Using a *Makerspace* approach to engage Indonesian primary students with STEM

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This paper examines the learning experiences of 291 Year 5 and 6 Indonesian primary school students, across four schools in North Jakarta, who participated in an integrated STEM project that used a 3-phase Makerspace approach: exposure, engagement and experimentation, and evaluation and extension. The Wiggle Bots project involved these students employing their skills and knowledge of technology and science to create a 'bot', and then completing a survey that examined their confidence, engagement, identification and application of science knowledge. The results indicated that a *Makerspace* approach was very effective in engaging students in the STEM space, and students were also challenged to work collaboratively in groups mentored by pre-service teachers. With the application of STEM knowledge and skills, we also posit that the *Makerspace* approach is effective in the acquisition and demonstration of 21st century skills: problem-solving, critical and creative thinking, collaboration, and communication.

Background

A *Makerspace* approach: STEM for the future

Employability and professional skill sets have evolved noticeably since the turn of the 21st century, with an emphasis on creativity, design, and engineering processes surfacing in educational contexts, as tools such as robotics, 3D printers, and web-based 3D modelling applications become more readily accessible (Sheffield, Koul, Blackley & Maynard, 2017). Access to these tools has enabled traditional library-housed *Makerspaces* to evolve into the digital technology realm.

There has been debate about the coining and subsequent growth of the term *Makerspace,* including its origin and what it encompasses. Literature indicates that the idea emanated from peoples' desire to connect and work together, either online in *Hackspace* (London Hackspace Ltd, 2017) or *FabLabs* (Fab Foundation, 2016) or in a more physical sense, thus resulting in the term *Makerspace*. The history of this concept has been fragmented and driven from what Smith and his team termed a "grassroots" push for connection (Smith, Hielscher, Dickel, Söderberg & van Oost, 2013). Sheffield and her colleagues (2017, p. 149) 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", and *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 project reported in this paper describes a *Makerspace* approach that is distinct from *Makerspace* in its original intent (that is, opportunistic creative enterprises resulting in maker-originated artefacts). Table 1 provides a summary of the points of difference between a traditional *Makerspace* and our *Makerspace* approach that we developed in our previous work (Blackley, Sheffield, Maynard, Koul & Walker, 2017; Sheffield, Koul, Blackley & Maynard, 2017) and employed in this Indonesian project.

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

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.

A *Makerspace* approach (shown in Figure 1 below) sees makers situated in groups of peers (communities) and mentored by pre-service teachers (in the context of this project) to produce a designated artefact - *Wiggle Bot*. The Wiggle Bot was selected for the first project (followed by two more in March 2017 with the same students) as the electric circuit that operates the Bot is covered in the Year 5 science curriculum in Indonesia.

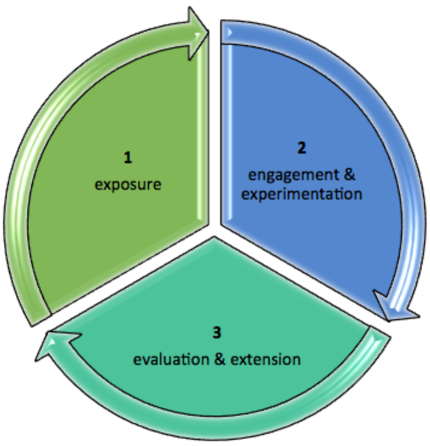


Figure 1: The *Makerspace* approach three-phase model

In the exposure phase, students are situated in groups (organised by the regular classroom teacher), introduced to their pre-service teacher (PST) mentor, shown the artefact (in this case, the Wiggle Bot, Figure 2) in action, and are provided with their kits of materials (Figure 3).

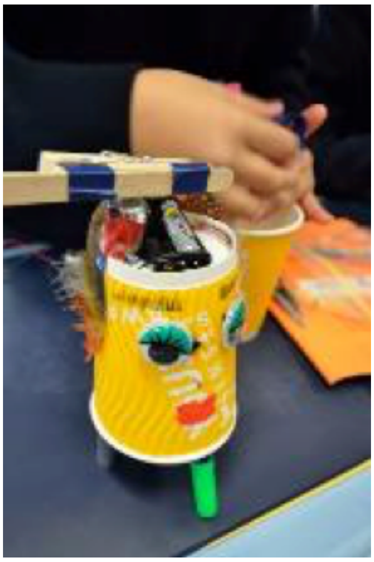


Figure 2: Demonstration of a Wiggle Bot in action
(This allows the school students to see how the component parts work together as a system and the intended functioning of the artefact)

Figure 3: Materials from the kit
(The key to these materials is their relative ease of procurement and assembly)

In the engagement and experimentation phase, the PSTs mentored their groups of students (Figure 4) by asking probing questions (e.g. "If there is no switch in your kit, how could you turn the Wiggle Bot on and off?"), asking "What if?" questions (e.g. "What if you changed the position of the peg?"), and scaffolded them to experiment (e.g. "How could you work out the best positions for the legs?"). The PSTs answered the students' questions and encouraged them to work collaboratively with the peers in their group.

Figure 4: A PST mentor working with her group
(She points out the functionality of the Wiggle Bot)

In the final phase, evaluation and extension, the students demonstrated their working Wiggle Bots (Figure 5) and were encouraged to critique their artefact in terms of its functionality: Was it balanced? Or did it keep falling over? What pattern did the Wiggle Bot create on the paper? Concentric circles or more abstract patterns? Why? Was the motor attached firmly enough? Did the wires obstruct the rotation of the peg? It was only in this phase that the students could witness the operation of their Wiggle Bot, and after their evaluation they were encouraged by their PST mentor to make modifications or to extend the base-model Wiggle Bot.

