Investigating learning in a STEM makerspace: India case study

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Abstract. In recent years Makerspace has developed within both online (Hackerspaces) and physical ‘spaces’ (Makerspaces) and provides students with opportunities for more open-ended learning experiences where they can ‘make’ and create. In open making teacher cannot control or direct the learning and with a crowded curriculum of facts and knowledge there is little time for open-ended making in schools. In India there is a strong focus on more traditional ways of teaching and learning including a transmissive approach of instruction from teacher to student. This paper posits that using a ‘directed’ or scaffolded Makerspace Approach to create a carefully defined product enables teachers or facilitators to bridge the gap between highly structured and open-ended pedagogical approaches to embed measurable STEM (science, technology, engineering and mathematics) knowledge and 21st century competencies into their program. The paper examines how a Makerspace impacts on the learning and engagement of primary school students in India and explores the creating of several artefacts including: Wigglebots, Catapults, and Pipelines. The collected data demonstrated primary students’ engagement in, and enjoyment of, the Makerspace program. This paper develops and trials a STEM theoretical framework which resulted from the comparison of several existing frameworks to incorporate content knowledge and 21st century skills.

Keywords: STEM education, Makerspace Approach, primary school students, India, 21st Century competencies, transversal competencies

1. Background
The STEMinist Project is an ongoing international project, which uses a structured approach to create specific STEM products. It develops and mentors STEMinists, in-training primary teachers (PST), who support primary students to create a series of artefacts that incorporate STEM skills and knowledge. The approach developed and used in this project is called the Makerspace Approach, which has been used internationally (including India) to support primary students.

This paper reports on the implementation of the STEMinist project in an Indian Primary School and examines the students’ engagement and their reported learning. It is based on analysis of students’ scientific drawings to demonstrate their understanding of underpinning scientific knowledge and uses categories including breadth, depth, extent, and skill mastery. The paper also examines the current thinking about the encapsulation of STEM, including the notion of interwoven content and skills through an embedded context and introduces the Infused STEM theoretical framework. This framework is based on the adaption, by Lowrie, Leonard & Fitzgerald of Kemmis’s Practice Architectures framework [1, 2]. It considers the progress of STEM and STEM education in India and offers a valuable
mechanism for analysing students’ understanding of content through drawing. It posits the use of Makerspace as a space that can encourage ‘disruptive’ pedagogical change in the classroom.

### 1.1. Makerspace Approach

In recent years Makerspaces are increasingly being heralded as opportunities for learners to engage in creative, higher-order problem solving through hands-on design, construction and iteration [3]. In previous generations there were many incidental and ad hoc tinkering activities in homes and communities. This then was lost as risk averse practices and new hobbies and activities became more popular. The resurgence in the need to Make and Tinker came around the same time that employers reported they were seeking graduates able to solve problems, be critical and creative versatile and agile thinkers ready for a more rapidly changing world [5]. This has resulted in a number of new frameworks, and standards being developed that focus on skills and knowledge application rather than knowledge acquisition [6, 7].

As previously stated, ‘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 [8]. These Makerspaces have been considered to be places where makers could create any unique item that their imagination, skills and capacity allowed thus engendering exciting and engaging places to experiment and play. There is still much variation in the definition of Makerspaces and some of the most interesting is the use of language to capture the essence of the space. For example Peppler and Bender [9] point to “a growing culture of hands-on making, creating, designing, and innovating… [and] a do-it-yourself (or do-it-with-others) mindset that brings together individuals… making nearly anything”. (p. 23).

![Figure 1](image-url)  
*Figure 1*. Expansion of Types of Makerspace adapted from the work Vuorikari R, Ferrari A and Punie Y [10] (Sheffield, Koul and McIlvenny, in press)

Authors [11] defined Makerspace as ‘the space, resources, and opportunity required for a collective to make an artefact or product that is often unique to the maker yet can be based on a common theme and even a common pattern’. It is posited here that the Makerspace as an Approach which balances a
slightly more directed approach with some intentional learning outcomes could provide an interesting
and engaging context for Indian primary students to learn STEM content and start to develop
competency in the transversal skills or competencies.

STEM Education
Across the world in recent years there has been a move towards increasing STEM education. Initially
this filled a perceived demand from business and industry, which indicated that a population with
advanced STEM skills and knowledge would generate solutions to many key issues of the 21st century
[12]. Many countries stipulated the need for increased numbers of skilled graduates in STEM, who
would keep abreast of technological advances [13]. In India and across the world, industry experts have
determined that creating more graduates in STEM is vital for continued economic success [14].
Consequently, the STEM pipeline - the creation of STEM graduates, developing from primary to
secondary school and through to tertiary - becomes important.

