ISBN: 978-81-941567-9-6
January 3-6, 2020

DEVELOPING 21ST CENTURY SKILLS AND STEM KNOWLEDGE IN PRE-SERVICE TEACHERS USING MAKERSPACE

Rachel Sheffield* and Rekha Koul
School of Education, Curtin University, Australia
R.Sheffield@curtin.edu.au

This paper explores the use of a STEMinist Makerspace Project to promote engagement and learning of STEM content and support the development of 21st century competencies in female Indian pre-service teachers. Using a 'Makerspace Approach' these pre-service teachers participated in a series of activities: firstly, as 'students' creating their own artefact supported through a scaffolded approach by educators; then reflecting on these experiences and developing supporting questions; taking their artefact and the materials to school and using the questions to scaffold and support primary school students to create their own artefacts. Pre-service teachers reported on their increased engagement using the Makerspace approach and cited their development of 21st century competences, listing; collaboration, critical and creative thinking, problem solving and applying knowledge, as valuable to their own learning.

BACKGROUND

The Workshop, *Cross-Nation Capacity Building in Science, Technology, Engineering and Mathematics (STEM) Education* was held in the Regional Institute of Education (RIE), Bhopal, with female pre-service teachers. The pre-service teachers participated in three Makerspace-type STEM activities that provided them with opportunities to create and learn through practical experiences.

Fifty-two pre-service teachers (PST) participated in three Makerspace-type STEM activities that provided them with opportunities to create and learn through practical experiences. The focus of this paper is the evaluation of the STEM Makerspace programs, including the development of female pre-service teachers' skills, both personally and professionally, through the workshops and classroom activities. The research questions were:

1. How effective was the Makerspace Approach in supporting pre-service teachers' engagement in STEM education?

2. What 21st century competencies did the pre-service teachers identify and demonstrate as a consequence of their participation in the project?

LITERATURE REVIEW

A Makerspace Approach

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). The Makerspace approach is different from a more traditional Makerspace. Traditional Makerspace has developed from a combination of online *Hackspace* (Copyright © 2016 London Hackspace Ltd.) or *FabLabs* (Copyright © 2015 Fab Foundation) and an actual physical place termed a *Place for Making* or *Makerspace* (Smith, Hielscher, Dickel, Soderberg, & van Oost, 2013). Makerspace sees artists and inventors coming together to create individual and collaborative original artefacts and can be anything from technology-rich items to knitting and craft materials.

The Makerspace approach sees makers situated in groups mentored to create a designated artefact. The artefact is presented to the makers who create and modify it to make it individualised and then take it 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, Rahmawati, Fitriani, Sheffield, & Koul, 2018, p. 231). Table 2 below highlights some of the key differences identified in a targeted Makerspace learning activity.

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 & 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

Table 1: Points of difference between traditional Makerspaces and the Makerspace approach

Education in India

There are more than 1.5 million schools with over 260 million students enrolled and at a tertiary level it has about 864 universities, 40026 colleges and 11669 institutes that cater for 3.57 million tertiary students (Mattyasovszky, 2017; United Nations Development Programme [UNDP], 2015). Education is controlled by each state as well as centrally through the government in Delhi and each state has its own Board of Education controlled by the Central Board of Secondary Education (CBSE), and responsible for conducting exams for Classes X and XII. 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) There are a number of STEM initiatives currently being implemented in Indian classrooms through a range of institutions and industry focused projects (Kishore Vaigyanik Protsahan Yojana, 2017, December 26).