Figure 5: School students operationalising their Wiggle Bots and evaluating functionality
(Provided opportunities for students to make refinements or adjustments to their Wiggle Bots)

The mentor PSTs undertook a 3-hour development session prior to the school visits, during which the members of the research team took them through the process they would be using with the school students (Figure 6), and coached them in formulating probing and what-if questions that they could use at the school site.

Figure 6: Indonesian PSTs in a development session, collaborating in groups as the school students would be doing the following day
(Construction of the Wiggle Bot was followed up with an evaluation of the artefact, a reflection upon the *Makerspace* approach and support to mentor the school students)

Whilst there is some capacity for modifications to the basic design, the goal is for each maker to end up with a complete and workable artefact. The *Makerspace* approach also has a definite and explicit focus upon the science, engineering and technology concepts involved, and the mentors were encouraged to use correct terminology as they questioned and supported the school students, and were provided with an information sheet to show how this could be done (Figure 7).

Science, technology, engineering and mathematics (STEM) education

Since the acronym STEM (Science, technology, engineering, and mathematics) was first coined in the late 1990s in the United States by the National Science Foundation, the resultant political strategising of the United States in regard to global superiority has not lessened (Blackley & Howell, 2015). Businesses in western nations continue to voice concerns over the current and future supply and availability of workers in STEM fields, and there are concerns that the demand for labour in STEM fields will only increase with time (Beede, Julian, Langdon, McKittrick & Doms, 2011). In the current world climate, STEM innovations are considered to be crucial to the economic future of all countries and so there needs to be funds, time and promotion for improving STEM education to ensure a robust pipeline of STEM engagement (European Union, 2015; Hackling, Murcia, West & Anderson, 2014). Improving STEM education in developed and developing countries remains a challenge (Caprile, Palmen, Sanz & Dente, 2015), and the USA National Research Council (2011) suggested that a way to increase students' interest and engagement in STEM education was to extensively use information and communication technologies (ICT) in STEM teaching and learning.

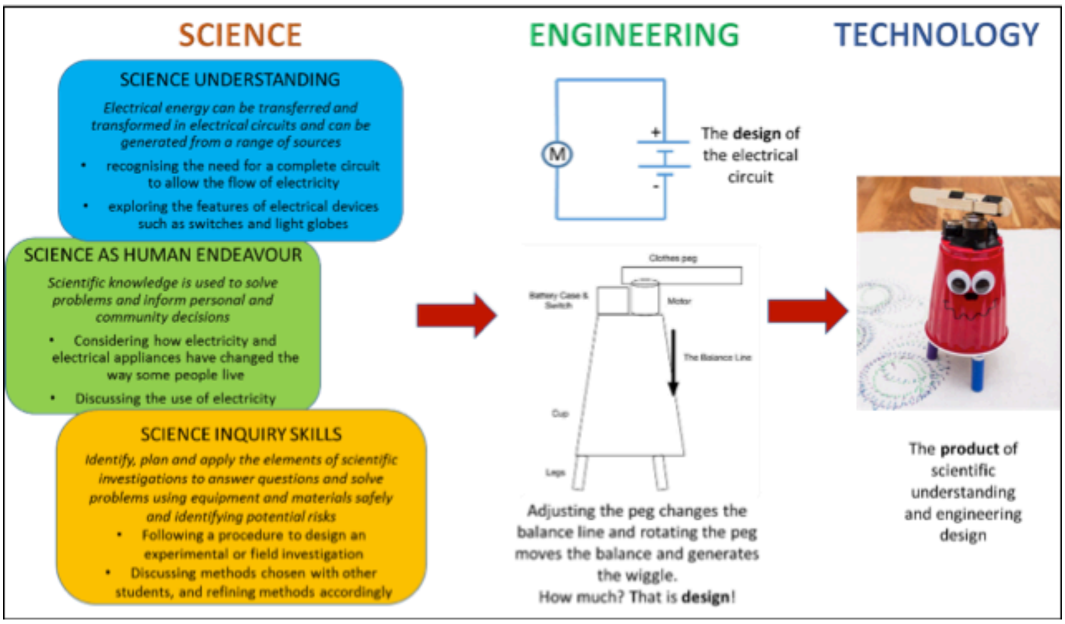


Figure 7: Curriculum and concept support provided to the PSTs

Key to this is how STEM education is enacted in *primary* classrooms, with research indicating that interest in STEM-related career options has already peaked by ages 10-12 (Brophy, Klein, Portsmore & Rogers, 2008). Our view of integrated STEM education is underpinned by the intentional integration of two or more of the disciplines (science, technology, engineering, mathematics), and potentially with other learning areas, with a focus on authentic problem solving (Sanders, 2009) or product creation, including the application of an engineering design process (e.g. brainstorming, creating, testing, improving). To achieve this, we have created and utilised a *Makerspace* approach to integrated STEM education.

Student drawings in science education

Diagrams in science learning and teaching can range from "picture-like depictions of objects linked spatially or temporally or causally by arrows or lines, through to examples where the objects have been reduced to symbols and the links have become a grid" (Gilbert, 2010, p. 9). Although science students are mainly involved in interpreting visualisations (encompassing drawings, photographs, diagrams, and graphs) created by others, we contend that, when involved in integrated STEM activities, students should be encouraged to create their own visual forms to represent their understanding of underlying concepts. Krampen (1991) in his seminal work suggested four developmental stages of drawing and linked them with approximate age ranges (Rennie & Jarvis, 1995): scribbling (age 2-3 years), fortuitous and failed realism (age 3-5 years), intellectual realism (age 5-8 years), and visual realism (age 8-12 years).