In many countries insufficient school students are studying in STEM disciplines which has prompted
increased attention towards the engagement of students in these subjects, and consequently, led to the
creation of STEM education [15]. This definition of STEM, has, however generated a complexity and
confusion of its own as it has ‘morphed’ into many iterations with associated acronyms like STEMM,
iSTEM and STEAM [16]. The broadest definition of STEM is the study of any of the disciplines -
Mathematics, Science, Engineering and Technology - separately or together, and its narrowest definition
is iSTEM or integrated STEM, which has components of all four disciplines integrated in equal
quantities [3, 17]. The STEM definition on which this paper is premised is the partial or total authentic
integration of one or more of the STEM discipline areas. There is an acknowledgement, however, that
this definition is not comprehensive, (discussed further below), and that STEM also needs to include a
range of identified skills [18].

Improving the flow of the STEM education pipeline in developing and developed countries has
proven to be a challenge [19]. Advocates argue that a more integrated approach is a more authentic view
of the world and adopting this approach would lead to more engaged and interested students [20].

With all the definitions of STEM that are proposed there is little consideration that in most countries,
high schools or secondary schools teach and, more importantly, assess STEM subjects separately, thus
reducing the incentive to focus on a more integrated and authentic STEM approach [17]. This has been
addressed in some countries, for example in the US, where engineering education has become
incorporated into science education [20]. In countries such as India, however, there is no engineering in
the curriculum and the subjects in senior secondary are still taught and assessed in separate silos. Thus,
Despite the intentions of major stakeholders in ‘STEM education’ there is little evidence of greater
systemic change [21].

Until recently, India’s focus has been on systemic programmes to improve levels of general
education across the board, and ensure all students have the opportunity to attend school to learn [14]. It
was legislated in 2009 that children had the right to education and, therefore, wealthier schools needed
to set aside 25% of their enrolments for children from much poorer areas [22]. Whilst this was an
admirable idea, the results have been mixed; many students who enter the school system from poorer
areas are unable to compete educationally with their wealthier class mates. The Wall Street Journal
noted:

“Business executives say schools are hampered by overbearing bureaucracy and a focus on rote
learning rather than critical thinking and comprehension. Government keeps tuition low, which
makes schools accessible to more students, but also keeps teacher salaries and budgets low. What’s
more, say educators and business leaders, the curriculum in most places is outdated and disconnected
from the real world” [23].

It also observes that thousands of Indian graduates are consequently unable to gain employment as
foreign companies shun Indian workers and choose to recruit employees from other countries [22].
There are moves to review the quality of Indian education and create a more agile workforce who are more creative and better problem-solvers, aligned with the identified needs of industry. It is recognised that science, mathematics and engineering skills and knowledge are needed and, consequently, the importance of science and STEM education in India is highlighted. A Science Academies 2017 report proposed a science and technology s initiative comprising a 3-year action plan, a 7-year strategy and a 15-year vision for achieving ‘scientific self-sufficiency’ ([24], p. 2). The report goes on to assert that India must ‘assume scientific leadership in the world, and that there has to be a 'sustainable scientific support revolution' ([24], p. 2; [25]).

In the meantime, there are pockets of innovative STEM projects that are being enacted in isolated classrooms, and outside classrooms in libraries, workshops, and Makerspaces [26]. In India there is evidence nationally of such projects through the creation of science education centres (for example Homi Bhabha Centre for Science Education) and also in a number of new initiatives including the Innovation in Science Pursuit for Inspired Research (INSPIRE) program sponsored and managed by the Department of Science and Technology [27, 28, 29].

STEM Concepts vs Skills

More broadly than just in India, there seems to be conflict between the narrow view in schools that STEM is focused on the more content-based domains within subjects of Science Technology, Engineering and Mathematics and a wider view of STEM in the real world emerging from economic and industry policy. This wider perspective argues that STEM represents more than a collection of content knowledge in science, technology, engineering and mathematics; that it is “a point of discontinuity, of society asking for a qualitative change in the objectives of education undertaken in the domain of the sciences” ([2], p. 7).

