact supported through a scaffolded approach by their educators; reflecting on their experiences; then taking their artefact and materials to scaffold and support primary school students to create the own artefacts that they were able to take home. It was evident that the pre-service teachers focused on the development of twenty-first century competences, listing collaboration, critical and creative thinking, problem-solving and applying knowledge as valuable to their own learning. Many of them also considered the learning skills that their students would need in the future.

Introduction

The Cross-Nation Capacity Building in Science, Technology, Engineering and Mathematics (STEM) Education Workshop was held in the Regional Institute of Education (RIE), Bhopal, and aimed at engaging female pre-service teachers in three Makerspace-type STEM activities that provided them with opportunities to create and learn through practical experiences. The program was conducted by researchers from Curtin University, Australia with support from the principal of the Institute and his academic team, including teachers from the Demonstration Multipurpose School on the RIE campus. Fifty-two female pre-service teachers from RIE under-

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going a dual Bachelor of Science, Bachelor of Education program and studying in their 3rd and 5th semesters participated in a series of three pre-service teacher (PST) workshops and three classroom-based workshops.

This chapter examines the literature around STEM education and gender, with a focus on STEM programs, and how a Makerspace approach supports the development of female pre-service teachers' skills, both personally and professionally, through a series of workshops and classroom experiences. Specifically, the research questions underpinning the project were:

(1) How was the Makerspace Project enacted in the Indian context?
(2) How effective was the Makerspace approach in supporting PSTs' engagement and self-confidence in STEM education?
(3) What 21st century competencies did the PSTs identify and demonstrate as a consequence of their participation in the project?

Background

Education in India

India is immensely diverse in terms of geography and it has a rich cultural heritage and ethnic background, a vast and diverse population, cuisine, language, religion, weather, economic status and above all education. India has the second largest population in the world, 1.3 billion people, and has about 2.5% of the Earth's total land mass (Mattyasovszky, 2017). It is one of the fastest growing economies in the world and has the highest number of youth, with an average age of 26.6 years and with 65% of the population below 35 years of age. India is fast improving in several human indices such as life expectancy (now ~68 years), literacy rate (now ~72%) and elementary education enrolment level (UNDP, 2015). Whilst historically it has had significant influence on science, technology and literature, it also has one of the largest populations of illiterate and malnourished people. India is still struggling with high maternal and child mortality rates and 21% of the population lives under the poverty line of $1.90 US per day (UNDP, 2015).

Due to its population, India has voluminous provisions for education at all phases of schooling. There are more than 1.5 million schools with over 260 million students enrolled and at a tertiary level, it has about 864 universities, 40,026 colleges and 11,669 institutes that cater for 3.57 million tertiary students. To address these issues *The Right of Children to Free and Compulsory Education Act*, which was sanctioned on 1st April 2010, encourages students to attend school (Government of India, Gazette of India, 2009). The Act requires all private schools (except minority institutions) to reserve 25% of places for poor and disadvantaged children (to be reimbursed by the state as part of the public-private partnership plan). Children are admitted into private schools based on caste-based reservations. It also prohibits all unrecognised schools from practising, and makes provisions for no donations or capitation fees and no interviews of the child or parent for admission (Nanda, 2017).

The Union Budget determined an outlay of Rs 79,685.95 *crore for the education sector for the financial year 2017–18, an increase from Rs 72,394 crore in 2016–17, a 9.9% rise (Nanda, 2017). According to the same report, of the total outlay, Rs 46,356.25 is for the school sector and the rest for higher education. *Sarva Shiksha Abhiyan*, the flagship central scheme for the universalisation of school education, has been given Rs 23,500 crore. The mid-day-meal programme has been allocated Rs 10,000 crore, up by Rs 300 crore from the last budget (Nanda, 2017). *crore is 10 million rupees (Rs).

In India, education is controlled by each state as well as centrally through the government in Delhi. Each state has its own Board of Education and is also controlled by an organisation under the central government, namely the Central Board of Secondary Education (CBSE), that is responsible for conducting the public exams for Classes X and XII. In addition, for curriculum-related matters including the designing and printing of textbooks, each state has a State Council of Educational Research and Training (SCERT) while, for the country, there is the National Council of Educational Research and Training (NCERT) (Sharma & Sharma, 2015). Besides this, the Council of Indian School Certificate Examination (CISCE) offers an Anglo-Indian pattern of school education in India and conducts three examinations at Classes X, XII, and for Vocational Education (CVE, Class/Grade 12). To cater for the needs of students who cannot undertake regular schooling, the National Open School or the National Institute of Open Schooling (established by the Government of India in 1989) provide opportunities to undertake public exams after studying through distance mode (Sujatha, 2002). Other than this, several religious boards also exist in India. Currently-e-learning has developed rapidly in India to enhance possibilities through education and, due to its large population, India has become the second largest market for e-learning after the United States of America.

Science Education

In India, education is divided into six major stages beginning with pre-school (age group 2–5 years), primary school (age group 6–10 years), and secondary school (age group 11–18 years). Science is taught individually at lower secondary level as an integrated whole rather than as a compartmentalised discipline (Ghosh, 2014). Discipline-oriented teaching and learning commences at XIth and XIIth standards, corresponding to the age group of 16–18 years. While curriculum is common to all students, without specialised subjects, until Class X, students select specific streams (science, humanities, commerce or vocational courses like pharmacy) only at the higher secondary levels (Class XI–XII) (Manna, 2017).

