Does stem.T4L improve student learning outcomes? Evidence from Teacher Survey and school case studies

In this report, we look at the data collected from NSW teachers to reflect their perception and evaluation of the stem.T4L Project and its potential benefits on student learning outcomes. We also present the findings from three school case studies to capture the impact and effectiveness of stem.T4L on learning gains.

Publish Date: April 2021
Author: Dr. Rose (Mahsa) Izadinia
Email: stem.T4L @det.nsw.edu.au

Technology for Learning Portfolio
Information Technology Directorate
NSW Department of Education

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Since 2018, the stem.T4L project has provided NSW public schools with access to new educational technologies – robotics equipment, 3D printers, virtual reality headsets and filming equipment including 360° cameras. In our previous research, we have explored the impact of stem.T4L on the self-efficacy beliefs of teachers and students in primary schools, the development of 21st century skills, online communities of teaching practice, student interest in STEM career pathways and the benefits and challenges that arise when implementing stem.T4L kits in high schools.

In this report, we look at the impact of stem.T4L in terms of student learning outcomes. We investigated whether using stem.T4L kits would help students make more progress against learning outcomes from NSW syllabuses than they would without the kits. We surveyed 408 teachers who were implementing the kits in their classrooms, asking them whether they felt the kits had a positive impact on student learning. We also developed a rubric by which teachers in two experimental groups (abbreviated as Ex Group 1 or 2), schools that used a stem.T4L kit, and one control group, a school without a stem.T4L kit, could assess the development of student learning against a series of indicators related to outcomes from the Stage 3 Maths, English, and Science and Technology syllabuses. Using both quantitative pre-post assessment (at a whole class level) and qualitative data on individual student progress, we present numerous findings that demonstrate gains in student learning when stem.T4L kits are implemented for one term.

Key findings from the research include:

- 94% of surveyed teachers believed the kits had either a positive or very positive impact on student learning (n = 386).
- Clustering of open-ended survey responses revealed that teachers characterised these impacts in consistent themes: the kits provided opportunities for students to engage in trial and error; they engendered a heightened sense of curiosity among students using them; there were opportunities for students to produce a product, where classrooms become workshops and laboratories for their creativity; students were able to recognise the real-life applicability of the learning activities that engage with the kits; and that explicit links were evident between using the kits and addressing a diverse array of key learning areas (KLAs).
- The rubric for the three case study schools asked teachers to assess whether their classes were 'Working towards', 'Working at' or 'Working beyond' a Stage 3 proficiency for several syllabus outcomes. Against numerous outcomes, we can see clear progress for students who were using the stem.T4L kits – particularly when compared against the control group.
- For Maths outcomes, students in the Ex Group (2) had learnt more than students in the control group. Using an outcome for identifying, describing and constructing three-dimensional objects, students using the 3D printer to design these objects exhibited greater progress than those in a non-stem. T4L environment (i.e. control group). In the Ex Group (2), there was a remarkable increase in the number of students that progressed to the 'Working beyond' category – from 3-4 students at pre-test, this proportion increased to 15-28 students at post-test across the four indicators. In contrast, the number of students in the control group who were 'Working beyond' the progress indicators remained the same at pre- and post-test.
- For English outcomes, we saw similar improvements when comparing data between the experimental and control groups. In the Ex Group (1), 97% of students are learning English as an additional language or dialect (EAL/D). Against two of three indicators for effective communication (EN3-1A), the number of students in the Ex Group (1) who were 'Working at' the level of the syllabus outcome increased from 10 to 16 when using the PC robotics kit – while the proportion of students 'Working beyond' also registered small increases. Yet, the majority of the students in the control group maintained the

same level of proficiency and did not progress to the next higher level by the end of the term, suggesting that learning attainments were more distinct in the Ex Group (1), despite having such a large number of EAL/D learners.

- In Science and Technology, results from both the experimental schools indicated that students progressed significantly against the outcomes. In the Ex Group (1), students used the PC robotics kit to program a soil moisture probe. Over the course of the term, a strong shift from 'Working towards' to 'Working at/beyond' was observed when students were using algorithms to develop solutions (ST3-3DP-T) and when using scientific knowledge and practice to examine living things (ST3-4LW-S).
- Similarly, students in the Ex Group (2) also exhibited strong progression against the indicators for planning and using materials and equipment to develop a solution for a need or opportunity (ST3-2DP-T). When students were using the 3D printer, the teacher observed clear growth in student learning over the course of the term. For example, the number of students who were able to identify appropriate refinements to a design solution and use fewer iterations of 'trial and error' increased from zero in the pre-test to 12 students in the post-test.
- When looking at smaller groups of students or the progression of individual learners, we can also see positive changes in their learning when using the stem.T4L kits. Over the course of the ten-week term, teachers observed their students gradually improving their ability to create, interpret and modify their algorithms (when using the PC robotics kit) or when distinguishing between the features of a three-dimensional object, before sketching, designing and producing an object (when using the 3D printer).

INTRODUCTION

Student learning outcomes, manifested in the gains in knowledge, abilities or skills, are closely documented and analysed by educators as a way to understand what a learner knows and does not know (Banerjee 2017). It is only through acquisition of such knowledge and building on best practice that better results can be achieved (DfE, 2014).

In STEM education, a common approach to assessing learning gains is to measure students' development in two main domains; cognitive and affective (Gao, Li, Shen & Sun, 2020). The cognitive domain includes knowledge and processes that are mentally performed such as understanding factual knowledge. The affective domain, on the other hand, deals with feelings and emotions such as interest, attitudes, and motivation. Many believe that a key outcome of an interdisciplinary STEM education is improvement of students' learning outcomes within the affective domain (e.g. Namdar & Shen, 2015). As such, there are many studies that report on the impact of different STEM intervention programs on students' STEM engagement, motivation, interests and attitudes (e.g. Blotnicky, Franz-Odendaal, French, & Joy, 2018; Hayden, Ouyang, Scinski, Olszewski & Bielefeldt, 2011; Kwon, 2017). For instance, Kwon (2017) found improvements in 7 to12 grade students' motivation and interest in mathematics and technical skills as they participated in a designing and 3D printing project. In another study, ICT-enhanced learning experiences positively impacted both male and female students' attitudes towards science and technology (Hayden et al., 2011).

The stem.T4L project, as an intervention that introduces STEM technology into K-12 schools and provides online and shoulder-to-shoulder professional learning to teachers, has created impressive results when it comes to student learning gains in the affective domain. In our previous reports on the stem.T4L project, we looked at students' STEM interests, motivations, attitudes and aspirations to ascertain the extent to which this initiative enhanced students' affective aspects (These reports are available at https://t4l.schools.nsw.gov.au/stemt4l/stem-t4l-research.html). For example, in the study conducted in Semester 1, 2019 on 3,494 students (80% primary and 20% secondary), we found that only 45% were interested in STEM fields before their participation in the project. A 5% increase was observed in students' STEM interest level by the time of the post-test (n=1,478) and 55% agreed that there was a change in their perspective towards STEM and their likelihood to choose a STEM career, after they worked with a stem.T4L kit for one term.

In line with the body of research on learning outcomes in the cognitive domain, we now shift our attention to explore whether schools that integrate stem.T4L technology in their daily learning activities observe any significant improvement in student performance in different Key Learning Areas (KLAs) over the course of one school term. To conduct this research, we collected data from two data sources; (1) teacher survey, which was administered to all primary and secondary teachers who used one of the stem.T4L kits, and (2) school case studies that yielded extensive qualitative data.

The data collected from each source helped us address the following main research question:

- To what extent does the stem.T4L project influence students' STEM learning gains?

In the following section, we will present the analysis on each part of the data and report on the findings of this research.

TEACHER SURVEY

Throughout the life of the stem.T4L project, the research team administered various pre-post teacher surveys, apart from student surveys, to measure the impact of the project on different aspects of teachers' careers including: changes in teacher confidence and competence in technology, teachers' perception and evaluation of the project, the uptake of the stem.T4L kits, and the impact of professional learning, to name a few.

For the present study, we ran a one-off teacher survey in Term 3 and 4, 2020 that aimed to explore teachers' professional judgment on the effectiveness of the stem.T4L kits in terms of student learning gains over a school term. To encourage a high level of participation by teachers, we kept this survey short, with only two multiple-choice questions and one open-ended item. The survey was sent out to all primary and secondary schools and produced a total of 408 completed responses.

When asked to rate their knowledge of educational technology, the majority of teachers indicated that they were either "average" or "above average" (38% and 45% respectively), conveying a moderately high confidence with using technology. The patterns of kit usage appeared promising, where only 28% had used their kit fortnightly, while the rest of the sample were more frequent users of the kit (e.g. weekly: 37%).

The demographic characteristics of the respondents are presented in the Table 1 below.

Table 1

Teacher survey	
Number of responses	408
Gender	Female: 76% Male: 24%
Type of school	Primary: 87% Secondary:6% SSP: 4% Central: 2%
Knowledge of educational technology	Somewhat above average: 45% Average: 38% Far above average: 11% Somewhat below average: 4%
Teaching experience	Over 15 years: 43% 5 to 10 year: 20% 10 to 15 years: 20% Less than 5 years: 17%
Frequency of kit usage	Weekly: 37% Fortnightly: 28% More than three times a week: 16% Twice a week: 12% Three times a week: 7%

Table 1. Breakdown of teacher survey respondents

Based on the demographic information, it was obvious that a large number of teachers that took part in our survey had relevant technological expertise, as well as adequate teaching experience (43% had over 15 years of experience), and had used their kit regularly in their class— factors that are likely to accentuate the positive effect of the kits on student learning. However, prior research suggests that variables such as differences in student motivation, abilities and behaviour, as well as teacher characteristics or training, influence student performance and outcomes to some extent, regardless of the type of educational activities and programs (Bishop et al., 2016; Ford 2018). While we were mindful of the impact that each of these factors could exert on student learning gains, given the focus of this study, we only looked at the role of the stem.T4L kits in improving student outcomes and did not control or examine other variables that might have influenced the dependent variable under study (i.e. learning outcomes). As the experts in the field, the first-hand experiences of the teachers involved in the project and their evaluation and feedback could help us accurately assess the role of stem.T4L technology on improving learning outcomes. Through the analysis of the data including teachers' commentaries and ratings, we found that integration of the stem.T4L kits does in fact result in higher learning gains, as will be explained below.

Survey outcomes: Did the stem.T4L project have a positive impact on student learning?

From teachers' perspectives, working with the stem. T4L kits had a definite positive influence on student learning. As Figure 1 below shows a solid 94% (n= 386) considered this impact either positive (30%) or very positive (64%).

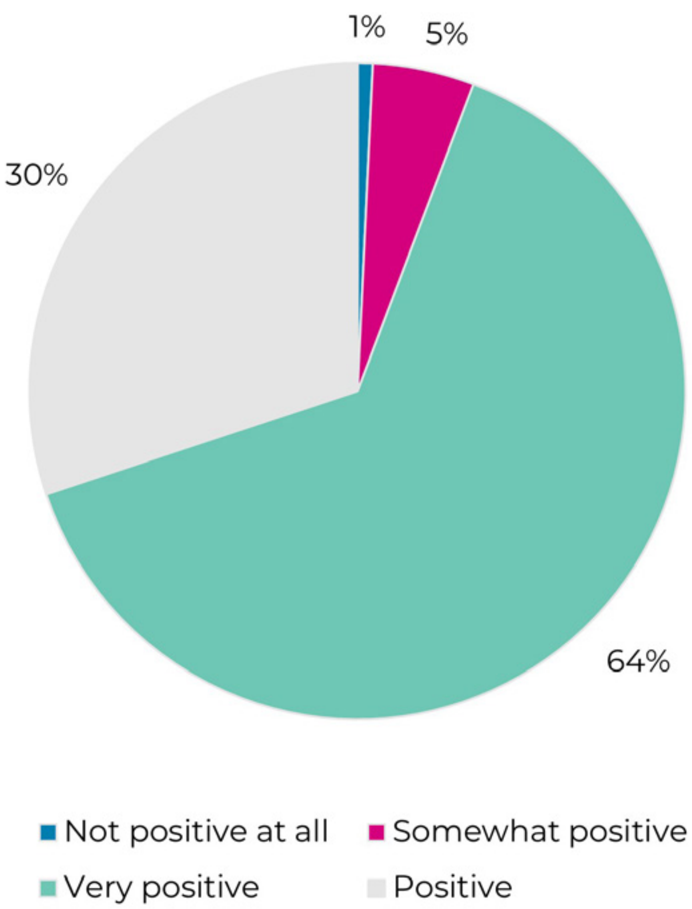


Figure 1: Teachers' perspectives on the impact of the stem.T4L kits on student learning.