Table 1. Comparison of 21st Century Framework [6], the International Society of Technology Education (ISTE) [7], and the UNESCO transversal competencies [5].

| 21st Century Competencies (2008) | ISTE Standards (2016) | UNESCO Transversal Competencies (2015) | British Council skills (2017) | STEM Practices (Lowrie et al., 2018; [2]) |
|---------------------------------|----------------------|--------------------------------------|-----------------------------|----------------------------------------|
| Empowered Learner | Intra-personal skills | Citizenship | Digital Literacy | Global Citizen |
| Knowledge Constructor | Global citizenship | Critical and innovative Thinking | Creativity and Imagination | |
| Digital Citizen Innovative Designer | | | | Imagination and creativity |
| Critical Thinking and Problem Solving Communication | Creative communicator | Inter-personal skills | Critical thinking and Problem Solving | Thinking Critically |
| Collaboration | Global collaborator | | Collaboration and communication | Working with others |

In more traditional systems e.g. in the 19th century, it was content knowledge that was greatly valued and considered to be of vital importance to graduates. With the advent of the internet and the escalation in the creation of and access to information, the status of content knowledge has, however, been relegated to the ‘back benches’ due to its ‘anytime, anywhere’ ubiquitous nature. What has now become the true currency of education systems is the far less tangible suite of key employability and professional skills that are today considered, not only essential for the workplace but are part of the focus of STEM education. These include 21st century skills [6], a strong digital focus through the International Society of Technology Education (ISTE) [7] and the widely encompassing UNESCO transversal competencies [5]. These represent skills and strategies, not limited to STEM education, but
which are widely used to measure a potential employee’s capacity to be successful in the 21st century. It can be seen here that there is a set of key skills which we will call competencies that are consistent in all these frameworks; these include problem-solving, creativity, communication, collaboration and citizenship. In this paper these identified skills will be referred to as 21st century or transversal competencies (Table 1).

This project sought to measure students’ capacity against UNESCO’s transversal competencies (see Table 2) which encapsulate a range of skills including critical and innovative thinking (which encompass creativity); inter-personal skills (which focus on working with others and providing leadership and collegiality); intra-personal skills (which focus on developing resilience, integrity and engagement) and; finally, global citizenship (which looks at tolerance of others and respect for the environment). The Indian students’ responses in three activities where they had to create artefacts, were considered through the lens of the transversal competencies domains and sub-domains. This ‘drilling down’ to the micro-level allowed for a closer interrogation of specific behaviours which, when combined reflect the broader description of the competence.

STEM Theoretical Framework

There are a number of integrative models and frameworks that consider how the subjects, science, technology, engineering and mathematics, S.T.E.M converge. This model uses the acronyms Stem, where the focus is on Science, or SteM, where the focus is on the context of Science and Mathematical knowledge. Whilst these models acknowledge that the STEM content knowledge can be in varying amounts and need not be represented in a completely integrated way, our research determined that this framework is too simplistic to measure the other more intangible aspects of students’ learning using a more holistic approach. Lowrie et al. [3] drew on the work of [2] practice architecture to develop a STEM practice framework which they noted ‘represents a qualitative shift in purpose from the content bound traditions of science, technology, engineering and mathematics education towards developing a greater capacity to use practices in diverse STEM ([3], p.7). This model is presented in Table 3.

Although we believe this represents a new view of STEM and one that ‘connects it to the real world not on the basis of disciplinary content, but through the diverse use of the sayings, doings and relating of STEM practice’ ([3], p. 12), we believe this represents too great a paradigm shift for educators who are still required to work within subject-siloed, assessment-based curriculums. The Worldly Perspective developed from decades of research in integration by Rennie, Venville, & Wallace [4], provides a balance between the integrated curriculum and the separate areas of Science, Technology, Engineering and Mathematics and considers the developing perspective from Local or ‘me’ to Global or ‘us’. Whilst this model provides greater depth it fails to consider the importance of the transversal competencies or skills that are so prominent in the articulated needs of industry and the wider community.

Table 2. UNESCO transversal competencies including sub-domains [5]

| Domains                | Sub-domains                                      |
|------------------------|--------------------------------------------------|
| Critical and innovative thinking | creativity, entrepreneurship, resourcefulness, application skills, reflective thinking, reasoned decision-making |
| Inter-personal skills  | presentation and communication skills, leadership, organizational skills, collaboration, initiative, sociability, collegiality |
| Intra-personal skills  | self-discipline, engagement, perseverance, self-motivation, compassion, integrity, commitment |
| Global citizenship     | awareness, tolerance, openness, respect for diversity, intercultural understanding, ability to resolve conflicts, civic/political participation, conflict resolution, respect for the environment |

Whilst it does consider integration holistically, it was felt that what was required was a more clearly articulated framework that considers how students develop the key skills or competencies. From our research we predict that, if a blend of these frameworks could be created which articulated STEM
content knowledge in total or partial integration, and the development of transversal competencies, this would create a more detailed theoretical framework.