In recent years the trend has been to provide increased content to students through the simple reading of textbooks and answering text-based questions. The over-burdening of the science syllabi is regularly legitimised by referring to the overwhelming amount of new content being created and stating that the syllabi need to grow to keep up with the times. The use of laboratories starts in secondary school, only after middle school, and teachers find that they lack the time to conduct demonstrations as more emphasis is on completion of the syllabus (Chunawala & Natarajan, 2012). Students are not encouraged to learn content through participation in hands-on activities and, as a consequence, they need to memorise facts to pass exams (Science Academies to The Honourable Prime Minister of India, 2017). Any change to either the over-burdened science curricula or rote learning is seen as a weakening that will negatively influence India's competitiveness (Manna, 2017). The introduction of science education as an arrangement of facts to be presented goes against the very premise of science as a creative and dynamic approach to explaining the world.

With the introduction of education for all through programs like *Sarva Shiksha Abhiyan* and *Right to Education*, the education of children up to the age of Class VIII has become a reality. However, a review of the curricula and pedagogical practices of science teachers in India suggest that the ultimate aim of science teaching is to produce scientists who have all the facts learnt through memorisation (Science Academies to The Honourable Prime Minister of India, 2017). The syllabus is dominated by compartmentalised sections of different branches of science and the content has been extended to cover more at an early age. No effort is made to make the content more practical by providing opportunities for hands-on learning. Thus, the emphasis remains on the product and not on the process (Science Academies to The Honourable Prime Minister of India, 2017).

STEM

The term STEM (science, technology, engineering, and mathematics) has become a catch cry for many countries of the Western World, in particular the United States, where the acronym was coined, the United Kingdom and Australia, where millions of dollars have been poured into developing STEM. Businesses and governments have argued that STEM will solve a multitude of 'big problems', prevent countries from entering into recession and help in maintaining their global competitiveness (Blackley & Howell, 2015). Whilst these claims seem excessive, there is a STEM skills shortage and the demand of STEM-skilled graduates is predicted to increase over time (Beede et al. 2011). Whilst there is widespread agreement that STEM will solve major problems and millions of dollars continue to be spent on STEM initiatives, there is a little consensus of the types of skills that are valuable and how they can best be developed in classrooms. In this chapter the term STEM skills are recognised as twenty-first century skills. It is noted that various terminologies are currently used to capture, organise and name this cluster of competences including 'twenty-first century skills', 'key competencies' (OECD, 2005), and 'soft skills'. 'twenty-first century skills' is widely used, but many argue that the skills and capabilities referred to were important well before the twenty-first century, while also noting that with rapid change, century-long milestones are inappropriate.

Table 1 Comparison of twenty-first Century Framework (Partnership 21, 2008), the International Society of Technology Education (ISTE) (2016, 2017), and the UNESCO pillars of education (United Nations Educational Scientific and Cultural Organisation, 2017)

21st century competencies	ISTE standards	UNESCO
	Empowered Learner: leverage technology to take an active role in choosing, achieving and demonstrating competency in learning goals, informed by learning sciences	**Learning to know**: to provide the cognitive tools required to better comprehend the world and its complexities, and to provide an appropriate and adequate foundation for future learning **Learning to do**: to provide the skills that would enable individuals to effectively participate in the global economy and society **Learning to be**: to provide self-analytical and social skills to enable individuals to develop to their fullest potential psycho-socially, affectively as well as physically, for an all-round 'complete person **Learning to live together**: to expose individuals to the values implicit within human rights, democratic principles, intercultural understanding and respect and peace at all levels of society and human relationships to enable individuals and societies to live in peace and harmony
	Knowledge Constructor: curate a variety of resources using digital tools to construct knowledge, produce creative artefacts and make meaningful learning	
	Digital Citizen: Students recognise the rights, responsibilities and opportunities of living, learning in an interconnected digital	

(continued)

Table 1 (continued)

21st century competencies	ISTE standards	UNESCO
Creativity and Innovation • Use a wide range of idea creation techniques, create new worthwhile ideas • Elaborate, refine, analyse and evaluate ideas to improve and maximize efforts • Be open and responsive to new and diverse perspectives; incorporate group input and feedback • Demonstrate originality and inventiveness in work and understand the real-world limits • View failure as an opportunity to learn; creativity and innovation is a long-term, cyclical process of small successes and frequent mistakes • Act on creative ideas make a tangible and useful contribution to the field	**Innovative Designer**: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful or imaginative solutions	
Critical Thinking and Problem Solving • Use Systems Thinking analyse how parts produce outcomes in complex systems • Make Judgments and Decisions • Effectively analyse and evaluate evidence, arguments, claims and beliefs • Synthesise and make connections between information and arguments • Interpret information and draw conclusions based on analysis • Reflect critically on learning experiences and processes • Solve different kinds of non-familiar problems in conventional and innovative ways • Identify questions clarify various points of view better solutions	**Computational Thinker:** Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions	

(continued)

Table 1 (continued)

21st century competencies	ISTE standards	UNESCO
Communication • Articulate thoughts and ideas effectively using oral, written and nonverbal communication skills in a variety of forms and contexts • Listen effectively to decipher meaning, including knowledge, values, attitudes and intentions • Use communication for a range of purposes (e.g. to inform, instruct, motivate and persuade) • Utilise multiple media and technologies, and know how to judge their effectiveness a priori as well as assess their impact	**Creative Communicator**: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats and digital media appropriate to their goals	
Collaboration • Demonstrate ability to work effectively and respectfully with diverse teams • Exercise flexibility and willingness to be helpful in making necessary compromises to accomplish a common goal • Assume shared responsibility for collaborative work, and value the individual contributions made by each team member	**Global Collaborator**: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally	

In Table 1 we considered these competencies by bringing together the 21st century competencies based on the *21st Century Framework* (Partnership 21, 2008), the International Society of Technology Education (ISTE) (2016) standards for students and for pre-service teachers (2017), and the UNESCO pillars of education (United Nations Educational Scientific and Cultural Organisation, 2017).