This finding suggested that not only does the stem. T4L project improve students' affective aspects (e.g. positive changes in attitudes towards STEM, STEM career aspirations, STEM confidence), as our previous studies especially in primary schools showed, but also leads to higher student learning gains. This in fact echoes the findings of other studies, the majority of which indicate STEM interventions programs that draw on robotics, programing, and virtual reality are effective in improving learning outcomes (Bers, Flannery, Kazakoff, & Sullivan, 2014; Ramachandran, Huang, & Scassellati, 2019).

How did the stem.T4L project improve student learning

The impact of the stem.T4L kits on learning, in general, and on STEM learning (15% Figure 3 below), in particular, was evidently significant, according to our respondents. Teachers commented that they had repeatedly witnessed a heightened sense of curiosity on the part of students, continuous cycles of trial and error, attempts to find solutions to real-life problems, and building and creating, all of which had facilitated a meaningful participation in learning and had made students co-constructors of knowledge. Teachers' explanations as to how the incorporation of the kits had promoted deeper learning corroborated constructivist theories of learning and reinforced the concepts of "learning by doing" (Dewey, 1997) and "learning through making" (Papert, 1993). These theories advocate learners' active engagement in the learning process, where they construct personal knowledge through making meaningful artifacts (i.e. leaning through making) or through personal actions (Chou, 2018), such as discovery and problem solving (i.e. learning by doing), which as our respondents acknowledged, occurred naturally in the stem.T4L learning context.

In addition, integration of the stem.T4L technology established a stronger and tangible link between different KLAs, as well as between theory and practice, which also contributed to student learning. Figure 2 depicts the main factors affecting student learning in the stem.T4L learning environment, as discussed by teachers. We will discuss each of these themes separately and provide some examples for further clarification.

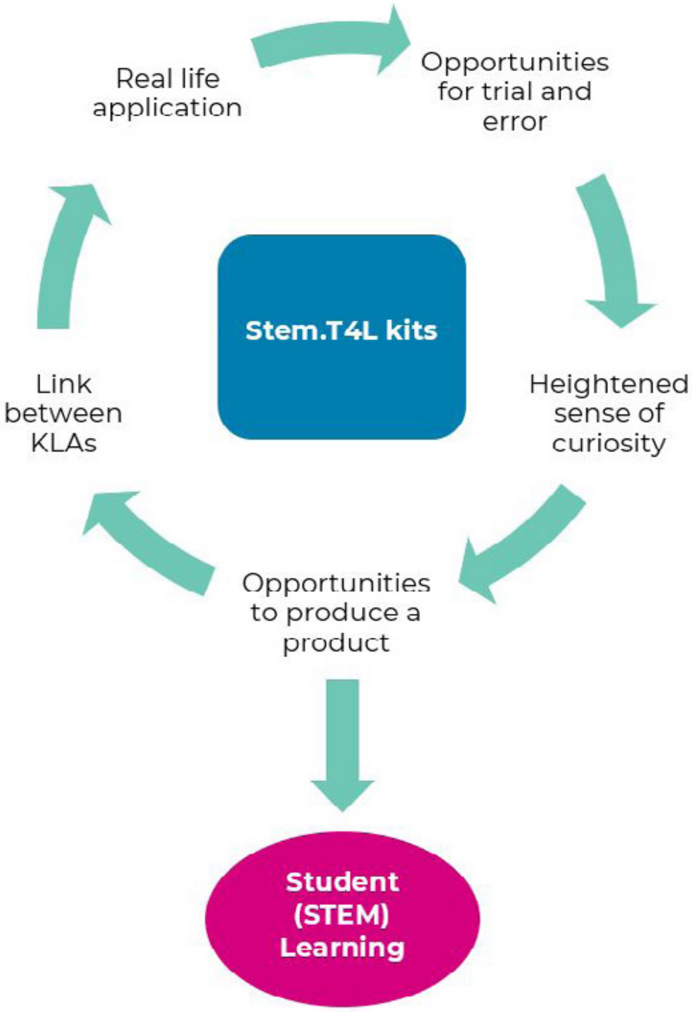


Figure 2. stem.T4L contributions to (STEM) learning

1. Opportunities for trial and error

An indispensable component of learning by doing is the cycle of exploring, testing ideas, failing, refining one's understanding, and trying again. All these elements were abundantly found in stem. T4L classrooms, as teachers stated. When students are introduced to stem.T4L kits, the first thing they quickly realize is that they are in the driver's seat, meaning although teachers are the "guide on the side", they need to take ownership of their own learning through taking risks and exploring. This unique opportunity that the stem.T4L kits provides for students to experiment with the unknown has tremendous influence on their learning, as suggested in the comments below.

- *They learnt - through trial and error - how to create clear visual instructions. This had an impact on learning beyond the lessons where Ozobots were used - handwriting improved and students took more care with presentation of work.*
- *Allowed students to experiment.*
- *The lessons were integrated effectively into our teaching programs. It also allowed for students to practise trial and error.*
- *It was great for teamwork and also trial and error. They would explore their own ideas and make adjustments.*
- *Students in ES1 used the Ozobots to introduce coding. They really enjoyed using them and the trial and error nature of drawing the codes.*
- *They used a range of skills to explore and experiment with the functions of the technology. Students understood how different systems operated and the coding required to operate the robots.*
- *Students were motivated, keen and engaged, even those who were reluctant at the start. It gave students the chance to experiment and take risks without the concern of failing.*

2. Heightened sense of curiosity

Another secret ingredient that the stem.T4L kits added to classrooms was boosting students' curiosity, manifested in students asking questions, showing interest in knowing how things work, as well as their ability to recall facts. This heightened curiosity facilitated learning through activating students' retentive memory, which is confirmed by previous researchers. There are many empirical studies that show a sense of curiosity is associated with improved learning and hence, better learning outcomes (e.g. Gruber, Gelman, & Ranganath, 2014; Wade & Kidd, 2019). In fact, it appears curiosity enhances learning by increasing activation in memory regions of the brain (Gruber, 2014), as was observed by our participating teachers.

- *Questions, questions and more questions perfect for learning.*
- *The stem. T4L kits enabled the students to gain a deeper understanding of what they were learning in Science, and develop a creative curiosity of how the mechanics of robotics works.*
- *It provoked curiosity and increased engagement. Students would say "this is so much fun, we never knew learning can be fun". The students always had lots of questions to which I didn't always have answers to and together we problem solved, modelling lifelong learning.*

- *It inspired their curiosity and encouraged them to learn the technical and content components of the subject we were exploring. Improved their recall of facts- memorable experience.*
- *Students were engaged in lessons and had a genuine curiosity for exploring different environments.*
- *The new technology fostered their natural sense of curiosity and inspired them to want to learn.*

3. Opportunities to produce a product

In a stem.T4L learning environment, classrooms become workshops, science labs, art studios, or "Makerspaces", where makers get involve in designing and creating (Dougherty 2013). Through assuming the roles of scientists, mathematicians, and designers, students develop the knowledge and skills they need to solve the problems they face (Martin 2015). Many teachers that commented told us that their students were able to design, give life to their creation through coding, and produce "a tangible object", which is how learning was further supported in stem.T4L classrooms.

- *My students in particular loved the building and creating of Lego creatures. Using the example, they were able to adapt movement and sound to create an animal of their choice. They are year 2 students and absolutely thrived learning this way.*
- *Students were able to make their history projects come to life using CoSpaces and students built strong connections and improved understanding of the history topics.*
- *The T4L kits provide the tools to the students to leverage the learning they have acquired in the classroom and to apply the skills in creative and innovative ways. Working with the kits allows kids to explore what they know and demonstrate that knowledge in so many different ways.*
- *Students could see the process from start to finish. They planned and designed, applied these ideas to computer construction / simulation and then could see the finished product in a tangible object.*
- *Students were able to make simple designs and see their design come to life.*
- *Students had the opportunity to create a Zoo and the robotics acted as the zoo animals. Students were able to code their 'animal' to behave in certain ways and it really gave students the opportunity to have an immersive experience for the whole school to visit.*

4. Real-life applicability

Another factor that promoted effective learning was the connection that use of the kits created between theory and practice. That connection made learning more meaningful and palpable as students were faced with real-life issues and engaged in finding solutions for them. Instead of textbook-based instructions, teachers were able to deliver personalised and contextualised experiences, through integrating the stem.T4L kits, which helped students "participate in worlds that they were studying".

- *Students utilised the homeless experience VR app. This related to the Community and Family Studies unit Groups in Context. Gave students a sense and experience of what it may feel like to be homeless.*
- *Students had to think about a real world problem and create a solution. The opportunity to refine continuously, aligns heavily to a value we are trying to embed at our school (high expectations). Which was a wonderful by-product of using the stem.T4L kit.*
- *My students collaboratively created a solution to a real-world problem.*
- *Getting hands-on allowed students to solve real-world problems and tackle the design process from 2D to 3D to VR.*
- *Students were able to participate in worlds that they were studying which gave more meaning and engagement for this experience.*
- *Provided students with real life applications to put their theoretical knowledge (e.g. maths and equations).*
- *Improved student learning as it met diverse learning needs of students. Its hands-on learning with real-world applications that helps develop a variety of skill sets, including creativity and 21st-century skills.*
- *High engagement combined with relevant real world need/interest.*
- *Provided opportunities to implement STEM practices and to employ a diverse range of mathematical skills and knowledge in a*

practical, real world context.

- *Mathematical learning was profound as it was real life and relevant.*

5. Link between KLAs

In our earlier research on the stem.T4L project, we frequently observed a degree of uncertainty on the part of teachers as to how to embed the kits into Maths, English, and other learning areas. They always lamented that there was a missing link with the curriculum and they needed a better understanding of how to integrate the kits so that they were not just stand-alone activities but could reinforce previous learning. The professional learning that has been continuously offered to teachers, over the last three years, and teachers' growing familiarity with the stem.T4L kits has manifested itself in teachers' stronger grasp of how to make an explicit link between the stem.T4L kits and learning outcomes in other KLAs. As the examples below show, teachers' success in creating that link such as integrating the kits into "history lessons", linking "literacy with digital technology" and "Geography to Science", "enabled a flow on effect" and led to higher learning.

- *Great way to link literacy with digital technologies.*
- *Exposure to robotics and coding languages, which has enabled a flow on effect to other aspects of their learning. Being more confident in the unknown.*
- *Students were able to link their learning from other KLA's and challenge concepts with problem-solving, and testing and retesting.*
- *Helped students make connections between key learning areas. For example, building a tractor with the robotics to tie into knowledge of sustainability and farming.*
- *Learning that was done was related to content being taught in other KLA's.*
- *Students were very engaged in using the filming kits and we were able to integrate the use of them into many key learning areas.*
- *By integrating IT into my history lessons.*
- *Students were able to connect their experience in technology to understand key concepts in science and technology. They were able to use hands on equipment to test theories, make sense and give meaning.*
- *We found that students were able to connect with the skills they had learned in literacy and numeracy sessions.*
- *Linking STEM practice and computational thought to literature studies through the library.*
- *The links to literacy were powerful and gave context to our reading and writing tasks. Speaking and listening was the foundation of the project with all student demonstrating collaboration skills.*
- *In particular, the 'Google Expeditions' app linked to Geography and Science units that were being taught.*

What skills did stem.T4L improve?

Measuring the overall impact of the project on student learning gains was the first goal of this study. In addition, we were interested to know which competencies and skills had enhanced the most after a one-term trial of the kits. To this end, we provided teachers with a list of "knowledge-based" (e.g. STEM learning), and "skill-based" (e.g. problem-solving, teamwork) outcomes (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014) and asked them to select all that applied to their students. What we also added to the list was 'student engagement'. The reason why we included this variable was that in our previous studies an overwhelming majority of teachers had repeatedly told us that student engagement was significantly impacted by the project, where higher level of engagement was observed in a stem.T4L learning environment.

Although student engagement might not immediately fall into the category of student learning outcomes, it is a key by-product of educational technologies, which once present and facilitated would lead to higher learning gains. So, we further examined how an increase in student engagement would compare with that of other skills. An 'other' option was also included to allow for any additional learning outcomes that teachers could possibly consider.

Although the commentaries suggested that some teachers were ambivalent to single out one or two skills, as they believed they all had improved, we were able to observe slight differences across the items. As shown below, 'Student engagement' received 20% of the choice count and topped the list.