**Table 3. STEM Practices ([2], p. 12)**

| The initiation into practices of the individual | Medium | The fostering of desired practice architectures |
|-----------------------------------------------|--------|-----------------------------------------------|
| **Individual world**                          |        |                                               |
| Ideas, Problem finding, Finding and validating evidence, Questioning, Proposing Designing and building, Exploring and challenging | Thinking, communicating | Understanding how the world works, Finding ways to make the world better |
| Methods, Generating ideas, Processing information, Encoding & decoding information Using appropriate language and vocabulary Using tools to produce artefacts Thinking critically | Designing, building, experimenting, modelling | A sustainable, economy community development, enjoying the world |
| Values                                        |        | The world we share                            |
| Curiosity, Integrity, Imagination, Creativity | Working with others | Participation in democracy, custodianship of nature, innovation and improving human lives |
| Teamwork                                      |        |                                               |
| Persistence                                   |        |                                               |

The STEM Infused Theoretical Architecture model provides the STEM context and content for the project or problem being investigated and, in a similar way, the Worldly Perspective *infuses* the STEM as a context providing content that is not measured in the amount of science or mathematics or engineering addressed, but as the context for the depth of the learning for the student. It acknowledges the move from a local to a more global perspective in the same way as that both the Worldly Perspective and the STEM Practices and incorporates the authentic use of content and skills to support student learning. This is it is envisaged that this theoretical framework supports student learning and we should be able to see the fusion in the findings of the research undertaken in India through the Makerspace Project described herein.

**Figure 2.** The dimensions of the Worldly Perspective: balance between disciplinary and integrated knowledge and connection between local and global contexts [4].
Figure 3. STEM Infused Theoretical Architecture Framework.

Figure 4. Transversal Competencies as outlined in the STEM Infused Theoretical Architecture framework.

Research Aims
The research aims for this paper were:

1) To develop and trial a theoretical model that can encapsulates the STEM learning of the Indian students using a Makerspace

2) To measure, through self-reflection, the effectiveness of activities to improve the engagement and interest of students,

3) To assess students’ science and mathematics knowledge and understandings as a consequence of the activities;

4) To identify the transversal competencies students demonstrated as they participated in the activities.
2. Research Design

Context

Pre-service teachers from the RIE (Regional Institute of Education) supported Makerspaces being created in four classes of (a total of) 126 primary students in grades V and VI at the Demonstration Multipurpose School (DMS). DMS is on the same campus and serves as a laboratory school for RIE, Bhopal. It caters for students from grades I to XII taught by experienced primary and secondary teachers.

Using a Makerspace Approach (Figure 1 above) student makers were situated in groups and mentored by pre-service teachers who were exposed to these activities a week earlier (in the context of the STEMinist programme) to produce designated artefacts which included Wigglebot, Catapult and Pipeline. There were three workshops, one to create each artefact.

Table 4. Showing the Phases of the Makerspace Approach.

| Phase                          | Description                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|
| Phase 1 Exposure              | The student makers are presented with an artefact, they examine how it       |
|                               | works and its key components, and then, using their own materials, they      |
|                               | make the artefact.                                                          |
| Phase 2 Engagement and        | The STEMinists support students by asking focusing questions and students    |
| Experimentation               | are encouraged to work collaboratively with their peers in their groups.      |
| Phase 3 Evaluation and        | The students demonstrate their working model, they were encouraged to       |
| Extension                     | refine and adapt their designs to improve the functionality of the model.    |

The three activities undertaken and the three artefacts produced were

- Wigglebot – demonstrated electrical circuits and symmetry (pyramid) in the pen/legs
- Catapult – demonstrated kinetic energy, force and distance and included measurement and design engineering
- Pipeline – demonstrated gravity, friction the students worked in groups

3. Methodology

The methodology for this project was based on interpretivist mixed method approach research, which considers how events unfold and what they are about [30], based on an exploratory case study to examine school students’ engagement with, and reflections on, a Makerspace Approach to create STEM artefacts. A purpose specific survey was used after each activity; thus, validation of the surveys was beyond the scope of this study.

Three paper-based surveys were deployed in English* to examine school students’ engagement and participation. Using Likert scale questions all surveys asked students about their perceived engagement and their participation, and numerical values and pictures were used (5 = strongly agree to 1 = strongly disagree) and symbols (□□□□□ to □□□□□) and an open-ended question reflecting on their learning experiences, which examined in this paper.