Of most relevance to the work described in this paper are intellectual realism (children draw what they know about the object) and visual realism (children draw what they actually see). Further, Ainsworth, Prain and Tytler (2011) noted that learners tend to select specific features on which to focus and make obvious in their drawings; we posit that teachers' understanding of this could reveal developing concepts or misconceptions and thereby direct further planning and teaching.

21st century skills

The term 21st century skills is generally used to refer to certain core competencies such as collaboration, digital literacy, critical thinking, and problem-solving that advocates believe schools need to teach, to help students thrive in a globalised society (*Partnership 21, 2008)*. In relation to these skills, the *International Society for Technology in Education (ISTE)* developed seven standards for the students: empowered learner, digital student, knowledge constructor, innovative designer, computational thinker, creative communicator, and global contributor (ISTE, 2016). In the Indonesian context, these 21st century skills are components of the K-13 framework (Ministry of Culture and Education, 2013). Therefore, we posit that our *Makerspace* approach will provide opportunities for students to develop and demonstrate these skills.

Indonesian context

Indonesia, the country with the fourth largest population in the world (Suprato, 2016), is geographically close to Australia, and is made up of 17,500 islands, thirty-three provinces, and more than 300 ethnic groups that share different values, beliefs and practices. This broad range of diversity influences the educational practices and values that in turn influence the implementation of the standards-based education system of Indonesia.

There are five principles of *Pancasila* (the official, foundational philosophical theory of the Indonesian state) that impact on the societal values and practices: the belief in the one and only God, civilised humanity, the unity of Indonesia, democracy guided by the wisdom of the deliberations among representatives, and social justice for all people of Indonesia. These five principles play an important role in guiding unity in Indonesia. In the education system, these five principles constitute the basic concept in civics education and are integrated throughout the education system. Indonesia uses a standards-based education system that consists of eight national education standards of graduate competencies, content, process, assessment, educators and supporting staff, financial, and management (Government Law 20/2003). These standards guide the educational process in all school types and levels in Indonesia, including formal and non-formal education.

The current curriculum in Indonesia, *Curriculum 2013 (K-13)*, is based on the principle of students meeting knowledge competencies and developing positive attitudes towards the national character. Prior to this curriculum, the predominant style of pedagogy was didactic, emphasising rote learning and promoting deference to the teacher's authority (Kuipers, 2011). The implementation of Curriculum 2013 also resulted in pressure for teachers to adopt different pedagogies: more emphasis on developing students' 21st century skills, a student-centred approach, and active learning. Indonesian teachers and students continue to face challenges in implementing these pedagogies in which they seek to transform the paradigm from teacher as *controller* to teacher as *facilitator*. Curriculum 2013 "emphasised personal experience through the process of observing, asking, reasoning and trying (observation based learning) to improve the creativity of learners, as well as the necessity of directing the learning process to Attitude, Skill, Knowledge (ASK)" (Putra, 2017, p. 12). From 2013 to semester 1, 2014, 6000 schools (primary, junior secondary, and senior secondary) trialled K-13 across the country. However, by the end of 2014, due to changes in the ministerial education structure as a result of the presidential election, schools that had begun the trial in semester 1, 2014 and those that had not commenced implementing the new curriculum were instructed to halt and to teach the previous school-based curriculum (Suyanto, 2017). The rationale for this was that teachers and principals had not been sufficiently prepared to implement K-13, which was radically different to the previous *Kurikulum Tingkat Satuan Pendidikan* (KTSP). The goal of K-13 was to develop productive, creative, innovative, and affective Indonesians through the integrated nurturing of their attitudes, skills, and knowledge (Ministry of Education and Culture, 2016).

Of particular concern was the promotion in K-13 of a scientific approach in the teaching and learning process (Suyanto, 2017) which requires the application of the 5Ms: (1) *Mengamati* (observing), (2) *Menanya* (asking questions), (3) *Mengumpulkan informasi* (information gathering), (4) *Menalar* (reasoning or data analysing), and (5) *Mengomunikasikan* (communicating) (Ministry of Education and Culture, 2014). Some schools may add two more Ms, namely (6) *Mencipta* (creating), and (7) *Membuat jejaring* (networking) (Suyanto, 2017). According to K-13, it is imperative that students actively seek and record information from many resources and activities, including experimenting and observing, as well as from the Internet. Teachers should also support students to be actively involved in the process of constructing meaning and communicating the results of their learning (Ministry of Education and Culture, 2016).

In regard to science, mathematics and technology education, the implementation of Curriculum 2013 has resulted in the following:

	Pre-K-2013	K-2013
Science	Three science subjects – physics, biology and chemistry. Biology and physics was taught to Years 1 to 10 whilst chemistry commenced in Year 10. No stipulated hours per week for instruction.	No science subjects in Years 1 to 3; two science subjects – physics and biology – in Years 4 to 6, stipulated 1.5 hours each per week, and from Years 7 to 10, at 2 hours per week.

ICT and mathematics	ICT and mathematics both taught from Years 1 to 12. No stipulated hours per week for instruction.	ICT and mathematics taught from Year 1 to 12 for 6 hours per week in primary school and 4 hours per week in secondary school

In Curriculum 2013 science (Science education in Years 1-3) has been integrated into other subjects of Bahasa Indonesian language through a thematic approach (Ministry of Education and Culture, 2013). For example, when students learn about the concept of "human being" they will explore themselves as human beings through science perspectives in the subject of Bahasa Indonesian language. According to Zubaedah (2013), elementary school teachers have difficulties in implementing Curriculum 2013, namely to develop scientific inquiry, a major focus of science education, in Bahasa Indonesian language as a subject. In addition, science concepts are developed generally in primary schools through hands-on learning and exploring nature (Harlen & Qualter, 2009), and the opportunity to do this in an integrated context could result in students not learning key concepts of science that they may otherwise develop in purpose-planned science lessons.