STEM in India

STEM Education has gained a considerable amount of attention in recent years (Narasimha, 2008). Due to its size and capacity, India creates large numbers of researchers in all areas of the STEM fields and professions (The World Bank, 2018). In the last decade, many STEM training organisations have been created, offering STEM programs to school students, graduates and as in-service courses to teachers.

Through these STEM programs students are engaging in hands-on learning in robotics, where they investigate and apply basic concepts like wheels, rigging, machines and systems; using advanced science labs with 3D printing; tinkering labs; and producer space labs.

Recent examples of initiatives in STEM education include:

1. *Innovation in Science Pursuit for Inspired Research* (INSPIRE) program, sponsored and managed by the Department of Science and Technology, for attracting young talent to the exciting creative pursuit of science as a career option in order to build the required critical human resource pool for strengthening and expanding the Science and Technology system and Research and Development base in the country. The INSPIRE Scheme consists of three components: (a) *Scheme for Early Attraction of Talents for Science* (SEATS), (b) *Scholarship for Higher Education* (SHE) and (c) *Assured Opportunity for Research Careers* (AORC). The target is to enrol 2,000,000 school children in the age group of 10–15 years, offer INR 5000 per child as scholarships and spread the awardees countrywide (Innovation in Science Pursuit for Inspired Research, 2017).
2. *Kishore Vaigyanik Protsahan Yojana* (KVPY) is an on-going national program of fellowships in basic sciences, initiated and funded by the Department of Science and Technology, Government of India, to attract exceptional and highly motivated students to pursue basic science courses and research careers in science (Kishore Vaigyanik Protsahan Yojana, 2017).
3. *Homi Bhabha Centre for Science Education* has been made the country's nodal centre for Olympiad programs in mathematics and science. The program aims at promoting excellence in science and mathematics among pre-university students (Olympiads: Homi Bhabha Centre For Science Education, 2017).
4. *NITI Aayog* (National Institution for Transforming India), Government of India has established the Atal Innovation Mission (AIM) as an initiative to promote innovation and entrepreneurship across India. It has been based on a study of the innovation and entrepreneurial needs of India for the years ahead (Atal Innovation Mission, 2018).

STEM and Gender

Many women and girls around the world are excluded from participation in science and technology activities by poverty and lack of education (at all levels), or by aspects of their legal, institutional, political and cultural environments. In 2007 the UNESCO publication, *Science, Technology and Gender: An International Report*, stated that there was a positivity about the levelling of the science and technology playing field, with both gender equality and education being part of a United Nations General Assembly resolution and the UNESCO Sustainability Goals (SDGs). So, why then in 2017 are young women still so poorly represented in research and in science, and in STEM research especially? (United Nations Educational Scientific and Cultural Organisation, 2007, 2017). This research program, not just in India but also in Indonesia and Australia, focused on developing the confidence and competence of young female pre-service teachers who worked with both male and female primary students. The female researchers and Indian female academics provided valuable role modelling (Chapple & Ziebland, 2018).

A **Makerspace** *Approach*

The turn of the twenty-first century signalled a shift in the types of skillsets that have real, applicable value in a rapidly advancing world. Makerspaces are increasingly being heralded as opportunities for learners to engage in creative, higher-order problem solving through hands-on design, construction, and iteration (European Union, 2015). Employers are reporting that graduates who are able to solve problems and be critical and creative thinkers will be more versatile and more agile in a rapidly changing world (United Nations Educational Scientific and Cultural Organisation, 2017). This has resulted in a number of new standards being produced and disseminated that focus on skills and knowledge application rather than knowledge acquirement (Partnership 21, 2008; The International Society of Technology Education (ISTE), 2016).

'Makerspace' has been developed organically from online *Hackspace* (Copyright © 2016 London Hackspace Ltd.) or *FabLabs* (Copyright © 2015 Fab Foundation) to an actual physical place termed a 'Place for Making' or Makerspace (Smith, Hielscher, Dickel, Söderberg, & van Oost, 2013). Originally the Makerspace consisted of workshops of artists creating individual artefacts which extended into knitting or crocheting circles and subsequently into schools.

Table 2 Points of difference between traditional Makerspaces and the Makerspace approach (Blackley et al., 2018)

Traditional Makerspace—recreational activity	Makerspace approach—targeted learning activity
Makers create their own communities	Makers are organised into pre-determined communities
Makers choose materials at their own discretion	Makers are provided with a base-level kit of materials
Makers envisage and produce individual, often unique, artefacts	Makers are shown a completed base-level and operational (as appropriate) artefact and are challenged to construct a similar artefact
Makers are not mentored	Makers are mentored (not instructed)
Makers might evaluate their artefact	Makers are scaffolded to evaluate their artefact
Makers might be cognisant of underlying science, technology, engineering, mathematics or other concepts	Makers are made aware of related underlying science, technology, engineering, mathematics or other concepts in line with curriculum documents

The project reported in this book chapter employs a 'Makerspace approach' (Blackley, Rahmawati, Fitriani, Sheffield, & Koul, 2018) that is distinct from Makerspace in its original intent.