In the Wigglebot survey students were asked about their scientific knowledge, in the Pipeline and the Catapult surveys students were asked about their science, mathematics and engineering knowledge in open-answer questions (e.g. ‘so, what was the science?’). As the medium of instruction in the DMS was English, it was decided to implement surveys in English. However, some students answered in Hindi and this was translated by a member of the research team who spoke the language. After the activities, students completed the survey. Students were asked to complete diagrams of all three activities, however, the only activity that was completed, analysed and then categorised, was the Wigglebot activity which has been presented here.
Data Analysis
The data gained from the surveys were analysed in three sections: (1) Likert-type responses to items from 1 (strongly disagree) to 5 strongly agree); (2) the free-text items, and (3) the participants labelled drawings.

**Table 5.** Statements included in the evaluation surveys.

| Statement |
|-----------|
| A I enjoyed the Makerspace activity. |
| B Working in a small group with a mentor helped me to complete the activity successfully. |
| C I can see that this activity uses science knowledge. |
| D I can see that this activity uses mathematics knowledge. |
| E I can see that this activity uses engineering knowledge. |

The frequencies of the Likert-type responses were collated (and the mean was calculated for each of the Items. Statements A and C were asked in all three surveys, whilst Statement B was only asked for the Wigglebot project, statements D and E were included in the Catapult and Pipeline survey as it was determined that there were more aspects of mathematics and engineering in these artefacts. For each of the Statements C, D and E students were asked to expand on their answer highlighting the concepts. These free-test sections were analysed using open coding: the text responses were read through by all three of the research team, and we then created tentative labels for chunks of data that emerged. Moderation was achieved by each member coding the samples and checking for inter-rater reliability – in this case it was 90% [30]. The surveys and open-ended questions were translated from a previous project conducted in Western Australia by Author [31-33].

**Table 6.** Examples of the drawing categories used to classify the Wigglebots.

| Description | Example |
|-------------|---------|
| 0 NIL       | Not labelled |
| 1 Breadth (B) Labelled diagram shows component parts of the Wigglebot; however, they are not evident as a system (i.e. do not indicate how the individual components work together) | ![Example](image1) |
| 2 Depth (D) Labelled diagram shows component parts of the Wigglebot and they are evident as a system. | ![Example](image2) |
| 3 Extent (E) Working artefact could be constructed using the diagram and labelling. | ![Example](image3) |
| 4 Mastery (M) Drawing of completed Wigglebot with labels showing connection that shows depth plus a caption. | ![Example](image4) |

The energy of motion, 2. Motor (dynamo), 3. Battery, and 4. Balancing by using markers

1. Markers, 2. Battery, 3. Motor (dynamo), 4. Propeller, and 5. The Wigglebot can work because of the chemical energy in the battery and dynamo turns into electrical energy, then it turns into motion energy. It can move for a long time because of the balance in its feet or markers
For the participants’ diagrams of the Wigglebots, labelling was categorised based on the work of Bowker [34] by identifying features that were privileged by the participants. Four categories emerged after two of the researchers and the research assistant trialled the scoring on the same sample [35]. It is deemed that providing students with opportunities to use drawings would provide an additional demonstration of their understandings [36]. The capacity for the use of multi-representations we posit, can reveal students’ misconceptions and therefore enhance teachers’ understanding. This work had been drawn from the seminal research by Krampen [37] who advanced four developmental areas linked to their approximate ages of which the Intellectual Realism (ages 5-8) and Visual Realism (ages 8-12 years) have been considered in the use of drawings for understanding [38]. The categories are described in Table 6.

4. Findings

Engagement of Students

The findings reported in this paper are based on the Makerspace student surveys where in each the focus was on student engagement and scientific knowledge, using triangulated data from the Likert-scale survey items, the free-text items, and in the Wigglebot case the students’ drawing of their artefact were also analysed. In each of the activities the students reported that they enjoyed making the Makerspace artefact with 96% of the students strongly agreeing they enjoyed the Wigglebot activity, this was 86% for the Catapult activity and then dropped to 73% in the pipeline activity. In the pipeline activity there were 12% of students who did not agree or strongly agree and therefore did not like the pipeline activity.