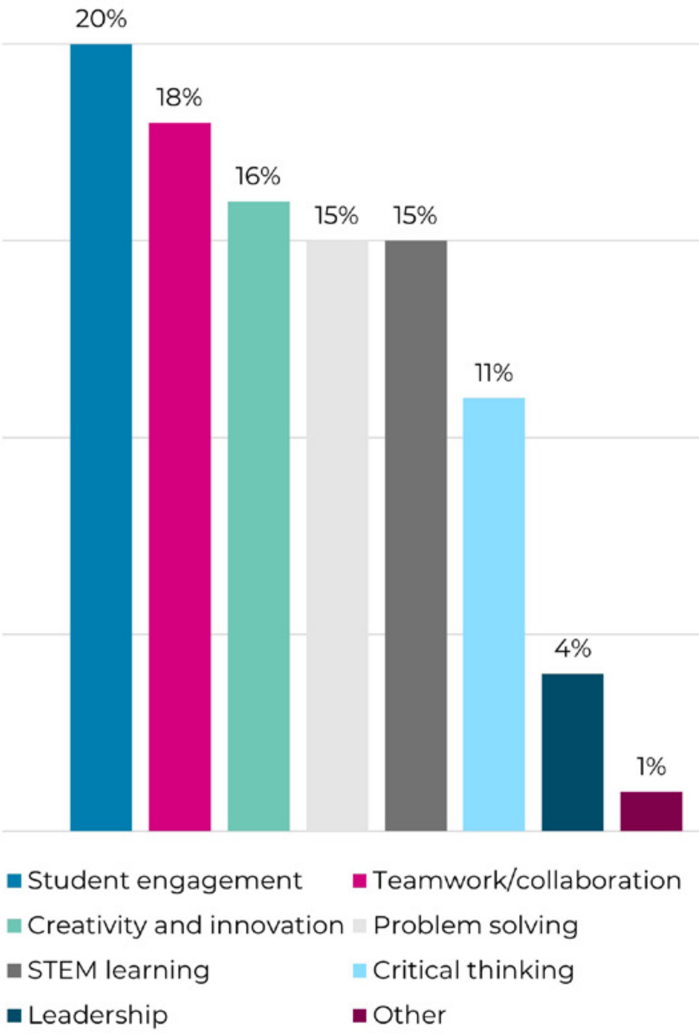


Figure 3. Skills improved after the stem.T4L experience

Examples of student engagement provided by teachers were ample and telling, indicating that the hands-on, minds-on nature of the stem-T4L kits had clearly changed classroom dynamics. Teachers who usually had to deal with disruptive behaviour were pleasantly surprised at the low occurrence of discipline issues, which as some teachers pointed out became "non-existent". Sustained level of focus even from students who struggled to stay engaged, a heightened motivation and genuine excitement to learn were also easily discernible when the kits were present.

Some other teachers found indicators of high engagement in their classroom such as students asking questions "willingly", showing up for school, and greater participation from shy students, all of which were those "things" that would "magically change" when students were given a robot, as teachers explained.

- *We have some students who struggle to stay engaged with their learning. By using VR and AR those students were completely engaged and could be prompted to stay on task with the knowledge they were participating in VR/ AR that day.*
- *Some students with behaviour or social issues were able to work in teams and engage with others, which improved their skills in class. Engagement, it takes a lot to get our kids to focus and apply themselves to a task to get quality work, add a robot and things magically change!*
- *Absent students were always present during filming sessions. Shy students worked with their team and participated.*
- *Behaviour issues were virtually non-existent and these lessons were the last 80mins when sometimes those behaviour problems occur.*
- *The students were very motivated and engaged leading to positive learning outcomes.*
- *Using the 360 degree cameras from Year 3 to 6 really helped improved student focus. They were engaged in their learning, remained on task, and appeared to enjoy the process.*
- *The students were excited for every single interaction with the robots. It was so wonderful to see them so engaged and working well together.*

- *The level of engagement was high so they wanted to learn.*
- *Students were engaged and on task in both Geography and STEM.*
- *Finding engaging activities can be difficult but it was never a problem when using the 3D printer from design to production.*
- *They were incredibly motivated to get involved in the learning process.*
- *Students engaged in hands-on lessons that accommodated a range of learning outcomes.*
- *These kits are amazing! Our students are accessing resources and developing knowledge and skills they would not develop otherwise. The engagement is high and the learning is dynamic, creative and exciting.*
- *Engagement was a huge factor. The usual content got a big boost when we added robotics.*
- *Student's engagement level and motivation to learn certainly have increased.*
- *Disengaged students have been more engaged.*
- *They were more engaged, asked more questions willingly/freely.*
- *Definite improvement in engagement by most of the students.*
- *I had very little discipline issues with any students during their use of the kit.*

21st century skills such as creativity, problem-solving, teamwork and collaboration, has been considered essential capabilities that students need to be equipped with, as all these "soft skills" (Lambert, 2017) are demanded by the workforce and tomorrow's society (World Economic Forum 2016). As there is prevailing consensus on the significance of these set of competencies, recently the focus of education researchers has been redirected from why to how to develop these skills in students (Scoular & Care, 2018). To this end, educational robotics (ER) have been researched widely and introduced as effective tools that can foster 21st century skills and promote higher-order learning, especially in mathematics and science (Atmatzidou, & Demetriadis, 2016; Chambers, Carbonaro, Rex, & Grove, 2007). Researchers argue that through using robotics, students become active technology/science creators rather than passive consumers of technology (Eguchi, 2014), they experience and discover things for themselves, and co-construct new knowledge by collaborating with peers, problem solving, and using their critical thinking skills (Blanchard, Freiman, & Lirrete-Pitre, 2010).

Based on the literature, ER appears instrumental in fostering the skills of tomorrow, but are the stem.T4L educational technologies, including robotics, equally powerful tools? The ratings provided by teachers (Figure 3) suggested that the kits had enhanced all 21st century skills almost to the same degree, with teamwork and collaboration scoring slightly higher (18%) than creativity (16%) and problem-solving (15%), for instance. A large number of teachers discussed how the kits facilitated increased communication, sharing, and teamwork, gave students the chance to work together on a shared goal, bounce ideas off each other, and collaboratively create and solve problems. Examples below are from teachers' commentaries on the contributions of the stem.T4L kits to students' teamwork, creativity, critical thinking, and problem solving skills.

- *The students gain so much from connecting with one another and building their teamwork/collaboration skills. Working as a part of a team that they don't 'usually' work with to build friendships.*
- *It helped them work as a team to find solutions to problems. They used each others skills to complete assigned tasks.*
- *Student learning improved as they were able to investigate, build, code and work collaboratively together.*
- *Students learnt to work together to solve a problem. They can now do this across other KLAs.*
- *Students became more engaged in learning and work together to get the job done.*
- *Working in a variety of group situations to achieve common goals, working together to solve problems and having success were all great experiences for them to have.*
- *For their final class project students demonstrated their collaborative ability to provide ideas, share roles, critique each others work and step outside their comfort zone to*

participate with their class.

- *Students were able to work together closely, and draw on the strengths of each other to create their projects.*
- *It allowed for students to work collaboratively, build on their communication skills in a creative way across multiple KLAs.*
- *Their creativity began to improve significantly and they began thinking outside the box to accomplish tasks.*
- *Further development of their critical thinking, communication skills, collaboration skills and creative skills have improved.*
- *Problem solving skills were developed through the use of the kit. Our students also developed collaborative skills in using the equipment.*
- *Developed their creative and critical thinking skills through design challenges.*
- *My K/1 students in particular displayed an amazing array of problem solving and innovation skills while using the Lego WeDo.*
- *We have been amazed at the skill level and the innovation created by students from kindergarten to year 6. Working with the kits allows kids to explore what they know and demonstrate that knowledge in so many different ways.*
- *Students were able to become problem solvers and critical thinkers in a fun and engaging way.*

As mentioned above, we collected detailed and extensive data from our school case studies on student learning that further provided insights into the advantages and impacts of the stem.T4L kits on learning. Below, we will discuss the findings on this phase of the research.

In order to measure student learning in STEM, researchers have drawn upon interviews and surveys, as we did in previous stem.T4L research. However, these self-report methods have limitations such as respondents "knowingly or unknowingly trying to please the evaluator, and over- or underestimating what they know or do" (Fu, Kannan, & Shavelson, 2019 p. 37). As a way forward, "more direct" ways of measuring student learning (e.g. classroom observations) have been suggested – yet these more direct methods often disrupt or intrude upon the learning experience (Fu et al., 2019).

In order to conduct a more direct and less obtrusive STEM learning assessment, we decided to put the classroom teachers involved in our project, in the driver's seat. Put differently, to safeguard against the interruption caused by researchers' presence in the classrooms, we invited three teachers from three different schools to collect first-hand data on student learning. We hypothesised that students that participate in the stem.T4L project (i.e. experimental group) will have noticeable improvements in a number of KLAs compared to students who will receive normal lessons and are not involved in the project (i.e. control group). Below, we will provide a description on the participating schools, the developed assessment rubrics, and the data collected from each school.

Research participants

The first step to conducting school case studies was to recruit a number of volunteer schools that had booked a stem.T4L kit for Term 3. 2020. Our previous studies had revealed that teachers' engagement and interest in research and their likelihood to generate data was higher in primary schools. This could be partially due to primary teachers' having the same group of students every day and using the stem.T4L equipment more consistently, and hence, more opportunities to participate in research to produce data. Therefore, focusing our attention on primary schools, we liaised with the stem.T4L leaders to identify a number of primary teachers who were highly engaged with the stem.T4L project. The leaders, who worked closely with schools to provide technical and professional support, had greater familiarity with teachers and hence were able to put us in contact with a few schools. Further communications resulted in recruitment of two schools that served as our experimental groups.

As mentioned above, a careful comparison of learning gains in the stem.T4L vs. non-stem.T4L learning environment would help us ascertain the impact of the project on student attainment more closely. As such, we endeavoured to recruit a school, as our control group which, firstly, was not using any stem.T4L kits, secondly, shared the same demographic characteristics (e.g. District, School gender, School subtype) as our experimental schools, and thirdly, their target learning outcomes matched those of our experimental groups in Stage 3 (as will be explained below). Reaching out to a number of primary schools, we located a school that met all the three criteria. Table 2 describes the characteristic of the three schools that participated in our case study research.

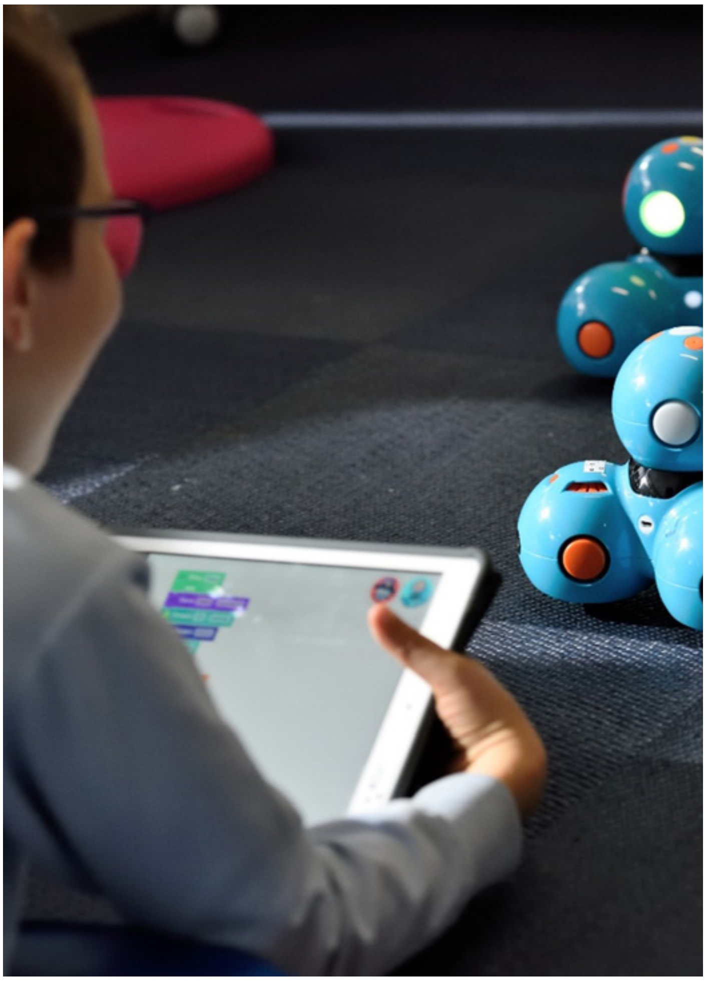


Table 2

School	Demographics	Stem. T4L Kit	Research participants	Syllabus outcomes measured	Aim of the lessons
Ex Group (1) PS	Western Sydney Mainstream Co-ed	PC Robotics	Stage 3	Science: ST3-4LW-S Science: ST3-3DP-T English: EN3-1A	Discovering how technology can support and improve living things
Ex Group (2) PS	South Western Sydney Mainstream Co-ed	3D printing	Stage 3	Maths: MA3-14MG Science: ST3-2DP-T	Toy story Learning challenge: creating/ modifying a toy for their buddy class.
Control Group PS	South Western Sydney Mainstream Co-ed	No stem. T4L kit	Stage 3	Maths: MA3-14MG English: EN3-1A	N/A

Table 2. Case study participants

Assessment Rubrics

An assessment rubric was needed to help teachers track and document the progress of students systematically. To develop such a rubric we needed to consider two factors: the Stage of our participating students, and the type of stem.T4L kit that the experimental schools were using. Communication with these schools revealed that a PC Robotics and a 3D Printer were the kits at the disposal of the two schools, which were intended to be used for Stage 3 in both cases. Using NSW syllabus outcomes as our guideline, we created an assessment rubric to measure student learning gains in the KLAs specifically targeted by the PC Robotics and the 3D Printer, namely; Science and Technology K-6, Maths K-10, and English K-10. Presenting the schools with the rubric, we asked the teachers to select learning areas that closely aligned with their syllabus and matched the focus of their learning activities for Term 3. So, the Ex Group (2), who were using the 3D Printer, decided to evaluate a Science outcome (ST3-2DP-T) and a Maths outcome (MA3-14MG). The Ex Group (1), on the other hand, which had the PC Robotics, assessed learning gains in two Science outcomes (ST3-3DP-T & ST3-4LW-S) and an English outcome (EN3-1A).