In addition to curricular challenges, Indonesia participates in large-scale international comparative studies such as *Trends in International Mathematics and Science Study (TIMSS)* and the OECD's *Program for International Student Assessment (PISA).* However, despite the reforms of Curriculum 2013 and an improved budget for education (Suprapto, 2016), Indonesian students still score low in both assessments. In 2015, Indonesia was ranked 64 out of the 72 participating countries in the PISA assessment (OECD, 2015). Based on an analysis of the results, it could be reasoned that Indonesian students lack higher order thinking skills, especially in science (Gherardini, 2016). In TIMSS Year 4 mathematics, Indonesia was ranked 44th out of the 49 participating countries (Mullis, Martin, Foy & Hooper, 2016), and Year 4 science, 44th out of 47 (Martin, Mullis, Foy & Hooper, 2016). Indonesia did not participate in the TIMSS assessment for Year 8 students. In relation to the context of this study, the Indonesian education system faces challenges in not only students' engagement, but also in students' scientific knowledge, understanding and inquiry.

When the *Association of Southeast Asian Nations* (ASEAN) Economic Community was established in 2015, Indonesia, as did other developing countries, faced major challenges in improving their competitiveness in manufacturing and labour markets (Milaturrahmah, Mardiyana & Pramudya, 2017) and this has resulted in a renewed government focus upon mathematics and science education in the form of integrated STEM education. The current K-13 provides opportunities for STEM education, particularly in the science and mathematics strands that focus on multidisciplinary approaches to develop 21st century skills. STEM education research in Indonesia is being undertaken and builds on previous STEAM research conducted in chemistry classes, which demonstrated that students developed higher order thinking skills, leadership, and media literacy better when an integrated approach was taken. The researchers faced the challenges of integrating STEAM within the chemistry curriculum, empowering students, managing the teaching and time, and finding or developing suitable resources (Hadinugrahaningsih, Rahmawati & Ridwan, 2017).

Research design

The methodology for this project was interpretivist qualitative research: Why does the phenomenon come about? How does it unfold over time? (Elliot, & Timulak, 2005), based on an exploratory case study to examine school students' engagement with and reflections on a *Makerspace* approach to creating a STEM artefact – in this case a Wiggle Bot. Whilst a number of different data sets were collected over the period of the project, this paper will report only on the data pertaining to the school students. The research team employed a paper-based survey (see Appendix A for the English language version) of school students' engagement and scientific knowledge, including their drawings of their Wiggle Bots, followed by open-ended questions and observations to verify students' engagement and reflections in the project. The surveys and open-ended questions were translated from a previous project conducted in Western Australia by Sheffield and Blackley (2016).

The survey consisted of three items (1, 2 and 3) that were statements requiring the participant to select from a Likert-type scale depicted by both a numerical value (5 = strongly agree to 1 = strongly disagree) and symbols (☺☺ to ☹☹). Item 3 had an additional free-text response, and Item 4 was free-text. Item 5 asked the participants to "draw a diagram, and label it, to show what makes the Wiggle Bot work".

Participants

In October 2016, 291 Year 5 and 6 students Indonesian school students and their parents gave informed consent to participate in a *Makerspace* approach activity, Wiggle Bots, with the pre-service teachers as their mentors. The students were from four locally situated schools in North Jakarta. After the activities, the students completed the survey and open-ended questions reflecting on their learning experiences which are examined in this paper.

The research questions for the school student component of this project were:

1. How effective was the *Makerspace* approach in supporting primary school students' engagement and self-confidence in STEM education?
2. What science knowledge and understandings did primary school students demonstrate as the consequence of the *Makerspace* approach?
3. What 21st century skills did the primary school students demonstrate as they participated in the project?

Data analysis

The data gained from the survey were analysed in three sections: (1) the Likert-type responses to items 1, 2 and 3; (2) the free-text items 3 and 4, and (3) the participants labelled drawings.

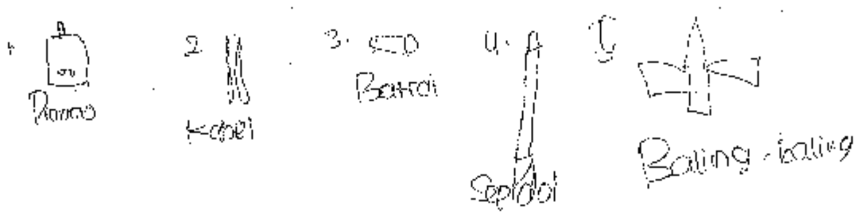
The frequencies of the Likert-type responses were collated numerically and the mean was calculated for each of the items 1 to 3. The free-test sections of items 3 and 4 were analysed using open coding: the text responses were read through several times by three of the research team, and then we created tentative labels for chunks of data that summarised what emerged, not based on existing theory. Moderation was achieved by each member coding the samples and checking for inter-rater reliability – in this case it was 90%.

For item 5, the participants' diagrams of the Wiggle Bots and labelling were categorised based on the work of Bowker (2007) by identifying features that were privileged by the participants. Four categories were developed after two of the researchers and the research assistant trialled the scoring on the same sample as for Items 3 and 4. The categories were:

1. Breadth: the labelled diagram shows component parts of the Wiggle Bot; however, they are not evident as a system (i.e. do not indicate how the individual components work together).
2. Depth: the labelled diagram shows component parts of the Wiggle Bot and they are evident as a system.
3. Extent: a working Wiggle Bot could be constructed using the diagram and labelling.
4. Mastery: a drawing of a completed Wiggle Bot plus a diagram that shows depth plus a caption.