Table 7. Students’ Engagement and Content Identification for the Wigglebot, Catapult and Pipeline Activities Survey Responses (n = 125).

| Statement                                                                 | Strongly Agree | Agree | Disagree | Strongly Disagree |
|--------------------------------------------------------------------------|----------------|-------|----------|------------------|
| Wigglebot                                                                |                |       |          |                  |                  |
| I enjoyed the Makerspace activity                                        | 96             | 4     | -        | -                |
| Working in a small group with a mentor helped me to complete the activity successfully. | 89             | 9     | 1        | -                |
| I can see that this activity uses science knowledge.                      | 82             | 18    | -        | -                |
| Catapult                                                                 |                |       |          |                  |                  |
| I enjoyed the Makerspace activity                                        | 86             | 10    | 1.5      | -                |
| I can see that this activity uses science knowledge.                      | 73             | 22    | 1        | 4                |
| I can see that this activity uses mathematics knowledge. N=123            | 75.5           | 18    | 4        | 1.5              |
| I can see that this activity uses engineering knowledge. N=118            | 73             | 23    | 3        | 0.5              |
| Pipeline                                                                 |                |       |          |                  |                  |
| I enjoyed the Makerspace activity                                        | 73             | 13    | 2        | 2                |
| I can see that this activity uses science knowledge.                      | 66             | 21    | 4        | 2                |
| I can see that this activity uses mathematics knowledge. N=114            | 70             | 21    | 6.5      | 2                |
| I can see that this activity uses engineering knowledge. N=110            | 75.5           | 17    | 3.5      | 3.5              |

10
**Wigglebot**

When students were asked to describe what the science or mathematics contained in the activity the students produced a variety of answers with some students’ answers being categorised into one than one response criteria. When discussing the science in the Wigglebot 34% described the motion of the Bot in non-scientific language for example, when the markers were put at a height if fell later the height of the pens were reduced and then it did not fall (Student 121), whilst 28% used scientific language for example, force, fan, battery, and energy (Student 122). Twenty eight percent used scientific language to describe the movement of the Bot, for example, battery and motor gives energy that's why it is moving (Student 108). A further 10% made an unrelated comment.

**Table 8.** Frequency of the drawing categories used to classify the Wigglebots (n=126).

| Category       | %  |
|----------------|----|
| No drawing     | 2  |
| 0 NL           | 22 |
| 1 Breadth (B)  | 8  |
| 2 Depth (D)    | 33 |
| 3 Extent (E)   | 17 |
| 4 Mastery (M)  | 1  |

With the drawings, the students demonstrated a range of detail and explanation with 22% drawing a picture but not labelling the picture and 33% drawing the picture and adding detailed labels demonstrating that they can connect the observational drawing with the science knowledge about the circuit and the connection of the battery to make the motor spin.

**Catapult**

Although 95% of the students agreed or highly agreed they could see the science in the activity their responses were limited in their description of the catapult. A total of 34% commented on the movement using non-scientific language for example, ‘the paper ball goes far because of rubber band’ (student 119) whilst 32% had used more scientifically appropriate language for example, ‘transfer of energy’ (student 103). In the remaining categories there was 19% who just mentioned components of the catapult for example, ‘I enjoyed fixing the elastic band’ (Student 42) and the remaining students who put either no comment or a sentiment about liking science.

When students were asked about the mathematics that the project contained 52% of all the responses related to the angles that were created including square base and the triangular sides of the artefact. For example, ‘square formation. Different angle. Same size of triangles’ (Student 86) whilst 7% of students recognised the measurement in the activity ‘spoon distance. Distance of paper balls. shapes making.’ (Student 122). Within the cohort 24% listed some of the items as the mathematics either by counting them ‘it is made by sticks’ (Student 95) or by listing them ‘matchsticks, rubber band’ (Student 90). The remaining 15% either did not list a mathematics description or included a science concept, such as elastic energy, and this was not included.

When students were asked about the engineering in the catapult 38% focused on the construction aspect of the experiment for example, joining of stick and spoon with rubber band (Student 126), five percent just wrote randomly about engineering and a further 20% wrote statements that could not be related to process/design or engineering generally. Twenty two percent gave a real life engineering example for example, I used to real life this catapult to through (to throw) paper and small stone (Student 38). Finally, a further 10% did not respond or could not see any engineering in this project.

**Pipeline**

In coding for the science concepts 40% of the comments related to processes for example ‘the science concepts involved is ball go from upper level to lower level’ (Student 126) whilst 24% related to language for example ‘gravity’ (Student 81) whilst if students used scientific language to describe the process in an extended answer for example ‘the gravity is used in it. We see the power of gravity and
heavy thing can pass through fastly (sic) and lighter things can pass through slowly cause of gravity’ (Student 122).

When coding the Mathematics answers it was decided that the categories would reflect the key mathematics ideas, angles (simple and complex answers), measurement, and general comments and when the student did not identify any mathematics or left the section blank. There were 183 responses coded to students, which included 41% of comments about angles that were identified as simple for example ‘there are angles in the pipeline’ (Student 66) or more complex responses, 10% that included angles ‘three angles must been greater (sic) than thirty and one is right angle’ (Student 67). 33% of responses included measurements, whilst 8% per generally mathematics related and another 8% were either empty or nonsensical responses. Some students mentioned angles and measurement and therefore were coded in both sections. For example, this is a simple angle comment and measurement ‘measurement of angles and measurement of the length of the pipeline’ (Student 58).