As shown in Table 3, three to four indicators of achievement were identified for each learning outcome, along with three performance descriptors, namely C (Working towards), B (Working at) and A (Working beyond). Initially, we asked our participating teachers (n=3) to identify the number of students in their class that were sitting in the A to C categories for each indicator, at the beginning of Term 3 (weeks 1-2), 2020. We were interested to know whether exposure to the kits or their absence would make a difference in students' progress, evident in them being re-categorised from, the C to the B or from the B to A, by the end of the term (weeks 9-10).

Table 3

Science ST3-3DP-T: Defines problems, and designs, modifies and follows algorithms to develop solutions	C Working Towards	B Working At	A Working Beyond
Indicator 1 Identify data required to formulate algorithms to improve a process	Is unsure of what data is needed for the soil sensor	Can successfully identify that data on soil moisture is required	Is able to customise data values to improve readings on the soil sensor
	Total number of students:	Total number of students:	Total number of students:
Indicator 2 Design, modify and follow simple algorithms	Is unable to follow simple algorithms	Can design, modify and follow simple algorithms	Can design, modify and customise more advanced algorithms
	Total number of students:	Total number of students:	Total number of students:
Indicator 3 Extend sequences of steps to provide a series of possibilities through branching	Is unable to follow simple algorithms	Can design, modify and follow simple algorithms	Can design, modify and customise more advanced algorithms
	Total number of students:	Total number of students:	Total number of students:

Table 3. Teacher Assessment Rubric: 1

Based on the data we obtained from the first rubric, it became clear that each teacher had a number of students in the C category (i.e. Working Towards) before the start of the intervention, which could allow us to monitor their progression during the term. So, a second rubric was developed and teachers were asked to choose three to five students from C and track their learning progress on a fortnightly basis using the second rubric (Table 4, below). This rubric was designed to provide an opportunity for teachers to document their evaluations, drawn from their daily observations, and to include further commentaries and work samples for each student individually.

Table 4

Science ST3-3DP-T: Defines problems, and designs, modifies and follows algorithms to develop solutions	C Working Towards	Using a range of your usual assessment practices and knowledge, please provide comments on how the student is "working towards" each Indicator. (please attach work samples for each entry if applicable)
Indicator 1 Identify data required to formulate algorithms to improve a process		Student A (ID....) Teacher's comments:
Indicator 2 Design, modify and follow simple algorithms		Student A (ID....) Teacher's comments:

Table 4: Teacher Assessment Rubric: 2

Additional data

To alleviate the demands on teachers' time in the control group, and hence encourage participation, we reduced the frequency and amount of data that the teacher was required to provide. More specifically, the teacher in the control group was asked to complete only assessment rubric 1, prior and after the conclusion of Term 3. Teachers in the experimental groups, however, completed both the first assessment (before and after using their stem.T4L kit), as well as the second assessment, fortnightly (Ex Group (1) completed five fortnightly assessments and Ex Group (2) three assessments). In addition, both experimental schools provided work samples and lesson plans, and participated in an online pre-survey, and virtual informal interviews. When conducted at the start of the term, the interview focused on issues such as teachers' overview on how they planned to use their allocated kit, the main KLAs they were hoping to tap into, and the proficiency of their students in each learning area, which were used as a blueprint to construct the assessment rubrics. When conducted towards the end of the term, the interview was used to seek additional clarity and detail from teachers on their assessments of student learning. Table 5 summarises the data provided by each teacher.

Table 5

Teacher	Pre-survey	Interview	Assessment 1	Assessment 2	Work samples and lesson plans
Ex Group (1) Zoe	✓	Pre: ✓ Post: ✓	Pre: ✓ Post: ✓	Week 2: ✓ Week 4: ✓ Week 6: ✓ Week 8: ✓ Week 10: ✓	Lessons plans: ✓ Work samples: ✓
Ex Group (2) Helen	✓	Pre: ✓ Post: ✕	Pre: ✓ Post: ✓	Week 2: ✓ Week 4: ✕ Week 6: ✓ Week 8: ✕ Week 10: ✓	Lessons plans: ✕ Work samples: ✓
Control Group	N/A	N/A	Pre: ✓ Post: ✓	N/A	N/A

Table 5. Data collected from each school

The data obtained from the Ex Group (1), as shown in Table 5, was more detailed and comprehensive, especially in terms of work samples and weekly lesson plans. Starting with this school, we will provide an introduction on how the two teachers in our experimental group implemented the PC Robotics and the 3D printer in their lessons.

Teachers' plans to implement the stem.T4L kit

Zoe and Helen [1] were the two teachers in our experimental groups, having 12 and over 25 years' experience under their belt (respectively). Zoe, teaching in a school where 97% of the students are a non-English speaking background, is a librarian teacher. Her work in Term 3, 2020, focused on developing students' digital technologies skills, in her unit on Living Things (Science). In her pre-survey and interview, Zoe indicated that the MakeCode website, Scratch and Tynker were her guidebook for inspiration and in planning activities for using the PC Robotics, which she was hoping to use more than three times a week with her Year 6 students. The eight lesson plans Zoe provided described the aim of the unit as helping students "discover how technology can support and improve living things", through using Micro:bits, as shown below:

Table 6

Lessons Year 6	Activity	Learning Intention and Success Criteria
1	Introduction to unit – Science and Digital Technologies Using Google Slides as a journal Revision of coding and algorithms Revision of computational thinking Unplugged algorithm activity	We are learning to think computationally ✓ I can organise my Google Slides ✓ I can think computationally ✓ I can save and open Makecode programs
2	SOLE - Investigation How can we use technology to meet the needs of plants?	We are learning to think like a scientist ✓ I can participate in a SOLE activity ✓ I can ask questions ✓ I can find answers ✓ I can explain the needs of a plant ✓ I can collaborate with others
3-5	Soil Moisture sensor 1. Set up soil moisture probe and code in Makecode 2. Check and record dry and wet soil numbers (average and use as a base) 3. Conditionals - if wet then … if dry then a. Code with conditionals - display image 4. User input button a and button b	We are learning to make and code a sensor ✓ I can think scientifically and computationally ✓ I can make my soil sensor ✓ I can use the Microbit correctly ✓ I can write code for my MicroBit ✓ I can collaborate with others
6-8	Design process Design a product to help people meet the watering needs of their plants.	We are learning to design a solution ✓ I can use the design process ✓ I can use the Microbit correctly ✓ I can write code for my MicroBit ✓ I can make mistakes ✓ I can collaborate with others

Table 6. Zoe's lesson plans

1 Pseudonyms are used throughout this paper to conceal the identity of teachers and students that participated in the case studies.

Zoe also provided us with PowerPoint slides, lesson activities, and resources that she had created for her unit on Living Things in Term 3. We have put together some of these learning materials to create a collage to show the learning journey that she took her students on.

Over in the second school (Ex Group 2), technology has been always "a strong focus", and Helen, drawing upon project-based learning, was going to implement the 3D printer three days a week, for use in PDHPE Positive Behaviour for Learning units with her Years 5 and 6 students. Helen told us initially that they had used the 3D printer in the past to produce a five-point token (with a slogan) to go with their Positive Behaviour Learning program. For Term 3, she was planning to create more enthusiasm around technology by making students "create or modify a toy for their buddy class". Table 7 shows the activities that Helen included in her PDHPE unit and shared with us

Table 7

Term 3 PDHPE Activities Ys 5 & 6		
1. Manipulating and discussing parallel lines on 3D shapes with teacher.	2. Physically making 3D shapes with play dough and cutting with plastic knives.	3. Sketching 3D shapes from different views
4. Constructing a 3D shape from a net and identifying the pairs of parallel faces.	5. Identifying the 2D shape that was made when an object was cut in half.	6. Completing a Seesaw activity, describing the differences between prisms and pyramids.
7. Creating a 3D object with toothpicks, sketching its net and describing its properties.	8. Students were given the top, front and side view of an object and had to physically make it using cubes and sketch it.	

Table 7. Helen's lesson plans

Tracking students' progress

We mentioned above that to capture student learning gains, we asked the teachers in our experimental group, Zoe and Helen, to conduct fortnightly assessments of five students who were at C category (Working Towards) at the time of the first assessment, and follow their progress throughout the term using Rubric 2. Extensive data was provided on ten students (five from each school) that included works samples, pictures, and commentaries. While presenting all the available information we have collected on these students is valuable, we will provide a full account on the progress of only one student from each school, for brevity, and then analyse the data in a more holistic manner.

John's learning journey

As part of the syllabus modules on the Living World and Digital technologies (shown in the Collage above), Zoe's students completed a Micro:bit exercise where they learned to code a soil moisture probe. Lesson one was an introduction and revision on coding, computational thinking, and algorithms. Students were instructed to complete a 'How to plant a seed' algorithm with the aim of recognising and reflecting on computational concepts and approaches they were applying.

John (pseudonym), like the other four students, was Working Towards achieving the learning outcomes for the two Science (Science ST3-3DP-T and ST3-4LW-S) and English (EN3-1A) outcomes. Zoe's notes on the first activity that John completed suggested that he was unable to independently design and modify simple algorithms, and required teacher assistance to complete most tasks using algorithms. Placing John in the C category, Zoe explains that John's ability to use data to support his explanations is limited (Indicator 4 (ST3-3DP-T), present data as evidence in developing explanations), and he requires examples from teachers and peers, as the example below taken from John's reflection indicates:

LESSON 1 REFLECTION

I used debugging when i was making the instructions easier for the computer to understand the algorithms of planting a seed

Assessment of other indicators of Science (ST3-4LW-S) narrates the same story in which John is struggling to complete most activities independently. Although still "Working towards" fulfilling English outcomes (EN3-1A), and requiring "modelled examples to be able to complete the task independently", John "participates in class discussions", and "sometimes contributes", although his contributions are not always "relevant to the discussions".

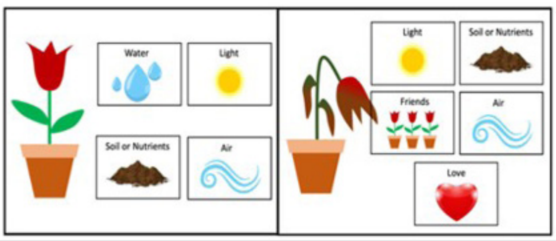
During Weeks 3 and 4, students worked on different tasks including building a sensor with nails or alligator clips, using a Micro:bit coding sensor to detect soil moisture and collect data for wet and dry soil, and using conditionals and user input. At the end of Week 4, Zoe completed a second round of assessments, where she indicated that John was in the same category of Working Towards for all indicators of Science and English except for one indicator (i.e. Indicator 1 ST3-4LW-S). To assess Indicator 1 (Plan and conduct a fair test to show the conditions needed for a particular plant or animal to grow and survive in its environment), Zoe designed the SOLE task in lesson 2 and as John's work sample below shows, he managed to complete this task and identified the needs of a plant "mostly independently". So, he was placed at B category (Working At) for Indicator 1.

WHAT DOES A PLANT NEED TO GROW?

Write a list of the things a plant needs to grow and survive.

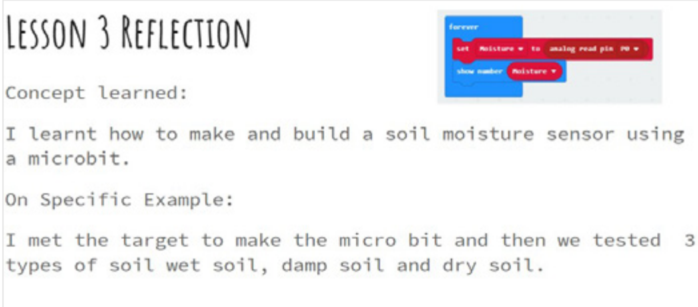
- Water
- Air
- Soil
- Space to grow
- Sun
- Sprinkler
- Heat

Copy and paste a diagram of the needs of a plant



Although the rest of Week 4 assessment signalled some learning growth, as also indicated in the above example on Indicator 1, John still needed assistance and “modelled examples” to complete tasks. Zoe’s comments on John’s work sample for Indicator 4 (ST3-3DP-T) shows the small steps he was taking during his learning journey:

Zoe: John “is starting to use some data to support his explanations and is on his way to working within this indicator. He does rely on modelled examples for assistance.