21st Century skills

"Skills have become the global currency of 21st century economies" (OECD, 2012, para. 5), and therefore it is important to consider not only student knowledge but also students' skills. The globalisation and internationalisation of the economy along with the rapid development of Information and Communication Technologies (ICT) are continuously transforming the way in which we live, work, and learn (Voogt & Roblin, 2012, p. 299). The skills and abilities required will shift to more social and emotional skills and more advanced cognitive abilities such as logical reasoning and creativity (Author, 2019). (United Nations Educational Scientific and Cultural Organisation [UNESCO], 2007) suggests that education policies and curricula must aim to incorporate a broad range of skills and competencies necessary for learners to successfully navigate the changing global landscape and that the curriculum needs to ensure that students develop attributes and skills necessary for a rapidly changing society and workplace. Various terminologies are currently used to capture, compartmentalise and name this shifting cluster of competences, including *21st century skills* or *21st century learning* (Griffin & Care, 2014; Kids, 2015), *key competencies* (OECD, 2005), *soft skills*, *new collar jobs* (Bughin et al., 2018) and *entrepreneurial skills* (Foundation for Young Australians [FYA], 2015). The term *21st century skills* is widely used, but many argue that the skills and capabilities referred to were important well before the 21st century, while also noting that with rapid change, century-long milestones are inappropriate (Voogt & Roblin, 2012, p. 301). For the purpose of this research the term transversal competencies from UNESCO is adopted and this includes the range of skills encompassed in the categories in Table 2.

UNESCO Transversal Competencies (2015)	21stCentury Competencies (2008)
Inter-personal skills	Critical Thinking and Problem Solving
Critical and innovative thinking	Creativity and Innovation
Inter-personal skills	Communication, Collaboration
Global Citizenship	

Table 2: Comparison of 21st Century Frameworks

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 creating STEM artefacts – in this instance Wiggle bot, Catapult and Pipeline activities (Steminists, n.d.). The Wiggle bot artefact was a basic circuit, an upturned paper cup, with peg and pop stick (balance) with three pens as legs. Catapult required perseverance as PSTs received pop sticks, a plastic spoon and elastic band to create the model. PSTs were required to make the models from pictures and a video, without instructions, employing their theoretical knowledge and trial and error. The Pipeline was a team task where the group must build an enclosed pipeline over 2 metres long with 4 angles using only paper and tape which a small ball could travel down unaided. All the activities incorporated aspects of science, mathematics, engineering and technology. The research employed a paper-based survey of PSTs' engagement, including open-ended questions and observations to examine PSTs' engagement and reflections around their learning. The survey items and questions were developed and validated during previous international research (Sheffield & Blackley, 2016).

Context

The participant pre-service teachers (PSTs) were studying and living on campus at the Regional Institute of Education (RIE), Bhopal, a constituent unit of the National Council of Educational Research and Training (NCERT).

Pre-Service Teachers

Fifty-two female pre-service teachers studying in their 3rd and 5th semesters volunteered to participate in the workshops and were given STEMinist t-shirts and became part of the STEMinist community through the Facebook and website.

METHOD

The Indian STEMinist program was implemented as shown in Table 3 below, with the phases following the Reflective STEMinist Identity Formation Model (Figure 1) that was developed from the Reflective Identity Formation Model (Authors, 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.

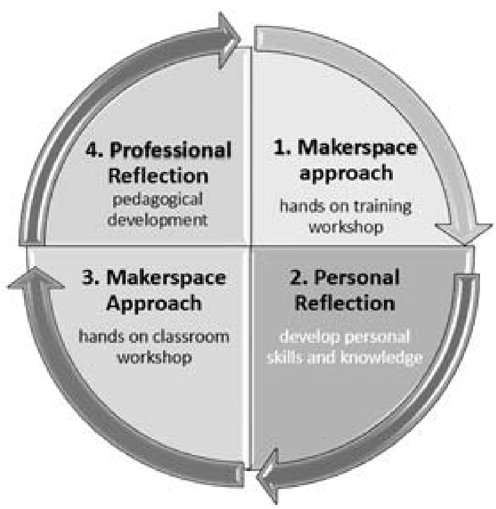

Figure 1. Reflective STEMinist Identity Formation Model

Data Collection

Anonymous surveys from 52 female pre-service teachers were collected as Part of Phase 2.

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 two researchers 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).

RESULTS

After completing the activity workshops before working with primary students the pre-service teachers were asked about their enjoyment.