When students were asked about engineering all the focus was on the process of creating the pipes and the majority (88%) discussed the activity using terms such as construction or the pipes or material (paper) were joined together. Ten percent could not identify engineering in the pipeline project and two percent wrote random comments. Three students (1.5%) recognised that there was planning and group work involved in the processes around engineering.

21st Century skills
The surveys used asked students to discuss the most interesting part of the activity and then these responses were classified into five major categories. Four of these categories; critical and innovative thinking, inter-personal skills, intra-personal skills and global citizenship were taken directly from the transversal competences and the remaining responses were categorised under Other. For all three activities over 50% of student responses determined that students were using the skills of resourcefulness, problem solving, creative thinking or decision making skills which are part of the Critical and Innovative Thinking domain from the transversal competencies. With the Wigglebot activity 75% of all the responses were related to the Critical and Innovative Thinking domain.

Table 9. The Critical and Innovative Thinking domain.

| Domains                  | Sub-domains                              |
|--------------------------|------------------------------------------|
| Critical and innovative  | creativity,                              |
| thinking                 | entrepreneurship, resourcefulness,        |
|                          | application skills,                       |
|                          | reflective thinking,                      |
|                          | reasoned decision-making                 |

Table 10. Percentage of students’ responses to survey question related to the most interesting aspect of the activity.

|                  | Critical and creative thinking | Inter-personal skill | Inter-personal skills | Global | Other |
|------------------|--------------------------------|----------------------|-----------------------|--------|-------|
| Wigglebot (n=132) | 75                             | 5                    | 2                     | -      | 21    |
| Catapult (n=130)  | 49                             | -                    | 27                    | -      | 24    |
| Pipeline (n=130)  | 50                             | 1                    | -                     | -      | 49    |

These results (Table 10) indicate students’ responses are highest in critical and innovative thinking and within this category there would seem to be a focus on the application of skills and to a lesser extent creativity related to the task. It was not unexpected that there were no responses in global citizen as
there were few opportunities for the students to demonstrate intercultural understanding and few
students mentioned they enjoyed ‘resolving conflict’. There were a high number of students who
expressed specific engagement and perseverance in the catapult activity demonstrating that this activity
had been difficult to create initially and in the Wigglebot five percent of students had commented on
working with their mentor or in a group but only one percent (2 students) mentioned this in the Pipeline
activity where students had been placed in groups and needed to collaborate to be successful. As the
Wigglebot was the first artefact this many have been why it was mentioned and in the Pipeline students
were more likely to mention that they did not enjoy the task or were unsuccessful.

5. Discussion
The effectiveness of the Makerspace approach in supporting primary school students’ engagement and
self-confidence in STEM education.
There was a universal agreement in the surveys about students’ enjoyment and engagement in the
creation of the artefacts in the Makerspace. Although the support of the activities dipped slightly in the
pipeline this was reflected in observations that not every group was successful in creating a pipeline that
met the design brief and therefore this may have explained why a few students reported that they did not
enjoy the activity.

The Makerspace provided students with the opportunity to complete hands on activities and share
them with their families. There was little evidence in the classroom that students completed hands on
activities besides some art work that was on the wall in one classroom, anecdotal conversations with
teachers also indicated that they had little supplies for (STEM) activities. Demonstrated content
knowledge did primary school students demonstrate as the consequence of the Makerspace approach.

Students all reported that they were able to identify the science, mathematics and engineering in the
three artefacts, 100% of the students agreed or highly agreed that there was science in the Wigglebots,
whilst 96% and 87% agreed or highly agreed they were able to identify the science in the Catapult and
Pipeline projects respectively. In the catapult 94% and 96% were able to envision the mathematics and
the engineering. Finally, in the pipeline activity 93% could see the engineering and only 91% could
identify mathematics in this activity.

When asked what was the science involved in the Wigglebot, 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
Wigglebots and its motion patterns. They also identified to the STEMinists 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, so 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 their knowledge (Harlen &
Qualter,2009). In all 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, and they considered why the pipes were enclosed and not left open
and that these conversations could have real life applications. They could see that if the pipes are left
open the water supply can 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’.