LESSON 3 REFLECTION

Concept learned:

I learnt how to make and build a soil moisture sensor using a microbit.

On Specific Example:

I met the target to make the micro bit and then we tested 3 types of soil wet soil, damp soil and dry soil.

Week 6 marks a new phase in John’s learning curve. As the highlighted parts in Table 8 suggests there is a shift from C to B category by the time of the third assessment (Week 6), for eight out of ten indicators of Science and English.

Table 8

John	Assessment 1 Week 2	Assessment 2 Week 4	Assessment 3 Week 6	Assessment 4 Week 8	Assessment 5 Week 10
Science ST3-3DP-T	Indicator 1: Working Towards	Working Towards	**Working At**	Working At	Working At
	Indicator 2: Working Towards	Working Towards	**Working At**	Working At	Working At
	Indicator 3: Working Towards	Working Towards	**Working At**	Working At	Working At
	Indicator 4: Working Towards	Working Towards	Working Towards	Working Towards	**Working At**
Science ST3-4LW-S	Indicator 1: Working Towards	**Working At**	**Working At**	Working At	Working At
	Indicator 2: Working Towards	Working Towards	**Working At**	Working At	Working At
	Indicator 3: Working Towards	Working Towards	Working Towards	Working Towards	Working Towards
English EN3-1A	Indicator 1: Working Towards	Working Towards	**Working At**	Working At	Working At
	Indicator 2: Working Towards	Working Towards	**Working At**	Working At	Working At
	Indicator 3: Working Towards	Working Towards	**Working At**	Working At	Working At

Table 8. John’s fortnightly assessments

Except in two indicators, one of which remains at C (i.e. Indicator 3 of the second Science outcomes), John displays modest and consistent learning growth in the second half of Term 3 in all areas under evaluation.

Zoe's commentaries in Assessments 3 to 5 indicate John's increasing understanding of algorithms and coding, as well as development of interaction skills, as illustrated in the two examples below:

Table 9

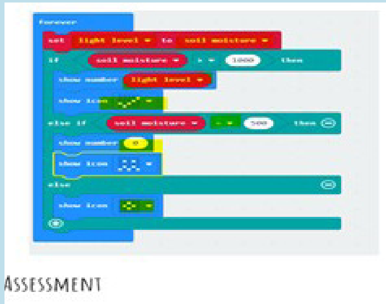
	Week 6	Week 8	Week 10
ST3-3DP-T **Indicator 2** Design, modify and follow simple algorithms	John demonstrated that he understood the example code shown during the last two lessons. He was able to modify this code to suit the soil moisture sensor task.		
EN3-1A **Indicator 1** Use interaction skills, for example paraphrasing, questioning and interpreting	John is developing appropriate interaction skills during lessons. He was assisting a student who had been absent the week before and worked well to communicate the task to the other student.	John is able to interact with his peers and teachers appropriately. He has developed the language necessary to explain his thinking or ask questions.	John is able to interact appropriately with his peers and teacher.

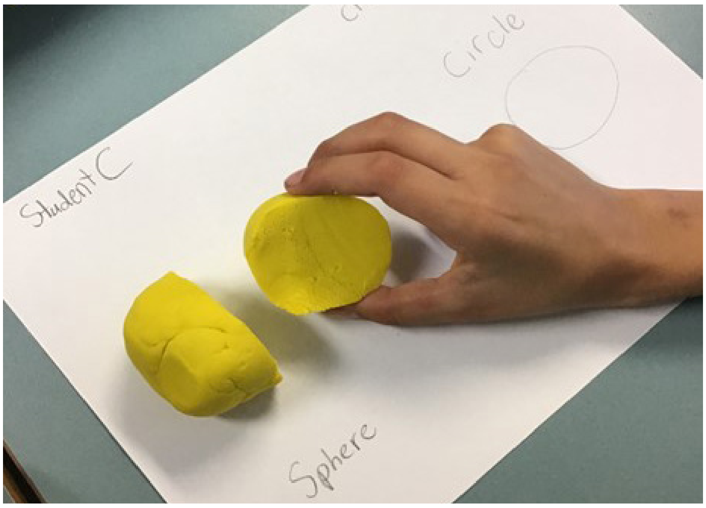
Table 9. Zoe's assessments on John progress, Week 6-10

Olivia's Learning Journey

Early in Term 3, Helen starts out the assessment cycles by estimating students' understanding of Maths (MA3-14MG) and Science (ST3-2DP-T) concepts, as aligned with the learning outcomes in the assessment rubric. For Maths, she introduces an activity to get students to manipulate and discuss parallel lines on 3D shapes, then physically make 3D shapes with play dough, and go on to sketch 3D shapes from different views.

Olivia is a Year 5 student in Helen's class (in Ex Group 2). Like the rest of students in the C category, she is working towards achieving the learning outcomes when assessed for all indicators of Science and Maths during weeks 1-3. For instance, she can identify and determine the number of pairs of parallel faces of three-dimensional objects but "on 1-2 objects only" (Indicator 1 of Maths). She can also draw but not visualise the objects' make-up when cut using concrete materials (Indicator 2 of Maths), as shown in her work sample (1) to the right:

We mentioned above Helen from the second experimental group, established a number of criteria for students to apply in their design including "the size of the printing tray in 3D printer, time in the 3D printer, not including too many moving parts, and the age of buddy class". Helen's notes on



Olivia Work Sample 1

Olivia's first attempts indicate that she had limited understanding of functional requirements in defining a problem (Indicator 2 of Science), was using limited appropriate technical terms (Indicator 3 of Science) and struggling to refine design solutions after numerous iterations (Indicator 4 of Science).

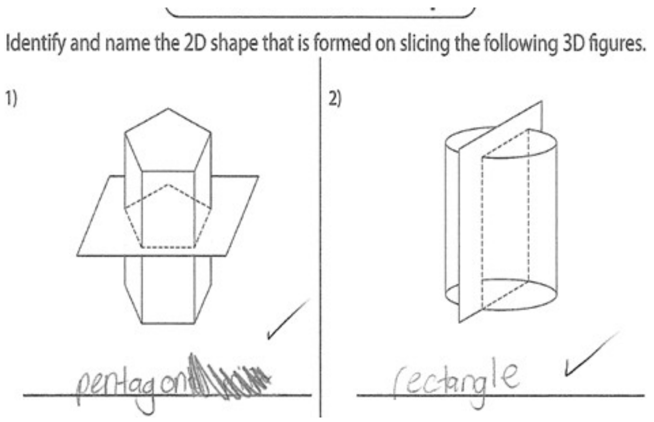
In the second assessment completed in Weeks 4-5, subtle signs of learning growth start to appear, where Olivia is placed in the B category (Working At) in 3 Indicators of Maths and one indicator of Science. Table 10 depicts Olivia's learning progress in weeks 4-5.

Table 10

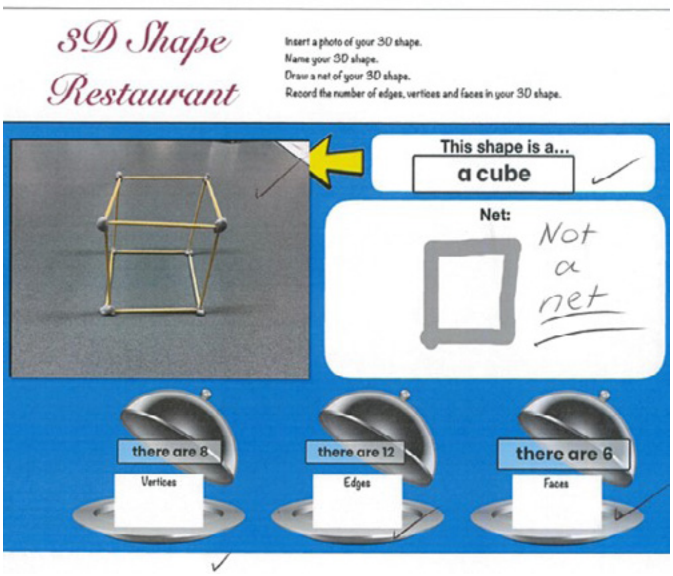
Olivia	Assessment 1 Week 2-3	Assessment 2 Week 4-5	Assessment 3 Week 6-7-8
Math	Indicator 1: Working Towards	Working Towards	**Working At**
MA3-14MG	Indicator 2: Working Towards	**Working At**	Working At
	Indicator 3: Working Towards	**Working At**	Working At
	Indicator 4: Working Towards	**Working At**	Working At
Science	Indicator 1: Working Towards	**Working At**	**Working At**
ST3-2DP-T	Indicator 2: Working Towards	Working Towards	**Working At**
	Indicator 3: Working Towards	Working Towards	Working Towards
	Indicator 4: Working Towards	Working Towards	**Working At**

Table 10. Olivia's fortnightly assessments

Olivia manages to identify four out of six examples of the 2D shape (Work sample 2) that were made when objects were cut in half (Indicator 2 of Maths), creates a 3D object with toothpicks (Work sample 3), and describes its properties (Indicator 3 of Math), as shown in her work samples below.

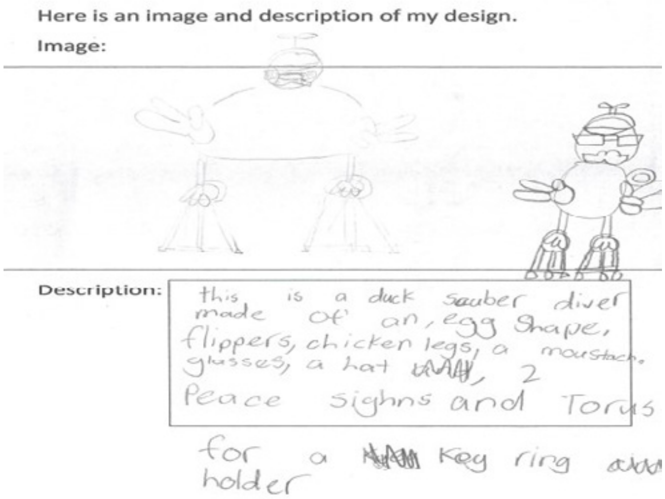


Olivia Work Sample 2



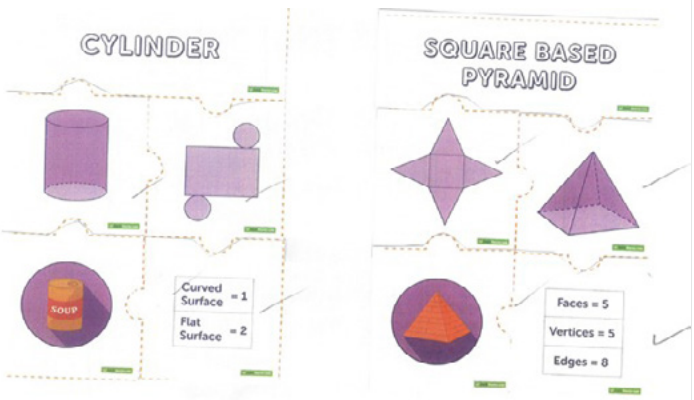
Olivia Work Sample 3

In Science, Olivia is showing small progress especially in Indicator 1 (Examine and critique needs, opportunities or modifications using a range of criteria to define a project), after she receives peer feedback on her modifications for her second design (Work sample 4). However, she remains in C for the other three indicators of science.