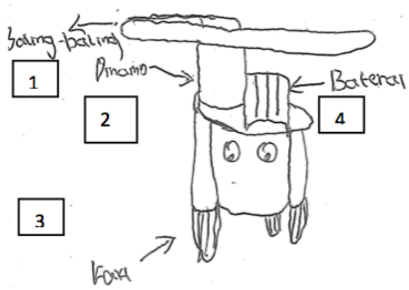
The following are examples of the categories.

Breadth



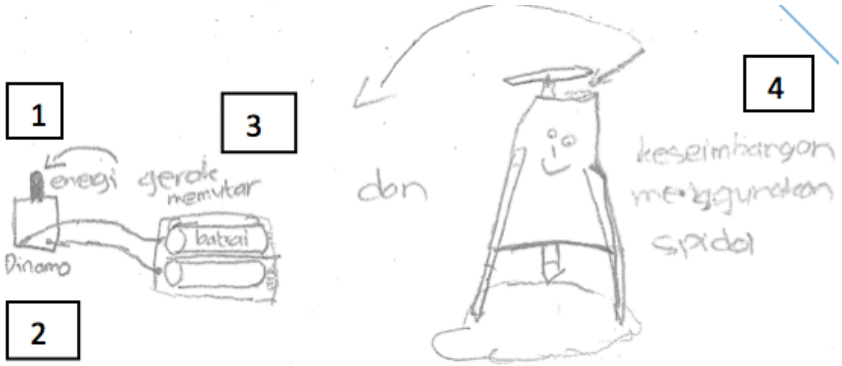
1. Motor (dynamo); 2. Cable; 3. Battery; 4. Marker pen; 5. Propeller

Depth



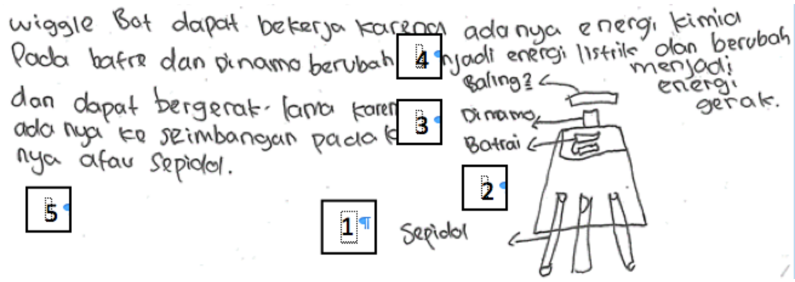
1. Propeller; 2. Motors (dynamo); 3. Feet; 4. Battery

Extent



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

Mastery



1. Markers, 2. Battery, 3. Motor (dynamo), 4. Propeller, and 5. The Wiggle Bot 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.

Findings

The findings reported in this paper are based on the *Makerspace* – Wiggle Bot, 2016: Student survey, where the focus was on student engagement, self-confidence and scientific knowledge, using triangulated data from the Likert-scale survey items, the free-text items, and the students' drawings of their Wiggle Bots.

Students' engagement and self-confidence

In this project, school students engaged in the activity in small groups (4-6 students). The pre-service teachers demonstrated their working Wiggle Bot to the school students at their table, so that the school students could see how the components interacted to form a functioning system (i.e. working Bot). This was done as they were not provided with written instructions and the pre-service teachers were not going to instruct them on how to make the Wiggle Bot. The school students were provided with all necessary components to make a Wiggle Bot, and were encouraged to use their logical reasoning and trial-and-error to make a working artefact. The Likert scale items on the students' engagement in the activity are displayed in Table 2.

Table 1: Indonesian students' survey responses (Items 1, 2 and 3 – engagement) (N = 291)

	Statement	Strongly agree 5	4	3	2	Strongly disagree 1	Mean
1	I enjoyed the *Makerspace* activity.	83.2%	14.8%	-	-	-	4.83
2	Working in a small group with a mentor helped me to complete the activity successfully.	85.3%	14.0%	-	0.7%	-	4.83
3	I can see that this activity uses science knowledge.	83.5%	15.4%	1.1%	-	-	4.65

Table 2 shows that 98% of the students enjoyed the activity of making a Wiggle Bot. There was also high agreement that working in a group with a mentor helped them to complete their Wiggle Bot successfully (98.9%), and 99.3% of students recognised the application of science in the construction of the Wiggle Bot. Participation in the *Makerspace* – Wiggle Bot activity allowed students to experience a different way of science learning - in contrast to their usual experience of following their teacher's instructions and working individually to complete tasks. The *Makerspace* approach encouraged students to develop the initiative of asking questions and seeking clarification. This different learning experience provided the students with new perspectives on science learning as indicated by the statements drawn from Item 4 of the survey (I found the most interesting part of the activity today was …).

The highest frequency themes were: (1) making a working Wiggle Bot – that is, a complete and successfully operating Bot (40%); (2) the Wiggle Bot movement – that is, the various ways in which the Bot moved on the A3 paper and consequent patterns made by the felt tip pen legs (28%); (3) assembling the components of the Wiggle Bot – that is, how the component parts came together to make a system (18%); and (4) 12% mentioned how much they enjoyed working together and/or with their mentor. Below are examples of each kind of theme:

> I made a very interesting Wiggle Bot. (Theme 1)
> When the Wiggle Bot moved and made circular patterns. (Theme 2)
> I really enjoyed fixing the battery to the dynamo using cables. (Theme 3)
> I was thrilled with my friends and my pretty mentor. (Theme 4)

The learning experiences provided by the *Makerspace* approach address some of the aims of Curriculum 2013, namely, to engage students in meaningful learning experiences. The students also found out the relevancy to their daily lives that helped them to understand the concepts (such as how an electrical circuit is constructed). This learning experience shows that science learning is not only the recall of facts and achieving good marks. In addition, students developed their collaboration and communication skills. They learnt that collaboration helped them to complete the tasks within an enjoyable environment. Figure 8 shows students learning from and with each other in building the Wiggle Bots.