> A Makerspace approach sees makers situated in groups of peers mentored through a scaffolded approach to produce a designated artefact. Whilst there is the opportunity for modifications and the demonstration of individuality the goal is for each maker to end up with a complete and workable artefact that they can take home. This approach also has a definite and explicit focus upon the science, engineering and technology concepts involved, and the mentors are encouraged to use correct terminology as they question and support the school students. (Blackley et al., 2018, p. 231)

Table 2 highlights some of the key differences identified in a targeted Makerspace learning activity.

Research Design

The methodology for this project was interpretivist qualitative research, based on an exploratory case study to examine pre-service teachers' engagement with and reflections on a Makerspace approach to creating STEM artefacts—in this case *Wiggle bot, Catapult and Pipeline activities.* The research employed a paper-based survey (see Appendix A) of PSTs' engagement, followed by open-ended questions and observations to verify PSTs' engagement and reflections during the project. The survey items and open-ended questions were developed and validated during the previous research conducted in Indonesia and in Western Australia by the research team (Sheffield & Blackley, 2016).

Context

The participant pre-service teachers (PSTs) were studying and living on campus at the Regional Institute of Education (RIE), Bhopal. The RIE is a constituent unit of the National Council of Educational Research and Training (NCERT), New Delhi, and focuses on teacher education and other educational requirements of the States of Chhattisgarh, Goa, Gujarat, Madhya Pradesh, Maharashtra and UTs of Dadra and Nagar Haveli, Daman and Diu. All students and some faculty live on the extensive campus in Bhopal. The Demonstration Multipurpose School on the campus is a laboratory school for Grades I to XII where students are taught by experienced primary and secondary teachers, thus providing an environment for PSTs to hone their teaching skills. The students in Grades V and VI included both boys and girls and worked in groups with a PST supporting them to complete the activities.

Pre-service Teachers

Fifty-two female pre-service teachers undergoing the dual B.Sc., B.Ed. program and studying in their 3rd and 5th semesters volunteered to participate in the workshops. Each PST was given a STEMinist t-shirt so that they would feel that they were part of this global project and called themselves STEMINISTS. All PST participants were living on the campus at RIE, Bhopal and the classes for that week had been cancelled to enable them to participate in the program.

Method

The Indian STEMinist program was implemented as shown in Table 3, with the phases following the Reflective STEMinist Identity Formation Model (Fig. 1) that was developed from the *Reflective Identity Formation Model* (Sheffield & Blackley, 2016). The phases for each activity were split, with phases one and two completed at RIE on the first two days in Bhopal, and then phases three and four completed at the Demonstration Multipurpose School.

Reflective STEMinist Identity Formation Model

Whilst it is acknowledged that in this instance the model only supported the 'development' of STEMinist identity during this short programme, the more substantial long-term STEMinist project in Australia did contribute to the ongoing development of pre-service teachers' identity as STEMinists. This model includes two iterations

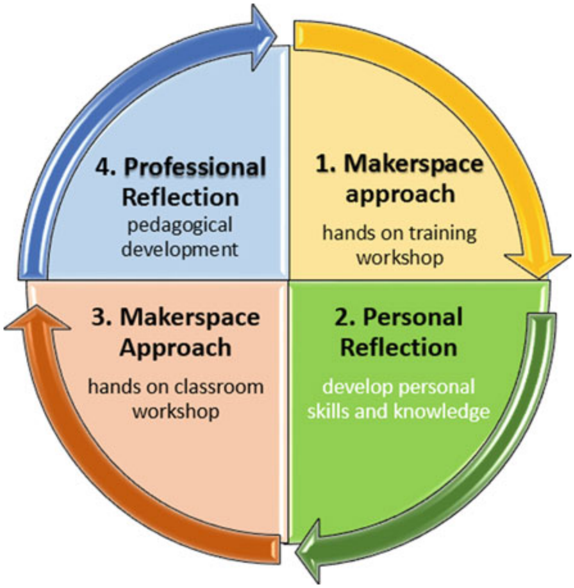
Table 3 Description of dates of the activities in the Indian STEMinist Program

Day	Activities	Where	With whom
14/11/17 9–11.30 am	Wiggle bot 1. Makerspace 2. Personal Reflection	RIE, Bhopal	Pre-service teachers (PSTs) University teacher educators (TEs)
14/11/17 2–4 pm	Catapult 1. Makerspace 2. Personal Reflection	RIE, Bhopal	Pre-service teachers (PSTs) University teacher educators (TEs)
15/11/17 9–12 am	Pipeline 1. Makerspace 2. Personal Reflection	RIE, Bhopal	Pre-service teachers (PSTs) University teacher educators (TEs)
PST Survey			
16/11/17	Wiggle bot 3. Makerspace	Demonstration Multipurpose School	Pre-service teachers (PSTs) students of classes V and VI
14/11/17	Catapult 3. Makerspace	Demonstration Multipurpose School	Pre-service teachers (PSTs) students of classes V and VI
17/11/17	Pipeline 3. Makerspace 4. Professional Reflection	Demonstration Multipurpose School	Pre-service teachers (PSTs) students of classes V and VI
PST Focus Group Interview			

of *the Makerspace Approach* phases. First, a technical, hands-on workshop was presented where pre-service teachers came together to engage in making a series of STEM-related artefacts using a Makerspace approach. They were scaffolded by the Australian research team and the Indian classroom teachers and academics who showed them models as examples and asked questions about their designs rather than provide them with a recipe style step-by-step approach. In this way the pre-service educators were required to make an artefact, similar to the one shown, using trial and error, seeking advice from their peers and using their science knowledge. The first *Makerspace approach phase* was followed by a *Personal Reflection* where pre-service teachers were encouraged to think about how they were demonstrating their STEM skills by answering questions about the underpinning science, mathematics, technology and engineering concepts and to consider how they learnt during the process.