All the PSTs said that enjoyed the project and some offered multiple perspectives (as a consequence N = 79 from a participant group of 52) Table 3 shows their responses to questions

What was the aspect that you most enjoyed?, What aspects did you find the most valuable?, What aspects did you find the most challenging?

Category	Responses (%)		
	Enjoyable	Valuable	Challenging
Collaborating	26	29	30
Applying science & maths	11	16	12
Problem Solving	14	23	19
Hands on Activities	20	7	12
Pedagogical skills	5	8	9
Engagement	13	2	9
Creativity	11	13	4
Other	0	2	4
Total	100	100	100

Table 3: PSTs' Responses

"I enjoyed, because it was teamwork, and also it was interesting, something which I haven't done before" was the response by one PST with 26% reporting that they enjoyed working with their peers. Another stated "It is the most creative learning project. It really teaches us to use the science, technology, engineering and mathematics in our daily life" with 20% of the PST listing a hands-on approach as a significant outcome. 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". PSTs were able to see the value of the activities in supporting their learning with a PST commenting, "Forcing us to think on our own. Motivating constructivism helps us to apply our knowledge and learn from ourselves".

Finally, PSTs documented 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 materials. They commented on the time constraints for all the activities and how having limited resources was also an issue.

Finally, in the PST were asked to consider the learning and make two comments about what they had learnt. These responses were aggregated and categorised into categories and these are presented in table 6. The majority of pre-service teachers, 66% articulated that they had developed a range of transversal competencies through the process of using the Makerspace Approach and creating artefacts. They reported that 32% developed collaborative and communication skills and were able to develop team skills. A smaller number 8% were focused on how the Makerspace workshops helped them to manage their time more effectively.

Category		Examples	%
General non specific		I would love any such amazing and full of life opportunity once and many more times.	6
Time Management		Keeping time limitation and unity	8
Pre-service teachers			
Self	General Knowledge	learn science technology and engineering	4
	General Skills	HOTS (High Order Thinking Skills)	9
	Communication	communicating our opinions to others in teams	12
	Collaboration	learning about communicating with others properly	20
	Problem solving	Thinking capability, problem solving skills	9
	Creativity	Creativity and collaboration	6
Teaching	General Teaching comments	Pedagogy- To teach learning by practical activity	3
	(School) Student learning focus	How to make the (school) students think (by asking questions)	13
	Total		100

Table 4: PST students to provide 2 new things that they have learnt related to your learning (N = 108 from a participant group of 52)

CONCLUSION

The Makerspace Approach in supporting pre-service teachers' engagement in STEM education

The pre-service teachers engaged enthusiastically in the STEM projects and made the Wigglebot, Catapult and Pipeline in the hands-on workshop, they reported that they found the workshops helpful and were very engaged.

"It is the most creative learning project. It really teaches us to use the science, technology, engineering and mathematics in our daily life" a pre-service teacher reported. They found the hands-on tasks engaging and were able to articulate the STEM knowledge they had learnt in these relatively simple artefacts. The pre-service teachers all reported enjoying the project, however, some also articulated issues that were challenging. When Collaboration was focused on, a total of 20% of PSTs articulated that it was the most engaging aspect of the projects and then 29% reported it to be the most valuable aspect to the activities but then 12% reported it as the most challenging aspect and one that they often struggled to manage.

Pre-service teachers identified a range of 21st century competencies as a consequence of their participation in the project

The PSTs learnt that, through these engaging activities, learning can take place and creativity can be developed. They also expressed the opinion that the activities were a wonderful method for developing 21st century competencies also known as transversal 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. They could clearly see how these skills were important to their learning and how the skills were an important part of the Makerspace alongside the content knowledge. PSTs also articulated that patience, guidance, perseverance and a desire to genuinely help the students learn are key aspects that need to be developed for them to become effective teachers.

ACKNOWLEDGEMENTS

This project was funded by **Australian National Commission for UNESCO Grants Program 2016-17** though the Commonwealth of Australia Department of Foreign Affairs and Trade (DFAT).