Figure 8: Students learning from each other during the Wiggle Bot activity

All students had the opportunity to make their own Wiggle Bot. They learnt from each other and reflected on how they worked in their group as indicated by the statements below.

> [We are] working together and helping each other.
> We are able to understand and make the Wiggle Bot. We were able to gather together in a small group.
> Succeeded in making the Wiggle Bot and playing around with friends.

In addition, working together stimulated student collaboration and communication skills. Students were interested in completing the project and experimenting with variations to the basic design, particularly in regard to stability and motor speed, and the nature of the patterns produced. Students showed that they understood the concepts of energy transfer, how the motor was part of the circuit, and principles of stability, balance and centre of gravity. They learnt not through the memorisation of facts but through hands-on experimentation and collaboration. The following statements are indicative of such learning:

> Chemical energy is changed into electrical energy by the dynamo and electrical energy will be changed into kinetic energy by the/a circuit.
> The most interesting thing is chemical energy becoming electricity that will move the dynamo, electrical energy will become kinetic energy that will move the Wiggle Bot.
> The balance of its legs that are made of textas needs to be maintained.
> I was happy in making the Wiggle Bot and thought about its stability/balance.

As stated previously, students engaged in the activities with a pre-service teacher mentor to *facilitate* the construction of the Wiggle Bot, rather than *instruct* the students. The school students were scaffolded by the pre-service teachers, and the school students were delighted with working in a group with their mentor – as indicated by the statements below.

> …happy and I am very interested in transforming/changing and would like to continue to transform new things. Making fun things and continue to want new things. Thank you to the sister [mentor] that taught me new things and enhanced my knowledge.
> We are able to understand and make the Wiggle Bot. We were able to gather together in a small group with a beautiful mentor, Kak Alin.
> I am happy because I was able to make the Wiggle Bot & this was really cool and creative. I was thrilled with my friends and my pretty mentor, Kak Prada.

Indonesian students are challenged to express their ideas and develop their knowledge and skills (Rahmawati & Taylor, 2015; Suprapto, 2016). Therefore, the development of self-confidence needs to be included in any learning design. In this project, the students applied their knowledge and engaged in problem solving strategies successfully to make the Wiggle Bot. As the mentors merely demonstrated their own Wiggle Bots, the student had to experiment to make the Wiggle Bot work and so experienced varying degrees of success and failure. In the process of making the Wiggle Bot, they started to talk and express their ideas, some of which were captured in the survey, as indicated below.

> I discovered an interesting fact that is I made a robot with simple materials and I can explain the knowledge about science.
> I am happy todays I was able to make the Wiggle Bot (robot). The most interesting thing for me was making the eyes and fixing the legs - although rather difficult but it was doable.
> I was able to assemble my own robot and also make a robot. I like this activity. This is the first time I assembled a robot. A sophisticated Wiggle Bot.
> Make it by myself. I like when Wiggle Bot moving (student's own words in English).

After making the Wiggle Bot, the students felt confident that they could make other *Makerspace* artefacts. They understood that the process was not easy; it not only required their application of scientific knowledge but also scientific methods and applying their socio-emotional skills of learning from their mistakes (such as collaboration, perseverance and resilience) to keep trying different ways to achieve an operational Bot.

Science knowledge and understanding

Scientific knowledge and understanding is one of the main aims of science learning in the Indonesia Curriculum 2013 (Ministry of Education and Culture, 2013). Students should have opportunities for not only developing their soft skills (e.g. collaboration, communication, and perseverance) but also knowledge and operational skills. The last item of the survey asked students to "Please draw a diagram and label it to show what makes the Wiggle Bot work". Based on the categories of the students' drawings, the school students demonstrated their level of scientific knowledge and conceptual understanding – the categories of *Breadth, Depth, Extent,* and *Mastery* were illustrated in the Data Analysis section. The term "diagram" was purposefully used (*Gambarlah sebuah diagram, berikan label/tanda untuk menunjukkan apa yang menyebabkan the Wiggle Bot dapat* *bekerja*) as we wanted the students to focus upon the components and the system they formed in their Wiggle Bot, rather than their ability to create a realistic drawing of their Bot. We had been assured by the class teachers that the children had "learned about simple electric circuits" in their science lessons, and so we wanted to see how they could convey their scientific knowledge in the context of the Bot and their diagram. Table 3 summarises the categorisations of the students' drawings.

Table 3: Categorisation of the students' diagrams and labelling (N = 291)

Categorisation	Percentage (%)
Breadth	25
Depth	37
Extent	9
Mastery	2
Total	73

Whilst categorising the drawings and moderating the decisions, three additional categories, that had not been expected, emerged: *no drawing, only a caption, drawing with no labels or caption,* and *no response to the item*. Participants responding in these ways made up the 100% as follows: 9% - no drawing, only a caption; 17% - drawing with no labels or caption; and 1% - no response.

Of interest are the diagrams that were categorised as "breadth" – that is, individual components are represented and labelled but do not constitute an operational system. Twenty of the 73 in this category (approximately 27%) linked the component parts with arrows in a linear fashion (see Figure 9) suggesting a knowledge of their relationship to each other but not necessarily how an electric circuit is created to operationalise the Wiggle Bot.