The PSTs were exposed to a pedagogical approach to integrate science, mathematical, technological and design processes that also incorporated probing questions, creativity and innovative thinking, problem-solving, communication and collabora-

Fig. 1 Reflective STEMinist Identity Formation Model



tion. Through the second *Makerspace Approach* phase, the PSTs created a hands-on technical workshop in a primary classroom, mentoring the school students to successfully create the same product, through a trial and error approach, whilst provided with a model. The second *Makerspace Approach* phase was followed by a *Professional Reflection* during which data were collected on the primary students' engagement and understanding of the STEM concepts as well as on pre-service students' reflections about their enactment of the mentor role and what they had learned about themselves as teachers (Blackley, Sheffield, Maynard, Koul, & Walker, 2017).

Data Collection

Three sets of data were collected:

- Three sets of anonymous surveys with 52 pre-service teachers
- Three sets of anonymous survey data from 160 primary school students
- Focus group interviews from 52 pre-service teachers.

Data were collected from all 52 participating pre-service teachers in the form of an anonymous survey of open-ended questions that they completed after they had undergone the first part of the activities, and before they were in the classroom working with the students. This survey asked the PSTs to comment on their engagement in the Makerspace Project, aspects that they felt were most valuable and the issues that challenged them (Appendix 1). The pre-service teachers also completed a group focus interview as the reflection part of phase four. The items included the following:

(a) How do you feel about experiences as a student? (b) How do you feel about your experiences as a teacher? (c) List an interesting 'teaching moment', and (d) List three attributes that typify twenty-first century competencies.

Data Analysis

The open-ended responses from the surveys were analysed using an aggregation of responses into themes; including problem solving, creative and critical thinking, applied knowledge and collaboration. This was undertaken by an Australian researcher and an Indian researcher independently and the results compared and moderated to ensure consistently. The group responses were analysed in the same way using the aggregation of responses into categories (Elliott & Timulak, 2005).

Findings

The STEM activities were enacted around the *Reflective STEMinist Identity Formation Model* with phases one and two of all three activities in the first two days of the program and phases three and four in the schools of the third and fourth days of the four-day program. The phases are described in more detail in Table 4.

Wiggle Bots

1. *Makerspace Workshop*—The provided material included a paper cup approximately 9 inches deep, a DC motor, batteries, battery holder, felt tip pens, an ice-cream stick and a wooden clothes peg. The pre-service teachers were given

Table 4 Outline of activities and phases

Activity	Phases
Wiggle bot	1. *Makerspace Workshop* 2. *Personal Reflection* 3. *Makerspace Workshop in the classroom*
Catapult	1. *Makerspace Workshop* 2. *Personal Reflection* 3. *Makerspace Workshop in the classroom*
Pipeline	1. *Makerspace Workshop* 2. *Personal Reflection* 3. *Makerspace Workshop in the classroom* 4. *Professional Reflection on all three activities*

one hour to prepare the Wiggle bot and were shown a video to assist them. The PSTs made the initial Wiggle bot, however, most of them were not stable when the power was connected. The PSTs were asked questions about stability, design refinement, and the angle of the legs and how they were positioned.

2. *Personal Reflection*—After the activity, the PSTs were asked questions about the science, mathematics, and engineering involved. The science was focused on the centre of gravity, circuits, chemical energy (battery), electrical energy, kinetic energy, height and mass, and the length of the wire from the battery holder to the motor. The mathematics included angles, length, and geometry (equilateral triangles). The engineering dimensions considered design evaluation and refinement to improve the pattern of movement, and positioning of the battery holder and the legs.
3. *Makerspace Workshop in the Classroom*—The PSTs were sent to designated classrooms where they demonstrated their Wiggle bots to small groups of primary students and encouraged and supported them to make their own versions. Each student was provided with the necessary materials that the PSTs had prepared the day before. The students were very excited to see the working Wiggle bots and enthusiastically engaged in the process of making one for themselves. Initially, the students were somewhat confused as to how to proceed, however, with regular intervention from the PSTs in the form of probing and prompting questions that made them think about the next steps, the students could work out how to progress with their projects. It was an enjoyable and engaging activity for all the students. Some of the students found that the Wiggle bots were not stable and kept falling; they were asked to find the reasons for this and to make necessary adjustments so that their Wiggle bot was stable when connected to the power supply.

Catapults

1. *Makerspace Workshop*—The PSTs were shown a photo of the completed catapult and provided with the necessary materials to construct their own using twelve ice-cream sticks, a plastic spoon and several rubber bands. The PSTs initially worked alone on making their catapults however they later realised that they needed support from their colleagues when trying to attach the rubber bands. Once the PSTs had made their catapults, they selected one person to represent them in a competition to see how far they could project an object. The winner was the PST whose catapult threw a tiny rolled paper ball the greatest distance. The PSTs suggested improvements to their catapults to make the projectiles go further; some of these were related to the construction of the catapult whilst others were related to the operation of the catapult.
2. *Personal Reflection*—When asked about the science concepts, the PSTs discussed potential energy, elasticity, projectile motion, elastic potential energy, kinetic energy, mass, and distance. The mathematics that they suggested was

about angles, units of measurement, distance, control of variables, number of trials, and recording data. For engineering aspects, they concentrated on evaluating and refining the design of the catapult to maximise the distance the projectile travelled.