Unfortunately, the students’ level of communication, when asked to use their written language to
communicate the science, mathematics and engineering, was a challenge with many answers exactly the
same indicating copying and often students struggling to express themselves clearly and in sentences in
English. This made it difficult to determine the exact level of understanding of the students using a
survey and therefore it would have been useful to have conducted interviews with the students to further
triangulate the data. Eight percent of the students answered the surveys in a language other than English,
it was initially thought that this was Hindi, however, the Hindi speaker in the research group was unable to translate it and thought it was a local dialect. This highlighted some of the issues of the students working in class in English using English texts and speaking in English and in Hindi but speaking another dialect at home.

Transversal competencies in Indian primary school students demonstrated as they participated in the project

This project sought to measure students’ capacity against UNESCO’s transversal competencies which encapsulate a range of skills including those around critical and innovative thinking which encompass creativity; inter-personal skills which focus on working with others and providing leadership and collegiality; intra-personal skills which focus on developing resilience, integrity and engagement and; finally global citizenship which looks at tolerance of others and respect for the environment. The Indian students’ responses in three activities creating artefacts were considered through the lens of the transversal competencies examining the domains and sub-domains.

It was determined that asking students about their interest may not have been the most successful mechanism to elicit data regarding the demonstration of the transversal competencies. More specifically, directed survey questions may have been considered leading and so it may have been better for the teacher to have assessed, through observation, some of the transversal competency skills demonstrated by the students across the workshops whilst creating the artefacts. It was felt that asking the pre-service teachers (STEMinists) may not have been appropriate as they may not have felt confident to identify the behaviours seen in the Workshops. A more suitable outcome may have been for the teachers and STEMinists to both examine students’ behaviour for a small number of transversal competencies that have been pre-identified. Both would be asked to note the actual behaviour that they thought may have indicate the skill being demonstrated and this could be discussed at the conclusion of the workshops.

In real classrooms where there are up to 35 students and one teacher the opportunity to observe and document the demonstration of these transversal competencies becomes a real challenge and additional burden to teachers’ ongoing busy schedule. To develop and trial a theoretical model that can encapsulates the learning of the Indian students

The newly developed theoretical model called the STEM infused theoretical architecture model, is a fusion model that seeks to bridge the gap between the current education model in schools that siloed learning content and assesses subjects individually, and the new paradigm of STEM education that it seeks only to focus on skills through a learner’s ideas, methods and values [2]. The model helps the learner move from an internal focus on themselves to a focus on the wider community and worldly focus and move from a focus on the individual learning of discrete subjects to a context that focuses on a needs-based approach of the knowledge and skills that are needed at that point to solve a problem in the community. The STEM-infused model draws on STEM knowledge which is measurable for the teachers and learners but the skills discussed here are less observable and therefore much more challenging to capture in this project. The next phase here will be to articulate clearly how each skill is defined and therefore how it can be captured and expressed. In the sense of if a teacher ‘sees’ a child being ‘creative’ or ‘problem-solving’ there needs to be a clear and shared understanding of what that means and how it can be captured and expressed to other educators. In this respect the model needs more definition as although the ideas can be expressed and measured, as can the methods, the values are much harder to capture, judge and assess.

6. Conclusions

Whilst the Makerspace was engaging and exciting for primary students and they were able to demonstrate their ability to create, make and then refine their projects, the assessment of their understanding of the content knowledge of science, mathematics and engineering was marred by the struggles in English language. In future it would be worth ensuring there were more surveys available in Hindi as well as English so that students could complete the survey in the language that they felt more comfortable using. In saying that they were able to successfully create the artefacts and also to articulate the applied science, mathematics and technology in the artefacts they created. This showed their ability
to apply their knowledge and demonstrated a more complex understanding than merely answering a rote learning multiple choice question.

Research from the UNESCO study [5] determined that teachers were not well acquainted with the transversal competencies and currently needed professional learning and support to help them develop a deeper understanding. One of the major challenges that teachers face is creating a reliable method of mapping students’ capacity around the transversal skills. The mapping of students’ achievement would be to a framework which should include knowledge, skills and attitude and be cogent of the notion that students will all progress at different rates and that they will develop throughout their lives.

![Figure 5. The updated STEM infused theoretical architecture model.](image)

The STEM infused theoretical architecture model was able to frame the science, technology, engineering and mathematical knowledge in these artefacts and help students to see a wider a more global application for the task especially for the pipeline activity, however, the framework needs further modelling to determine if the skills categories encompass all the transversal skills or competencies that industry has identified as significant and important. It may be that the values in the model can be replaced by the transversal competencies to ensure all the skills are included. It seems promising at this stage, however, needs further time to determine if the model has a viable future.

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