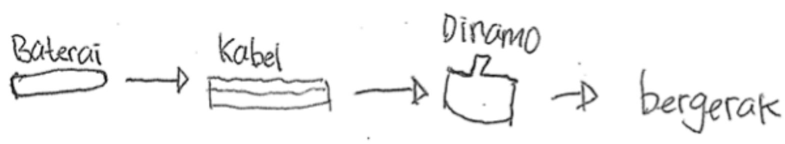


Figure 9: Component parts linked with arrows

In the "depth" category (individual components are represented within an operating system) 42 of the 107 (approximately 39%) drew a "diagram" (a stylised image with some degree of recognisable scientific representation of circuitry – see Figure 10 for an example) as opposed to a realistic "drawing" of the Wiggle Bot (see Figure 11).

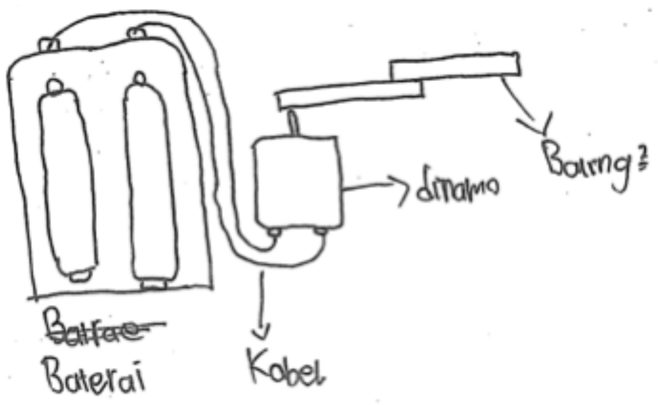


Figure 10: Diagram – stylised image, representing the relationship between the components

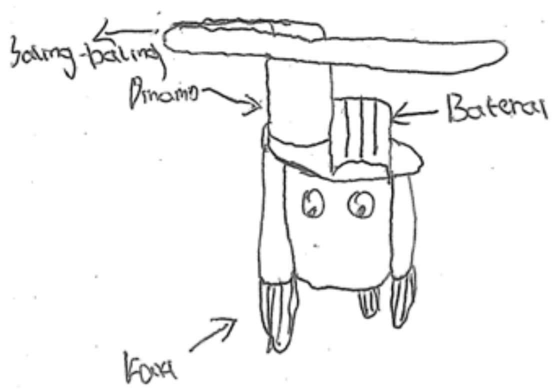


Figure 11: Realistic drawing of Wiggle Bot

Whilst the drawings showed different levels of scientific understanding, the student responses to item 3 of the survey "I can see that this activity uses science knowledge. If so, what is the science?" provide more evidence of scientific understanding, as indicated by the following samples.

> The battery is the source of energy. If there is no battery, the dynamo will not work.
> Wiggle Bot can move because there is a propeller and battery as without the battery and propeller, the dynamo cannot move the Wiggle Bot.
> Science [in the Wiggle Bot] is converting chemical and electrical energy into kinetic energy.

Students' 21st century skills

This study shows that the students learned or honed the 21st century skills of critical and creative thinking, problem solving and collaboration skills, and also some of the ISTE standards of empowered learner, knowledge constructor, and creative communicator

(ISTE, 2016). During the Wiggle Bot project, the students developed inquiry skills of asking questions, trying different ways of developing the Wiggle Bot, and reflecting on their success. The activity developed their curiosity and to some extent their critical thinking as they struggled to assemble a stable, operational and robust Wiggle Bot. Their creative thinking was developed by experimenting with the best way to make the Wiggle Bot work, including the positioning of the battery holder and the legs. In developing the Wiggle Bot, the students applied their scientific knowledge through critical and creative thinking skills as indicated below.

> We got to learn science and we are able to enhance our knowledge and we will be more creative.
> Able to enhance my knowledge, so was able to create my own creation.
> Making the Wiggle Bot's legs that need to be balanced. Fitting the dynamo to the battery holder to work like a switch.

The students also tried to solve the problems that arose as a natural consequence of hands on learning. They realised that to solve the problems, they needed to reflect on their understanding and experiences. The identification of and solving the problems needed critical reflective thinking which was also facilitated by the mentors. The students were satisfied that they could solve the problems to finalise their Wiggle Bot as indicated below.

> I was happy that I was able to make the Wiggle Bot because I was able to identify the energies and their respective usage.
> What I know about this activity is what makes the battery have electrical energy. So, from there I am able to make the robot from the dynamo and battery.

The students were also able to develop their collaboration skills as they worked alongside each other and with their mentor. In developing the Wiggle Bot, some students realised that group work and collaboration provided the opportunity to achieve the best results, as indicated by the following statements.

> Making the Wiggle Bot together in a great small group.
> The diagram [dynamo] will turn on when connected to the electricity. Having fun working together.
> Got to learn/discover the methods in making a robot move and able to work together/cooperate!!
> We got to learn to make the Wiggle Bot with help from friends and mentors.

The researchers note that all students were able to construct a working Wiggle Bot by the end of the 90-minute session and were pleased to participate in a different approach to STEM education. Whilst the Wiggle Bot, as the selected project/artefact on this occasion, had a strong science component (ie electric circuits, energy transfer and centre of gravity) the students also engaged with a technology-based design process (eg ideate, create, evaluate, and modify) an engineering problem solving approach (eg how to turn the Wiggle Bot on and off without a switch), and the mathematics of equilateral triangles and the result of rotations inscribing concentric circles.