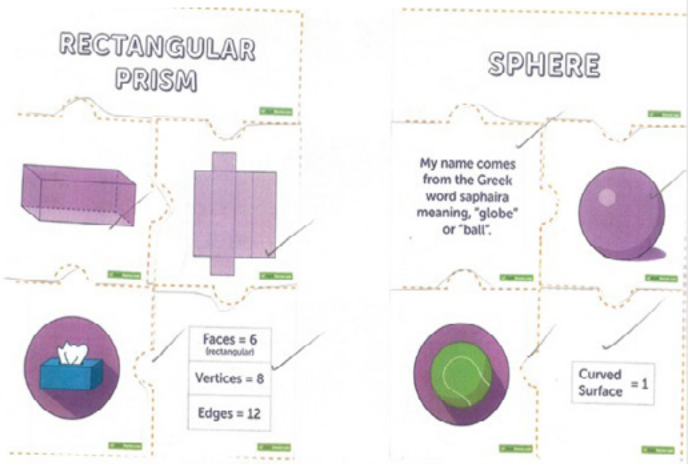


Olivia Work Sample 4

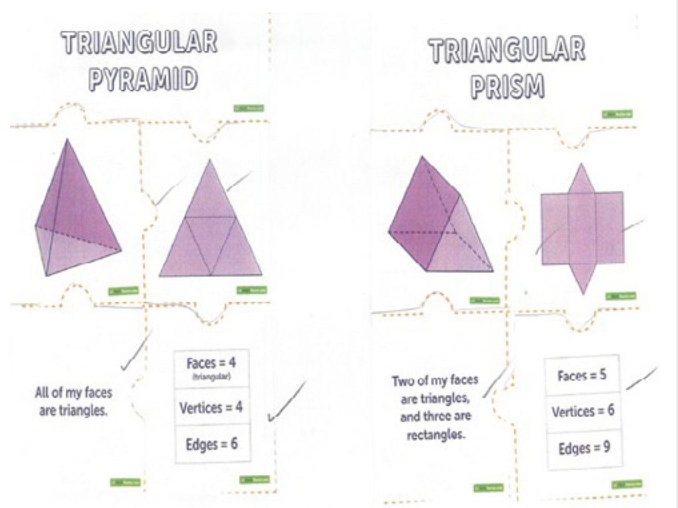
In the last assessment that Helen provides for weeks 6-8, she rates Olivia's Maths performance in Indicator 1 at B, which in the second assessment was still a C. This means, now she can easily distinguish the number of pairs of parallel faces of three-dimensional objects (Work samples 5-7). For the other three indicators of Maths, she continues to be at B and consistently demonstrates an understanding of properties of prisms and pyramids. So, we observe that towards the end of Term 3 Olivia moves from "Working towards" to "Working at" for all indicators of Maths.



Work Sample 5



Work Sample 6



Work Sample 7

There is also noticeable progress in Science, as she arrives at B by the time of the third assessment for three out of four indicators of Science. Although we did not receive work samples of the final 3D toys that students created, Helen informed us that Olivia, like other students, used Tinkercad to re-design her toy, as shown below.

Work Sample 8

Learning progress of other four students

As the assessments and work samples of John and Olivia suggested both students moved from C to B category in all or the majority of the indicators of Science, English and Maths. In this section, we first turn to the other four students from each experimental school and evaluate the changes in their learning progress. For brevity and clarity, we compare students' performance from the first assessment with the final assessment, but we will note any findings of significance over these 10-week cycle. We will then view the bigger picture of class progress when using the kits, by exploring the whole class data from Rubric 1 to identify the extent of learning progress at a larger scale.

Starting with Zoe's students, we see similar patterns of improvement in the learning outcomes of other four students, besides John. In the first Science outcome (first two columns of Table 11), all four students progressed from C (Working Towards) to B (Working At) in all indicators by the time of the final assessment. However, it is worth noting that all of these students, including John, arrived at B earlier in the Term (i.e. in the third assessment in week 6), but remained in this category for the rest of the term.

For the second science outcome (second column of Table 11), the four students achieved the same learning growth (i.e. moved from C to B). Looking across the assessment cycles, we observed that the four students made swift progress in Indicator 1, going from C to B by week 4 (second assessment). However, for Indicator 2, learning growth was more modest and signs of learning started to appear in week 6 (third assessment), again from C to B. Three students (John, Lucas, and Eva) appeared to struggle when assessed for Indicator 3. Although, as mentioned, except John, all four arrived at B by the end of the term, progress was slow for Lucas and Eva and it was in week 10 that their learning improvement was satisfactory and they were placed at B.

For English outcomes, besides John, two other students (Noah & Mia) progressed from C to B in all three indicators by the time of the final assessment. Eva improved on Indicator 1 of English only during the final week, but remained at C for Indicators 2 and 3. During the final interview that we conducted with Zoe, we learned that Ava was an EAL/D learner and although she would always try hard, she was still "hesitant to put her hand up and contribute freely in class". So, for her, science was a more comfortable zone and she was making progress more noticeably in science because she did not "have to communicate verbally" and could "have success without needing to verbalise it", as Zoe suggested.

For Lucas achieving the outcomes of Indicator 2 of English was somewhat difficult but he managed to progress to B for indicators 1 and 3 in week 3 (assessment 3). Again, Zoe told us in her interview that Lucas although was an English speaking student, he was "incredibly shy and would not speak in front of the class". He was able to achieve the learning outcomes in science through building and using the Micro:bit, but he did not "want to talk to people in front of the class".

Table 11

	Science: ST3-3DP-T 4 Indicators		Science: ST3-4LW-S 3 Indicators		English: EN3-1A 3 Indicators	
	First Assessment Week 2	Final Assessment Week 10	First Assessment Week 2	Final Assessment Week 10	First Assessment Week 2	Final Assessment Week 10
Lucas	4 Indicators at Working Towards	4 Indicators at Working At	3 Indicators at Working Towards	3 Indicators at Working At	3 Indicators at Working Towards	**2 Indicators at Working At**
John	4 Indicators at Working Towards	4 Indicators at Working At	3 Indicators at Working At	**2 Indicators at Working At**	3 Indicators at Working Towards	3 Indicators at Working At
Noah	4 Indicators at Working Towards	4 Indicators at Working At	3 Indicators at Working Towards	3 Indicators at Working At	3 Indicators at Working Towards	3 Indicators at Working At
Mia	4 Indicators at Working Towards	4 Indicators at Working At	3 Indicators at Working Towards	3 Indicators at Working At	3 Indicators at Working Towards	3 Indicators at Working At
Eva	4 Indicators at Working Towards	4 Indicators at Working At	3 Indicators at Working Towards	3 Indicators at Working At	3 Indicators at Working Towards	**1 Indicators at Working At**

Table 11. Zoe's assessments of five students' learning gains

The further details that we received on Lucas and Eva highlighted the impact of other key variables that at play and how the extent of learning gains are mediated by students' behavioural traits or background. Having said that, exposure to the stem.T4L kits had clearly transformed the learning environment and boosted learning through creating sustained level of engagement. For those students with a tendency to stay quiet, either due to language proficiency or their introvert personality, the stem.T4L kits offered an alternative where they could demonstrate their learning through "doing a physical task" rather than "communicating verbally", as suggested by Zoe. When we asked Zoe to gauge the impact of the project on her five students, she confidently pointed out that three of those students would make "no progress at all". Somewhere else in her interview, she again highlighted the difference she had observed in her students' engagement and behaviour when the kit was present:

So at least I would say two of those students are often very disengaged. So that's probably where the PC robotics kits and those sorts of kits come in. I saw it with another particular child that wasn't part of the study, but in another class, who is often late to school, very hesitant to do anything, needs to be pushed constantly to get on task. And I observed him as well. He would be one of these disengaged kids, he was on time and he was barely away on a Thursday when his classes were held and they would come in and he'd be really enthusiastic about the program. So, I think that's probably the big difference with definitely a few of those kids. (Interview with Zoe, Week 10).

What was the pattern of learning improvement in the Ex Group (2)? Helen's assessments (Table 12), suggested that in 3 indicators of Maths, the four students progressed from C to B by the time of the second assessment (weeks 4-5), and remained in the same category until the end of the term. Victoria and David were continuously placed at C when assessed on Indicator 1 throughout the term. Moving on to Science, Sofia, Victoria and David progressed from C to B in three out of four indicators by the final assessment. While these three made quick progress on Indicator 1 and arrived at B in the second assessment, their progress on Indicator 2 was slower and they achieved the learning outcomes for this indicator in the final assessment (week 8). Except Jack, the other three students, struggled with Indicator 3 and were consistently rated at C in the three assessments. Jack (Year 6), who was ahead of his peers and rated at B at baseline, remained in the same category and did not display further learning gains in the four indicators of Science.

Table 12

	Maths: MA3-14MG 4 Indicators		Science: ST3-2DP-T 4 Indicators	
	First Assessment Week 2-3	**Final Assessment Week 6-8**	**First Assessment Week 2-3**	**Final Assessment Week 2-3**
Sofia	4 Indicators at Working Towards	4 Indicators at Working At	4 Indicators at Working Towards	3 Indicators at Working At
Jack	4 Indicators at Working Towards	4 Indicators at Working At	4 Indicators at Working At	4 Indicators at Working At
Olivia	4 Indicators at Working Towards	4 Indicators at Working At	4 Indicators at Working Towards	3 Indicators at Working At
Victoria	4 Indicators at Working Towards	4 Indicators at Working At	4 Indicators at Working Towards	3 Indicators at Working At
David	4 Indicators at Working Towards	4 Indicators at Working At	4 Indicators at Working Towards	3 Indicators at Working At

Table 12. Helen's assessments of five students' learning gains

Classroom assessments

Interesting findings emerged from the two class assessments that both Zoe and Helen completed for us at baseline and conclusion of Term 3. Beginning with Zoe's students, we observed considerable learning gains not only from C to B, but also from B to A (Working beyond). As Table 13 below shows for Indicator 1 of Science (ST3-3DP-T), 22 out of a total of 25 students were placed at C (Working towards) at baseline. For Indicator 3, all 25 students in the class were 'Working towards' this element of the outcome. In the post-assessment, we see a surge in the number of students in the B category for Indicators 1 and 3, with 15 students sitting in B, leaving the number of students in C at three. While there were no students at A at baseline for Indicators 1 to 3, seven students were moved to A in the post-assessment. In the post-assessment for Indicator 2, there was a rise in the number of students sitting in the B category (N= 16): the majority progressed to this category, and only 2 students remained at C from an initial 13. For Indicator 4, there was minor re-categorisation from baseline to post-evaluation, with five students moving from C to B. The number of students in the A category (Working beyond) also increased slightly to five from an initial three.

Table 13

Science ST3-3DP-T: defines problems, and designs, modifies and follows algorithms to develop solutions	C Working Towards		B Working At		A Working Beyond	
Indicator 1 Identify data required to formulate algorithms to improve a process	Is unsure of what data is needed for the soil sensor		Can successfully identify that data on soil moisture is required		Is able to customise data values to improve readings on the soil sensor	
	N Pre 22	N Post 3	N Pre 3	N Post 15	N Pre 0	N Post 7
Indicator 2 Design, modify and follow simple algorithms	Is unable to follow simple algorithms		Can design, modify and follow simple algorithms		Can design, modify and customise more advanced algorithms	
	N Pre 13	N Post 2	N Pre 12	N Post 16	N Pre 0	N Post 7
Indicator 3 Extend sequences of steps to provide a series of possibilities through branching	Is unable to extend algorithm sequence to accommodate branching		Can use branching to extend sequence of steps to provide a series of possibilities		Can extend sequence of steps into a greater series of possibilities through more advanced branching	
	N Pre 25	N Post 3	N Pre 0	N Post 15	N Pre 0	N Post 7
Indicator 4 Present data as evidence in developing explanations	Provides anecdotal explanations without data, or uses data that does not support explanations		Presents relevant data as evidence when developing or communicating explanations		Presents detailed or extensive data to support explanations or to identify hypotheses for further investigation	
	N Pre 7	N Post 2	N Pre 15	N Post 16	N Pre 3	N Post 7

Table 13. Zoe's class assessment: Science outcomes (1)

For the second Science outcome (Table 14), most students moved from C to B for Indicators 1 and 3, leaving only two students at C in the post assessment. Category A, with no students at baseline, contains seven students for the 3 Indicators of science at the end of Term 3.

Table 14

Science: ST3-4LW-S: examines how the environment affects the growth, survival and adaptation of living things (Indicators)	C Working Towards		B Working at Students can successfully:		A Working beyond Students can successfully:	
Indicator 1 Plan and conduct a fair test to show the conditions needed for a particular plant or animal to grow and survive in its environment	Is uncertain of requirements of a fair test or what the conditions are for the survival of living things		Can plan and conduct a fair test and articulate what conditions are needed for the survival of living things		Can plan, conduct, modify and refine a fair test, to illustrate how soil moisture interacts with other conditions for survival of living things	
	N Pre 16	N Post 2	N Pre 9	N Post 16	N Pre 0	N Post 7
Indicator 2 Describe how changing physical conditions in the environment affect the growth and survival of living things	Is uncertain of how environmental change can affect growth/ survival of living things		Can describe how changing physical conditions affect growth and survival, in relation to soil moisture exercise		Is able to describe physical conditions and processes affecting growth and survival, beyond the specific examples used in the soil moisture exercise	
	N Pre 7	N Post 2	N Pre 18	N Post 16	N Pre 0	N Post 7
Indicator 3 Understand that scientific and technological knowledge is used to solve problems and inform personal and community decisions	Is uncertain or unaware of the role or relevance of sci. & tech. knowledge for themselves or society		Understands how scientific and technical knowledge can be used to solve problems or inform decisions		Is able to recognise or hypothesise on how scientific or technological can help investigate/support unresolved problems or complex decisions	
	N Pre 16	N Post 2	N Pre 9	N Post 16	N Pre 0	N Post 7

Table 14. Zoe's class assessment: Science outcomes (2)

For Indicator 1 of English (Table 15), the majority (N=18) remained at B from pre to post evaluation. However, two students progressed to be at A, making the total number of students sitting at A, five from an initial three. For Indicators 2 and 3, progression was observed in seven students, who were moved from C to B from pre to post. Only one and two students were placed at A in post evaluation for Indicators 2 and 3, respectively.