REFERENCES

Blackley, S., Sheffield, R., Maynard, N., Koul, R., & Walker, R. (2017). Makerspace and Reflective Practice: Advancing Pre-service Teachers in STEM Education. *Australian Journal of Teacher Education, 42*(3).

Blackley, S., Rahmawati, Y., Fitriani, E., Sheffield, R. & Koul, R. (2018). Using a Makerspace approach to engage Indonesian primary students with STEM. *Issues in Educational Research*, 28(1), 18-42. http://www.iier.org.au/iier28/blackley.pdf

Sheffield, R., & Blackley, S. (2016). Makerspace in STEM (MIS) for girls: An Exploratory Study. *Proceedings of the International Society for Technology in Education (ISTE) 2016 Conference and Expo*. Denver, Colorado: US. (Conference proceedings)

Bughin, J., Hazan, E., Lund, S., Dahlström, P., Wiesinger, A., & Subramaniam, A. (2018). Skill shift: Automation and the future of the workforce. *McKinsey Global Institute. McKinsey & Company*. Retrieved from https://www.mckinsey.com/featured-insights/future-of-work/skill-shift-automation-and-the-future-of-the-workforce

Elliott, R., & Timulak, L. (2005). Descriptive and interpretive approaches to qualitative research. In J. Miles

& P. Gilbert (Eds.), *A handbook of research methods for clinical and health psychology* (Vol. 1, pp. 147-159). Oxford, England: Oxford University Press.

European Union. (2015). Horizon 2020: The EU framework programme for research and innovation. Retrieved from https://ec.europa.eu/programmes/horizon2020/en

Foundation for Young Australians [FYA]. (2015). *The new work order*. Retrieved from https://www.fya.org.au/wp-content/uploads/2015/08/The-New-Work-Order-FINAL-low-res-2.pdf

Griffin, P., & Care, E. (2014). *Assessment and teaching of 21st century skills: Methods and approach*. New York, NY: Springer.

National Education Association (2019). P21 Partnership for 21st century learning. National Education Association Retrieved from http://www.nea.org/home/34888.htm

Kishore Vaigyanik Protsahan Yojana. (2017, December 26). Kishore Vaigyanik Protsahan Yojana. Retrieved from http://www.kvpy.iisc.ernet.in/main/index.htm

Mattyasovszky, M. (2017). The largest countries in the world. Retrieved from https://www.worldatlas.com/articles/the-largest-countries-in-the-world-the-biggest-nations-as-determined-by-total-land-area.html\

OECD. (2005). *The definition and selection of key competencies*. Retrieved from https://www.oecd.org/pisa/35070367.pdf

OECD. (2012). OECD launches Skills Strategy to boost jobs and growth. Retrieved from https://www.oecd.org/education/oecdlaunchesskillsstrategytoboostjobsandgrowth.htm

Sharma, S., & Sharma, P. (2015). Indian higher education system: challenges and suggestions. *Electronic Journal for Inclusive Education, 3*(4), 6.

Smith, A., Hielscher, S., Dickel, S., Soderberg, J., & van Oost, E. (2013). Grassroots digital fabrication and makerspaces: Reconfiguring, relocating and recalibrating innovation? *Science and Technology Policy Research SWPS 2013-02, 2*. Retrieved from https://www.ioew.de/uploads/tx_ukioewdb/Smith_Hielscher_Dickel_S%C3%B6derberg_Oost_-Grassroots.pdf.

Steminists. (n.d.). Makerspace projects. Retrieved from https://steminists.weebly.com/makerspace-projects.html

United Nations Development Programme [UNDP]. (2015). *Human development report*. Retrieved from http://hdr.undp.org/sites/default/files/2015_human_development_report.pdf

United Nations Educational Scientific and Cultural Organisation [UNESCO]. (2007). *Science, technology and gender: An international report*. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000154045

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of curriculum studies, 44*(3), 299-321.