Discussion

The Wiggle Bot project, delivered using a *Makerspace* approach, appears to address the need for education in Indonesia to provide learning experiences in which students solve problems, reason, manage time, and use a variety of tools (Milaturrahmah et al., 2017). The unusual context of the *Makerspace* approach within a social constructivist pedagogical frame seems to have provided a stage for the students to showcase their 21st century skills and some of the 2016 ISTE standards without being expected to do so. In this manner, approaches such as the one undertaken in the Wiggle Bot project could be a way for developing Indonesian students' competencies in global citizenship as well as their STEM capabilities, and perhaps even addressing the issues, such as unprepared teachers and the difficulties to change teachers' mindsets from the previous curriculum to Curriculum 2013 (Kurniasih, 2014). We believe that the *Makerspace* approach in particular could support teachers in Indonesia to implement the 5Ms of Curriculum 2013, namely *(1) Mengamati* (observing), *(2) Menanya* (asking questions), *(3) Mengumpulkaninformasi* (information gathering), *(4) Menalar* (reasoning or data analysing), *and (5) Mengomunikasikan* (communicating), and most certainly provides a way forward in the development of project-based and inquiry-based learning.

How effective was the *Makerspace* approach in supporting primary school students' engagement and self-confidence in STEM education?

The Wiggle Bot project in conjunction with the *Makerspace* approach appears to have been a positive learning experience for students, as indicated by the survey data – 100% of the students reported *strongly agree (83.2%)* or *agree (14.8%)* to the statement "I enjoyed the Makerspace activity". They engaged and developed confidence in expressing their ideas, as indicated in the free-text parts of the survey, and using their scientific knowledge and understanding, as demonstrated in everyone's success at producing an operational Wiggle Bot and to some extent by the drawings and labels in survey item 5. The students overwhelmingly cooperated in the project; from the rearrangement of their classrooms in groups of desks, to strangers (the pre-service teachers and our research team) taking over from their classroom teacher, to the surveys and photos and videos that were captured.

What science knowledge and understandings did primary school students demonstrate as the consequence of the *Makerspace* approach?

The three stages of the *Makerspace* approach, exposure, engagement and experimentation, and evaluation and extension, stimulated the students' scientific knowledge development through an inquiry process, collaborating, asking questions, explaining ideas, and applying knowledge. The students demonstrated scientific knowledge through both the free-text part of survey item 3 and item 5 (drawing and labelling). The majority of students self-reported that they could see the science in the project, and, when prompted to describe what the science was, were able to describe energy transfer – some also described issues to do with stability and centre of gravity. Forty-eight percent of the students produced an integrated drawing (i.e. illustrating the component parts and how they related together in an operational system) with labelling and in some cases captioning. As we are not sure whether drawing in STEM lessons (or science lessons) was a usual practice in the four schools, we cannot make assumptions about the ability of these students to do this effectively. However, it was apparent that the combination of observing an operational Wiggle Bot, producing their own version, and trialling its functionality, followed by describing the underpinning science concepts and illustrating the artefact, aligns well with best practice in science education (Ainsworth et al., 2011; Chang, 2012; Madsen, 2013), and we posit that this is also the case for integrated STEM education.

What 21st century skills did the primary school students demonstrate as they participated in the project?

As indicated by the photos, the students demonstrated 21st century skills of collaboration, communication, problem solving, and, to a lesser extent, creativity. We believe that the apparent lack of creativity was a result of the initial instruction given to them in their groups by their pre-service teacher mentor – "You have everything you need in your bag to make a Wiggle Bot like this one". Understandably most students focused on replicating their mentor's Wiggle Bot – however some experimented with locating the "legs" on the inside of the paper cup, the positioning of the paddle pop stick and the wooden peg, and situating the battery holder and motor inside the cup or on the side rather than on top. The third stage of the *Makerspace* approach (evaluation and extension) occurred when the students activated their Wiggle Bots – this was when they could actually see whether their Bot was stable and the legs, battery holder and motor were secured sufficiently to not fall apart. This was also the time during which they could witness the significance of the placement of the peg and paddle pop stick, and also see the result of the positioning of the legs – if situated at the vertices of an equilateral triangle, the Bot will be stable and will produce concentric circles. Further, the efficacy of the manner in which the Bot could be turned on and off came into question: the "switch" could be created by displacing and replacing one of the batteries or detaching and re-attaching the wires to the motor – there were pros and cons for each method, and some students were heard commenting that an actual switch was needed.

The culminating activity was a "Battle of the Bots" during which groups of Bots were placed on a large flat surface to battle – the last one standing went into the next round, and so forth until a "winner" was declared. This encouraged many of the students to make improvements and modifications to their Bots – a natural evolution of the engineering process – to improve stability and longevity in the arena.

The data indicate that the *Makerspace* approach facilitates integrated STEM education and the development and demonstration of 21st century skills, and so may be a way forward for any country wishing to pursue and improve the uptake of STEM, as is the case for Indonesia.

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Appendix A

Makerspace – Wiggle Bot, 2016: Student Survey

Year ………

1. I enjoyed the Makerspace activity. *Colour or circle your response.*

☺☺	☺	😐	☹	☹☹
5	4	3	2	1

2. Working in a small group with a mentor helped me to complete the activity successfully.

☺☺	☺	😐	☹	☹☹
5	4	3	2	1

3. I can see that this activity uses science knowledge.

☺☺	☺	😐	☹	☹☹
5	4	3	2	1

If so, what was the science?

4. I found the most interesting part of the activity today was …

5. Please draw a diagram, and label it, to show what makes the Wiggle Bot work.

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