3. *Makerspace Workshop in the Classroom*—The PSTs demonstrated their catapults to the students and asked them to make their own using twelve ice cream sticks, one plastic spoon and rubber bands. Initially, it was difficult for the students to understand the design of the prepared catapult, however later, when PSTs instructed them to observe the catapult carefully and asked them questions, for example (a) Why do you think there is a base? (b) Why do we need a structure like the two triangles? (c) What is the purpose of the two parallel sticks; the students began making the catapults and experienced success. The students found that it was difficult to tie the rubber bands on their own and asked the PSTs to help them, but the PSTs encouraged them to collaborate with each other. Some of the students who were not able to understand the design were asked more questions for example (a) What should be the position of the sticks? (b) Why is it necessary to tie the rubber bands? (c) What happens if the rubber bands are loose? In a relatively short period of time most of the students had completed their catapult. Students were encouraged to have a competition where the winner would be the students whose catapult projected small rolled up piece of paper the greatest distance. After the competition, those whose catapults projected a lesser distance were asked to hypothesise reasons for this and if possible to improve on the design so that their catapult would throw the load a greater distance. It was noticed that the time taken by the students to complete both projects was less than the time taken by PST's when they were given the tasks. All the students enjoyed the activity and wanted these types of activities to be held frequently in the school.

Pipeline

1. *Makerspace Workshop*—The construction of the pipeline was stipulated by a design brief, and specifications were set for both the PSTs and the primary school students. The pipeline had to be 2 m long, with a right angle, three bends with angles of more than 30° through which a golf ball and ping pong ball could pass without obstruction. The PSTs were provided with six A3 sized sheets of paper and the whole pipeline was to be able to stand alone without any support at the height of a chair, i.e. 50 cm.

The PSTs, in groups of five, were required to plan their design, according to the guidelines, in one hour. They were told that a competition would be held at the end. All of the groups made unique designs, and for most of the groups both the balls travelled through the pipeline without incident, with only two groups out of the twelve groups being unable to make the balls travel through the pipeline successfully.

2. *Personal Reflection*—The science in this activity included the friction of the balls in the paper tubes, the importance of gravity as the balls must travel unaided and the issues around mass and the kinetic energy of the light ping pong ball and the golf ball. The mathematics concepts included measurement, angles, diameter, time, the use of a protractor, and time scheduling. The engineering aspect was the design brief and project plan, as well as evaluation and modifications.

When asked what type of questions they could pose to encourage the students in the classroom, the PSTs suggested that they could ask the students to indicate (a) the 90° angle; (b) How do you use a protractor? (c) At what height should the first pipe be positioned so that the ball has maximum impact of gravity and where should the other angles be made? (d) How will the pipeline stand up? (e) What could be done to keep the model stable? And (f) Why can't we have a system of open pipelines?

3. *Makerspace Approach in the Classroom*—On the fourth day, the PSTs were to instruct the students in making the pipeline. This time there were six students and two PSTs in each group. Each class had five to six groups and they had to make a pipeline which was at least 2 m long, had one 90° angle and at least 3 angles more than 30°. The pipeline should be designed so that a ping pong ball and a golf ball can pass-through it one after the other. Each group was provided with one full-size sheet of art paper and three A3 sized sheets of paper to construct their pipeline. They were also provided with cello-tape, a ruler (1-m-long), a protractor, a ping pong ball and a golf ball.

All the PSTs and students were engaged in the project. This was a more difficult project for the students as there was no model in front of them to view. Initially, the PSTs also found it difficult to explain to the students what was expected of them as the students were not aware of measurement and angle in a practical, hands-on sense, although they had studied it in their textbooks. Gradually, as the project proceeded, the students started thinking and reasoning, with the help of the questions from the PSTs, and prepared individual components of the pipeline and checked whether the balls passed through them. Some found that the balls were not moving and rectified the mistakes in the design. Later they tried to join the sections with cello-tape and measured the angles with the protractor. Then they tried to make the balls pass through the pipelines, although many were unsuccessful. However, when the students became frustrated the PSTs motivated them, urging them to find reasons why the balls became stuck and then use these to refine their designs.

The pipeline activity needed a lot of patience on the part of the PSTs, and resilience and perseverance on the part of the students. After about two hours, most of the groups were ready for the competition in which a moderator launched the balls through the opening in the pipelines. The groups were graded on the length of the pipeline, the 90° angle, three angles of more than 30°, and the instances when the ping pong and the golf ball passed through the pipeline. In each class there was at least one group whose balls did not pass all the way through the pipeline. They were asked to rework the design.

4. *Professional Reflection*—The PSTs did not reflect at the end of this activity due to time constraints, however, they reflected with their student groups about all the activities: Wiggle bot, Catapult and Pipeline. The PSTs then reflected together on their pedagogical approaches and what they had learned.

The primary school students commented to the PSTs that they had learnt how to concentrate and demonstrate teamwork, sharing and cooperation. They had learnt to respect other's view points and that there could be more than one way of completing a task. When asked what was the science involved in the activities, the students were able to identify force, friction and gravity, and they learnt how to make a connection between the source of power in the Wiggle bots and its motion patterns. They also identified that if they put the pens inside the paper cup, the pattern created on the paper was different than when they were attached outside the cup, understanding that this design variance impacted on the outcome. The position of the motor and the battery holder also affected the movement and students sought to apply this knowledge (Harlen & Qualter, 2009). In all of the activities, the students correctly identified the mathematics that they had used, including measurement of length, angles, and diameter, and they used a protractor to determine the correct angle.