Table 15

English EN3-1A: communicates effectively for a variety of audiences and purposes using increasingly challenging topics, ideas, issues and language forms and features	C Working Towards		B Working at		A Working beyond	
Indicator 1 Use interaction skills, for example paraphrasing, questioning and interpreting nonverbal cues and choose vocabulary and vocal effects appropriate for different audiences and purposes	Interaction skills or vocabulary are often under-developed or inappropriate when working with peers or teacher		Has interaction skills, vocabulary or vocal effects that are proficient and suited to working with peers or teacher (e.g. frequency or relevance of questioning)		Interaction skills, vocabulary and vocal effects are highly proficient and facilitate collaboration and communication with teacher or peers (e.g. is able to paraphrase complex issues into simpler language for peers)	
	N Pre 4	N Post 2	N Pre 18	N Post 18	N Pre 3	N Post 5
Indicator 2 Participate in and contribute to discussions, clarifying and interrogating ideas, developing and supporting arguments, sharing and evaluating information, experiences and opinions	Participation and contribution is limited or peripheral, whether small group or whole-of-class (e.g. tends not to seek clarification of ideas or contribute opinions)		Participates in and contributes to whole of class or small group discussions (e.g. shares relevant ideas or experiences with peers, willingness to evaluate ideas)		Sustained participation in or contribution to whole of class or small group discussion, and proficiency in interrogating arguments or evaluating information.	
	N Pre 12	N Post 5	N Pre 10	N Post 16	N Pre 3	N Post 4
Indicator 3 Identify and summarise key ideas and information...e.g. note-taking or using digital technologies	Tendency to overlook key ideas or information provided by teacher, or more limited capacity for summarising information.		Can identify and summarise key ideas and information		Is adept at extracting and communicating key messages from teacher instruction and proficient in condensing information.	
	N Pre 12	N Post 4	N Pre 10	N Post 16	N Pre 3	N Post 5

Table 15. Zoe's class assessment: English outcomes

Helen's classroom assessments indicate significant learning gains from baseline to the end of Term 3. In pre-evaluation, the majority of students were distributed fairly equally between C and B categories for all indicators of Maths, with only 3-4 sitting at A. In the final assessment, no student was rated at C for Indicators 1, 2, and 3, and for Indicator 4, only six still remained at C, meaning the majority were re-grouped to be at either B or A (Table 16). The number of students Working beyond (A) for Indicators 1 to 3 is impressive— by the final assessment over 23 (out of 31) students were working beyond the requirements of this indicator, from an initial figure of 3-4.

Table 16

Maths: MA3-14MG: identifies three-dimensional objects, including prisms and pyramids, on the basis of their properties, and visualises, sketches and constructs them given drawings of different views	C Working Towards		B Working at Students can successfully:		A Working beyond Students can successfully:	
Indicator 1 Identify and determine the number of pairs of parallel faces of three-dimensional objects	Can identify and determine these features on 1-2 objects only		Identify and determines these on a range of objects		Identify and determine these on an extended range of sophisticated objects	
	N Pre 14	N Post 0	N Pre 13	N Post 6	N Pre 4	N Post 25
Indicator 2 Visualise and draw the resulting cut face (plane section) when a three-dimensional object receives a straight cut	Is unable to visualise or draw the object make up when cut		visualise and draw the cut face on an object		visualise and draw the cut face on simple and more complex objects	
	N Pre 18	N Post 0	N Pre 10	N Post 8	N Pre 3	N Post 23
Indicator 3 Identify, describe and compare the properties of prisms and pyramids, including: number of faces, shape of faces, number and type of identical faces, number of vertices, number of edges	Can identify, or describe some properties on 1-2 prisms and pyramids		Identify, describe and compare the full range of properties that make up prisms and pyramids.		Identify, describe and compare prisms and pyramids and has explored additional features	
	N Pre 18	N Post 0	N Pre 10	N Post 3	N Pre 3	N Post 28
Indicator 4 Visualise and sketch three-dimensional objects from different views, including top, front and side views	Is unable to visualise or sketch 3D objects from different views		Is able to visualise and sketch 3D objects from all different views		Using great detail is able to visualise and sketch complex 3D objects from a range of views.	
	N Pre 18	N Post 6	N Pre 10	N Post 10	N Pre 3	N Post 15

Table 16. Helen's class assessment: Maths outcomes

Unlike student performance on Maths at pre evaluation, Science and Technology appeared to be a more challenging subject for students, especially before using the stem.T4L kits. As Table 17 shows, there was no student at A in pre-assessment in all indicators, with the majority clustering at C. The final assessment suggests noticeable learning growth, where 16 to 20 students were placed at B across the four indicators. Also, category A contained a few residents, with 12 students sitting at this category for Indicator 4 by the end of the term.

Table 17

Science: (Digital Technologies; Design & Production): ST3-2DP-T plans and uses materials, tools and equipment to develop solutions for a need or opportunity	C Working Towards		B Working at Students can successfully:		A Working beyond Students can successfully:	
Indicator 1 Examine and critique needs, opportunities or modifications using a range of criteria to define a project	Is unable to identify needs or opportunities in defining a project		Can examine and critique needs, modifications and opportunities when defining a project		Is able to examine and critique needs and opportunities – and propose effective modifications – using criteria that is more sophisticated than peers	
	N Pre 27	N Post 11	N Pre 4	N Post 18	N Pre 0	N Post 2
Indicator 2 Examine and determine functional requirements to define a problem	Has limited understanding of functional requirements in defining a problem		Can examine and determine functional requirements to define a problem		Is able to examine, determine and propose creative solutions to a range of functional requirements	
	N Pre 27	N Post 11	N Pre 4	N Post 18	N Pre 0	N Post 2
Indicator 3 Develop, record and communicate design ideas, decisions and processes using appropriate technical terms	Communicates design ideas and decisions with only occasional reference to appropriate technical terms		Can develop, record and communicate design ideas, decisions and processes with adequate technical terms		Can develop, record and communicate design ideas, decisions and processes with an expanded vocabulary or more advanced understanding of technical terms	
	N Pre 27	N Post 7	N Pre 4	N Post 20	N Pre 0	N Post 4
Indicator 4 Develop solutions through trialling and refining using iterations	Struggles to refine design solutions after numerous iterations, or is easily frustrated with trial/error process		Is able to iteratively trial and refine design solutions		Is able to identify appropriate refinements through fewer iterations or trials	
	N Pre 27	N Post 3	N Pre 4	N Post 16	N Pre 0	N Post 12

Table 17. Helen's class assessment: Science outcomes

Experimental groups vs control group

Based on the information obtained from the experimental schools on the learning progress of ten students (five from each school), as well as the two class assessments (pre vs post) we conclude that the majority of the two cohorts achieved observable learning improvements in the syllabus outcomes assessed for this study, meaning most of these students moved to the next higher performance level, (i.e. from C to B or B to A). Now the question is to what extent did the stem.T4L project contribute to student learning outcomes when compared against the control group? In other words, did the exposure to stem.T4L serve as a catalyst for learning growth, or did we observe the same level of learning attainment in our control group, which was not involved in the stem.T4L project?

In order to answer these questions, we compared the class assessments from the experimental schools with the control group. For Maths, we compared the control group with the Ex Group (2) as they both assessed the same learning outcomes (MA3-14MG). Table 18 depicts the performance of students in these two schools. Of note is the slight difference between the number of students in the two samples, where the Ex Group (2) had 31 students compared to 24 students in the control group.

The pre-assessment indicated that in the control group the average was weighted towards "Working towards", with 14 to 17 students sitting at C across Indicators 1 to 4. Comparted to the Ex Group (2), although we had a sizable number (10-13 students) categorized at "Working at", still the majority (14-18 students) were grouped under "Working towards" at pre-evaluation, suggesting that both schools were performing at the same proficiency level at the beginning of Term 3 in Maths. Another similarity between the two schools was the number of students in the A category (Working beyond), which was less than five students in both cases.

The post-assessments indicated a dramatic increase in learning growth in Maths for the Ex Group (2), after being exposed to the stem.T4L kits. More specifically, while we observed improvement in learning in the control group, where the majority of students were regrouped under "Working at" at the end of the term (i.e. move from C to B), there was still the same number of students (2-4) at A (Working beyond) at the conclusion of the term. However, in the Ex Group (2) we had a remarkable increase in students in the A category from 3-4 students in pre to 15-28 students in post across Indicators 1 to 4 of Maths. The findings imply that the stem.T4L kits tie into different learning capabilities and developmental stages. The learning challenges they present not only attract less engaged students, but also appeal to more advanced students by triggering their curiosity to discover and learn more. That is why we see students in the Ex Group (2) making progress across all the three performance levels, not just from C to B, but a noticeable surge in the A category.

Table 18

Maths: MA3-14MG	C Working Towards		B Working at		A Working beyond	
Indicator 1	Can identify and determine these features on 1-2 objects only		Can identify and determines these on a range of objects		Can identify and determine these on an extended range of sophisticated objects	
Control Group	N Pre 14	N Post 4	N Pre 6	N Post 18	N Pre 4	N Post 2
Ex Group (2)	14	0	13	6	4	25
Indicator 2	Is unable to visualise or draw the object make up when cut		Visualise and draw the cut face on an object		Visualise and draw the cut face on simple and more complex objects	
Control Group	N Pre 16	N Post 4	N Pre 4	N Post 18	N Pre 4	N Post 2
Ex Group (2)	18	0	10	8	3	23
Indicator 3	Can identify, or describe some properties on 1-2 prisms and pyramids		Can identify, describe and compare the full range of properties that make up prisms and pyramids		Can identify, describe and compare prisms and pyramids and has explored additional features	
Control Group	N Pre 18	N Post 2	N Pre 4	N Post 20	N Pre 2	N Post 2
Ex Group (2)	18	0	10	3	3	28
Indicator 4	Is unable to visualise or sketch 3D objects from different views		Is able to visualise and sketch 3D objects from all different views		Using great detail is able to visualise and sketch complex 3D objects from a range of views	
Control Group	N Pre 17	N Post 6	N Pre 6	N Post 16	N Pre 2	N Post 2
Ex Group (2)	18	6	10	10	3	15

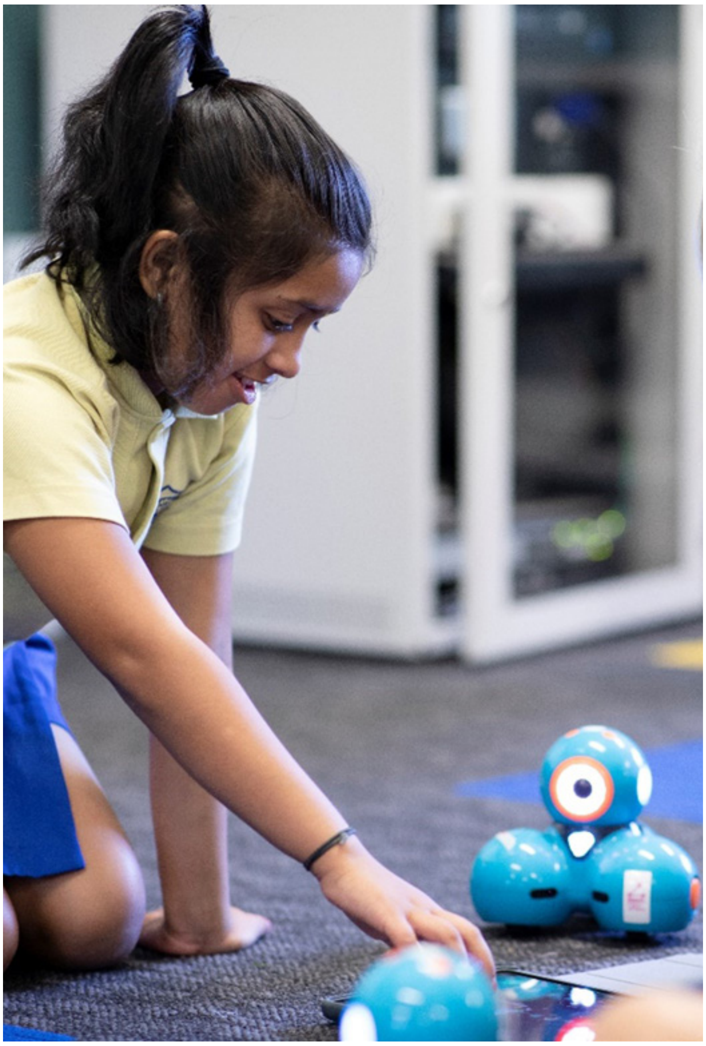
Table 18. Comparison between control group and Ex Group (2): Maths outcomes

The second learning area monitored and evaluated by the control group was English (EN3-1A). The Ex Group (1) measured this learning outcome too, hence a comparison of leaning achievement in the two cohorts was attainable. Before looking at the data, we need to underline an observed difference in the percentage of students from non-English speaking background in each school. In the case of the Ex Group (1), it appeared that 97% of students were EAL/D background, whereas in the control group they were only 18%. Such disparity could have a bearing on student achievements of English outcomes. In other words, it was likely that EAL/D students' participation and interaction patterns were coloured by their language limitations. In Fact, there are studies in higher education that indicate non-English speaking students have lower level of participation in collaborative learning and obtain smaller gains in literacy than their peers (Liu, Hu, & Pascarella, 2019). Some educators also believe language barriers or lack of language fluency negatively impact student engagement and interactions with peers and teachers (e.g. Ghannaj, n.d.). The baseline data we collected from the two cohorts confirmed these arguments, where we found a gap in English proficiency of the two groups especially for Indicators 2 and 3 at the outset of the term.