For the pipeline specifically, when asked about the engineering involved, the students discussed the key aspects of design, they considered why the pipes were enclosed and not left open and recognised that these conversations could have real-life applications. They could see that if the pipes are left open the water supply could be contaminated, mosquitoes would have ready access to breed and vast quantities would be lost due to evaporation. The students also volunteered that, during the course of the preparation of the pipeline, they found that the greater the slope of the pipe the more easily the balls moved. The students said that, when joining the pipes together, they needed each other's help which taught them that, when working together, tasks become easier and stated that 'friendships become stronger'. They also stated that they had learnt that each person had strengths and weaknesses, so they needed to accept friends as they are as no one is perfect. They also expressed that they understood that every activity was an opportunity to learn and they should try to make the most of it.

Survey Data

After the PSTs had experienced all of the activities, and prior to them going to the schools, they participated in a survey (see Appendix 1). The first question asked the PSTs to indicate what aspect of the project they had enjoyed. All the PSTs responded positively that they had enjoyed the project and some offered multiple perspectives (as a consequence $N = 79$ from a participant group of 52) (Table 5). Twenty-six percent of PSTs reported that they enjoyed working with their peers, with one PST commenting, 'I enjoyed, because it was teamwork, and also it was interesting, something which I haven't done before'. Twenty percent of PSTs enjoyed the hands-on aspect of the

Table 5 Response to question 'What was the aspect that you most enjoyed?'

Category	*N*	%
Collaborating	20	26
Applying science and maths	9	11
Problem solving	11	14
Hands on activities	16	20
Pedagogical skills	4	5
Engagement	10	13
Creativity	9	11
Total	79	100

learning, with one PST stating that, 'It is the most creative learning project. It really teaches us to use the science, technology, engineering and mathematics in our daily life', adding that the hands-on approach was unique and that she could see all the STEM aspects and how they work together.

When the PSTs were asked about the aspects they felt were most valuable, they reported that working in their groups and solving problems together had been the most valuable experiences (Table 6). Twenty-nine percent of comments in this category related to collaboration and a further 23% to problem-solving, with one PST summing up, 'Problem-solving and collaboration to solve a problem with cooperation and team is most valuable'. Another student acknowledged, 'Forcing us to think on our own. Motivating constructivism helps us to apply our knowledge and learn from ourselves'. So the PSTs were able to see the value of the activities in supporting their learning. It was interesting to note that one PST looked at the bigger picture and commented, 'The concept of STEMinist was the most valuable because it supported the women to come forward and show their skills', which articulated the ultimate goals of the Australian researchers.

Finally, PSTs were asked to document the major challenges they experienced and 30% spoke specifically about issues with the Pipeline activity in including the number and size of the angles that were in the specifications and the use of the

Table 6 PST responses to the question 'What aspects did you find the most valuable?'

Category	*N*	%
Collaborating	22	29
Applying science and maths	13	16
Problem solving/critical thinking	18	23
Hands on activities	6	7
Pedagogical skills	7	8
Time management	2	2
Creativity	10	13
Other	2	2
Total	80	100

Table 7 PST response to the question 'What aspects did you find the most challenging?'

Category	*N*	%
STEM activity specific issues	20	30
Applying science and maths	8	12
Problem solving/critical thinking	13	19
Collaboration	8	12
Resource scarcity	6	9
Time management	6	9
Creativity	3	4
Other	3	4
Total	67	100

materials (Table 7). They commented on the time constraints for all the activities and how having limited resources was also an issue. A very articulate student summed up the challenges of the activities, 'The project required High Order Thinking Skills. We had to think out of the box and that our teammates had their own opinions'.

Interview Data

The focus group responses were categorised into two sets: (1) the PSTs as learners (Table 8), and (2) the PSTs as educators (Table 9). With regard to the first category, they generally outlined how much they enjoyed doing the simple activities and how much easier they perceived learning was in this context. They reported being interested and motivated, and could see value in using a hands-on approach to apply their STEM knowledge.

With regard to the PSTs as educators, they articulated the challenges they had with trying to facilitate learning through a constructivist approach rather than a didactic, more positivist approach. They could see value in this method of teaching but were challenged by some of the behavioural issues that arose when students were motivated, excited and enjoying their learning. It was interesting to note that, by working with small groups of students, the PSTs were able to see that students had a range of skills and abilities and learning styles that they recognised and needed to consider. One group commented, 'We saw that different students had different ideas and approaches to finish the given tasks and they have their own creativity in it which was very interesting to see as a teacher'.

A focus group discussion was held with the PSTs at the conclusion of the week and they were asked about their experiences. All unanimously reflected that the performance of the students was better than their own, as the students first, took less time in preparing the projects and second, they had better ideas and made projects with unique and creative designs. The PSTs noted that creativity was not dependent on academic achievement. They said that they had asked the students who were

Table 8 The focus group interview questions from the PSTs collated around them as learners

Criteria	Group 1	Group 2	Group 3	Group 4	Group 5
How do you feel about experiences as a student	Applying STEM, integrating, problem-solving, hit and trial (keep trying all possible ways), teamwork, understanding everyone's perspective	Learning anything theoretically is not as effective as learning practically. It really builds up our concepts and helps in gaining effective knowledge about the subject. Learning something practically is easy and fun thing to do then to just mug up (sic)	The activities were quite interesting, and we enjoyed a lot while doing them. We applied STEM at the same time. We performed every activity in different forms the focus was to learn the concept behind every activity with some creative ideas	Interesting, learn management skills, got to know where we lack, twenty-first century skills we learn through them	We were very curious about doing the activities, use of STEM in existing stuff which are even simple was enjoyable, we learned about the importance of teamwork and motivating each other throughout any process/activity as it will increase the progress of the project, time management is ultimately the most important
What was the best thing you discovered as a student	My patience with numerous failures and attempts, keeping cool, being focused on the task	The best thing we discovered was the victory they have earned. They were really motivated with the reward. The feeling of success	In every activity we discovered different concepts involving STEM	It is important to apply the concepts that are presented in the books	Uses the concepts of STEM in basic things which are fun and used in daily activities. Experiential learning gives best results

Table 9 The focus group interview questions from the PSTs collated around them as educators

Criteria	Group 1	Group 2	Group 3	Group 4	Group 5
How do you feel about experiences as a teacher	Directing students towards goal not telling directly, motivating students, understand their point of view, handling them delicately	To handle the students is the most difficult part of being a teacher. Not to help them and to let them do things on their own as a teacher to keep them motivated is a big deal	Doing these activities with students was a major task. Understand the concept behind the activities and motivate them to do the activities by themselves. As a teacher we enjoyed a lot and also learned new ideas from students	Frustrated at times, felt responsible, it is important to let the student discover the science on their own. It is important to teach 21st century skills through activities	Taking the knowledge to the level of the student is the most important part of the activity
List an interesting 'teaching moment'	Learning with them or from them, innocent fun	To make them distribute the work amongst them for better performance, to make them work in teams, to not to help them	Completion of tasks successfully students cheer up	When a student has already reached to the conclusion and has understood everything while few still struggling with what things were about we have to take a different path to make them learn	We saw that different students had different ideas and approaches to finish the given tasks and they have their own creativity in it which was very interesting to see as a teacher

(continued)

Table 9 (continued)

Criteria	Group 1	Group 2	Group 3	Group 4	Group 5
What was the best thing you discovered as a teacher	Students can be creative and innovative without telling instructions, when my students finally succeeded in the task	Girls said if we do something with determination and concentration we can do anything. It really touched our hearts	Practical use of every theory students learn the concept clearly	Students observe teachers very carefully in class and teachers should be aware of the behaviour with students as it affect them a lot	Every child has different learning styles and different creativity level which is best in their own way
3 attributes in terms of 21st century competences	Patience, understanding students Listening to students	Practical knowledge, discipline, endurance and patience	Constructivist approach, motivation positive re-enforcement	Motivates, gender equity social equity	Motivation Management Team work

considered the 'best' in the class but found that these students were not always very creative. Some students who were not talented academically surprised them, both with the speed of completion and the way in which they developing strategies from situations in which they were initially challenged. Many also worked towards making designs that were different from the ones that were shown to them. The PSTs queried them about whether the alternate design would work but the students were keen to try them and further refine their ideas. Many were sure that the alternate design would be better and would fulfil the specifications.

They also learnt that the students were more eager than the PSTs to try something different when they were stuck, and they recognised that there can be other approaches. The PSTs were continually reflecting on how to support the students to apply their understanding of concepts in the particular situation and how to make the activity more meaningful. The PSTs learnt that, through engaging activities, learning can take place and creativity can be developed. They also learnt that patience, guidance, perseverance and a desire to genuinely help the students learn are key aspects that need to be developed as an effective teacher. They also determined that students need to be regularly motivated and that constructive criticism helps in the positive growth of the students. Finally they expressed the opinion that the activities were a wonderful method for developing 21st century competencies such as cooperation, reasoning, time management, problem solving, team work, precision, accepting defeat and rejection, thankfulness, collaboration, respect for others, listening and accepting others viewpoints, accepting what is useful and neglecting what is unwanted, concentrating even when facing failures and learning from mistakes and rectification.

Conclusions

In this chapter, we posit that the STEM components of these projects, whilst significant, are less significant than the development and demonstration of twenty-first century skills or competencies. In Table 9 we considered these competencies by aligning them with the twenty-first century competencies, based on the *21st Century Framework*, and we noted that there are overlaps in these competences, positing that teaching these key skills or competencies can only be completed efficiently by engaging teachers and pre-service teachers in transformative professional learning. The importance of implementing a different approach which allows pre-service teachers more time and opportunities for reflection, as they demonstrate and develop their own skill sets which they can then help develop in their primary students, is stressed.

As stated in the background, Indian classrooms have a very positivist pedagogical approach to teaching and learning, and this STEM program, with a hands-on integrated approach which strongly focused on twenty-first century competencies, really challenged the PSTs' teaching identity. The program has helped develop a deeper understanding of authentic learning, collaboration and problem-solving skills that can be developed through the Makerspace approach. With regard to the content aspects of science, technology, engineering in the form of design, and mathematics, the PSTs considered these aspects as they participated in the projects themselves in Phase 1 and 2; and in their pedagogy in Phases 3 and 4. The PSTs understood that, although they may have an understanding of the content and concepts, passing it on to the students through activities cannot be done until certain teaching and behaviour management skills are acquired. Lastly, they themselves experienced that, through conducting an activity, various values and skills can be developed among the students.

The fact that they initially struggled with the tasks themselves, gave the PSTs greater awareness of the challenges that the primary students may experience and, therefore, they were able to develop strategies to support them. Moreover, at its inception, the STEMinist program was designed to empower young female primary pre-service teachers, by building their confidence and competence in STEM education, and also to inculcate them into a wider, global community of supportive women. Throughout the developing and developed world women continue to be underrepresented in STEM professions. By engaging and empowering primary PSTs, however, this program may encourage and excite young female students to embrace STEM at school and continue through the pipeline into the STEM professions (Chapple & Ziebland, 2018).

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