Considering Indicator 1 (Table 19), in the control group, 18 students (out of 25) were performing at B at baseline. In the Ex Group (1) students were hovering at the same level, with 18 out of 24 placed at B, as per the first class assessment. Post assessments suggested that learning gains for the two schools for Indicator 1 of English was slow, with only four students in the control group and two students in the Ex Group (1) moving from C to B categories. In other words, the majority of students remained in the B category from pre to post in the two schools.

The gap in English proficiency of students from the two cohorts was wider for Indicators 2 and 3, as mentioned. At the outset, the majority of students (15-18) in the control group were rated at B, while only 10 in the Ex Group (1) were performing at this level, suggesting that students in the control group had a higher proficiency level in English outcomes at the beginning of the term, compared to Ex Group (1) for Indicators 2 and 3. In both schools, however, students sitting at the A category were only 2-5 across the three Indicators, at baseline. The final assessments suggested that only four-five students in the control group moved one level higher for Indicator 2 (five students from 'Working towards' to 'Working at' and four students from 'Working at' to 'Working beyond'). The rest of the students maintained the same level of proficiency over the term. For Indicator 3 [2], almost all students remained in the very same category. So, based on the post-assessment we conclude that, in total, students in the control group only exhibited slight differences in learning gains for three indicators of English, and the majority did not make any progress during one school term.

When we looked at the Ex Group (1), it was evident that higher learning gains were achieved by students in this group for Indicators 2 and 3, where students sitting at B increased from 10 to 16.



2 There was a slight disparity between the number of students assessed in our control group in pre and post evaluations. The first assessment included data on 24 students, however, the teacher observed and evaluated 26 students, as indicated by the final evaluation.

Table 19

English EN3-1A	C Working Towards		B Working at		A Working beyond	
Indicator 1	Interaction skills or vocabulary are often under-developed or inappropriate when working with peers or teacher		Has interaction skills, vocabulary or vocal effects that are proficient and suited to working with peers or teacher (e.g. frequency or relevance of questioning)		Interaction skills, vocabulary and vocal effects are highly proficient and facilitate collaboration and communication with teacher or peers	
Control Group	N Pre 5	N Post 1	N Pre 18	N Post 19	N Pre 2	N Post 4
Ex Group (1)	4	2	18	18	3	5
Indicator 2	Participation and contribution is limited or peripheral, whether small group or whole-of-class		Participates in and contributes to whole of class or small group discussions		Sustained participation in or contribution to whole of class or small group discussion	
Control Group	N Pre 5	N Post 0	N Pre 18	N Post 19	N Pre 2	N Post 6
Ex Group (1)	12	5	10	16	3	4
Indicator 3	Tendency to overlook key ideas or information provided by teacher, or more limited capacity for summarising information.		Can identify and summarise key ideas and information		Is adept at extracting and communicating key messages from teacher instruction and proficient in condensing information.	
Control Group	N Pre 4	N Post 3	N Pre 15	N Post 19	N Pre 5	N Post 4
Ex Group (1)	12	4	10	16	3	5

Table 19. Comparison between control group and Ex Group (1): English outcomes

The findings are of significance especially because of the observed achievement gap in English proficiency of the two cohorts at the beginning of the term. We anticipated that cultural/linguistic limitations inherent in the EAL/D context of the Ex Group (1) would slow down learning attainments. However, this cohort outperformed their counterpart in the control group contradicting the research that suggests first and second generation immigrant students achieve less well than native students (Blom & Severiens, 2008). This outstanding success was attributed mainly to the presence of the stem.T4L kits, which as so many teachers have pointed out encourage deeper level of student engagement and lead to higher learning.

CONCLUSION

The purpose of the present study was to explore the effectiveness of the stem.T4L project in improving student learning outcomes. To measure the extent of progression, we collected data from two sources: a teacher survey, and school case studies. 408 teachers participated in the survey administered to all schools that had booked a stem.T4L kit in Term 3 and 4, 2020. In addition, we developed case studies on three schools in Term 3 (two experimental groups and one control group) to trace and document the learning progress of students in a number of KLAs.

The findings indicated that the stem.T4L project had great potential to enhance learning outcomes, with 94% of teachers (n = 386) attesting to its positive impact. For these teachers the effect was evident in a heightened student engagement, which had led to noticeably higher learning. Like other STEM interventions that draw upon educational technologies such as robotics, 3D printers and virtual reality, stem.T4L had also created ample opportunities for students to trial without fear of failing. Curiosity was an element that was clearly and profusely evident in the stem.T4L environment, turning students into 'makers' able to establish a stronger link between theory and practice. Teachers told us that through doing and making, students learned to be in charge and took on the exciting challenges, which working with the kits would normally present, to solve real-world problems.

In addition to the survey, the school case studies confirmed the powerful impact of the stem.T4L kits on learning. Students in the experimental groups, on average, achieved higher learning gains compared to the control group. In Maths, students in both cohorts were at the same proficiency level (Working towards) at the outset of the term, yet students in the experimental group that had worked with the stem.T4L kits outperformed the control group when the final assessment was completed. We observed that a significant number of these students had achieved the learning outcomes of Maths on Indicators 1-4 and were regrouped under the A category (Working beyond). For English outcomes, the same findings emerged: although students in the experimental group were slightly behind their counterparts in the control group, they reached a higher performance level by the end of the term especially for Indicators 2 and 3. In other words, the presence of the PC robotics kit had created unique opportunities for students to participate in discussions and share their experiences, and as such enhanced their English proficiency even though the majority were EAL/D learners.

Based on the empirical findings presented in this paper we argue that working with the stem.T4L kits positively affects learning gains through awakening students' sense of curiosity and engaging them in higher-order thinking. Making and creating, which are "highly tolerant of errors" (Martin, 2015 p. 37), occur throughout every step of the stem.T4L journey, bringing in an element of playfulness that begets experimentation and adaptability when challenges arise (Hatano & Inagaki, 1986). An environment so conducive to making supports student autonomy, advocates a growth mindset (Azevedo, 2011; Dweck, 2000), and leads to powerful forms of learning where students learn through receiving *recursive feedback* (Okita & Schwartz, 2013) and from "the actions of their creation" (Martin, 2015 p. 37).

We conclude this report by highlighting two factors, which we often come across during the administration and synthesis of the research, that seem to moderate the extent of effectiveness of the stem.T4L kits' implementation:

1. The close link that teachers make between the kits and the KLAs remains a defining factor in how students receive the kits and the extent to which they benefit from them. The stronger that link, the more meaningful learning activities will become for students. Additionally, the adoption of a learning approach, such as problem-based leaning that Helen in Ex Group (2) implemented, will put into perspective and define a purpose for using the kits for students, which in turn will affect how they interact and engage with the kits.

2. The second key factor that determines the success and significance of using the kits is the consistency of usage and teachers' willingness and readiness to take on the challenge of

implementing the kits. So many teachers repeatedly tell us that time constraints and fitting the kits into an already crowded curriculum interfere with the uptake of these technologies. However, studies consistently show a longer exposure to STEM related activities, including use of STEM technology, facilitate higher learning achievements (e.g. Wahono, Lin, & Chang, 2010). The findings of the present research corroborated previous studies where we observed teachers in our experimental schools that invested a great deal of their time in preparing for and implementing the kits achieved considerable outcomes. The quote below points at the time and effort that the Ex Group (1) staff, including Zoe, dedicated to the stem.T4L kit to upskill, and to ensure a smooth integration, which as the findings showed, came into fruition:

You need to be using it regularly. This was maybe the introductory lessons that come before the equipment, but we always do our lesson around just what the equipment is and how to handle it and how to use it. We did that sole session on the Living Things without touching the equipment. So, it's not necessarily that it's the equipment all the time, but using it kind of regularly, you're building on the skills. The more you do it, the better you get at it. Like everything else, it's practice and training and that's how you improve (Interview with Zoe, Week 10).

Although interdisciplinary STEM education has found its way into many classrooms, there is still limited knowledge on how student learning should be assessed and evaluated in STEM, bringing to the fore the need for developing STEM assessment tools and guidelines for classroom use (Gao et al., 2020). The rubrics developed for this research can address this gap as it proved to be a practical assessment tool for teachers to utilise when evaluating students' learning outcomes.

ACKNOWLEDGMENT

The researchers would like to thank participating schools and teachers for their time and effort in collecting data and contributing to the research on the stem.T4L project.

REFERENCES

Atmatzidou, S., & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. Robotics and Autonomous Systems, 75, 661-670.

Azevedo, F. S. (2011). Lines of practice: A practice-centered theory of interest relationships. Cognition and Instruction, 29(2), 147-184.

Banerjee, P. A. (2017). Does continued participation in STEM enrichment and enhancement activities affect school maths attainment? Oxford Review of Education, 43(1), 1-18.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. Computers & Education, 72, 145-157.

Bishop, P., Downes, J., Hennessey, S., Olofson, M., & Swallow, S. (2016). Collaborative action research for middle grades improvement. Educational Action Research, 24(2), 194-215.

Blanchard, S., Freiman, V., & Lirrete-Pitre, N. (2010). Strategies used by elementary schoolchildren solving robotics-based complex tasks: Innovative potential of technology. Procedia-Social and Behavioral Sciences, 2(2), 2851-2857.

Blom, S., & Severiens, S. (2008). Engagement in self-regulated deep learning of successful immigrant and non-immigrant students in inner city schools. European Journal of Psychology of Education, 23(1), 41-58.

Blotnicky, K. A., Franz-Odendaal, T., French, F., & Joy, P. (2018). A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students. International Journal of STEM Education, 5(1), 22

Chambers, J. M., Carbonaro, M., Rex, M., & Grove, S. (2007). Scaffolding knowledge construction through robotic technology: A middle school case study. Electronic Journal for the Integration of Technology in Education, 6, 55-70.

Chou, P. N. (2018). Skill development and knowledge acquisition cultivated by maker education: Evidence from Arduino-based educational robotics. EURASIA Journal of Mathematics, Science and Technology Education, 14(10), em1600.

Dewey, J. (1997). Experience and education. New York: Free Press.

DfE. (2014). What is the most effective way of increasing young people's take-up and attainment of strategically important subjects, especially science and maths? (DFE-00093-2014). Retrieved from: www.gov.uk/government/publications

Dougherty, D. (2013). The maker mindset. In M. Honey & D. E. Kanter (Eds.), Design, make, play: Growing the next generation of STEM innovators (pp. 7–11). New York: Routledge.

Dweck, C. (2000). Self-theories: Their role in motivation, personality, and development. Psychology Press.

Eguchi, A. (2014, July). Robotics as a learning tool for educational transformation. In Proceeding of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education Padova (Italy).

Ford, C. (2018). Effective practice instructional strategies: Design of an instrument to assess teachers' perception of implementation. Studies in Educational Evaluation 56, 154-163.

Fu, A. C., Kannan, A., & Shavelson, R. J. (2019). Direct and unobtrusive measures of informal STEM education outcomes. New Directions for Evaluation, 2019(161), 35-57.

Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. International Journal of STEM Education, 7(1), 1-14.

Ghannaj, A. (n.d). How to improve engagement in the language learning classroom. Retrieved from https://www.teachthought.com/pedagogy/how-to-improve-engagement-in-efl-esl-language-classroom/

Gruber, M. J., Gelman, B. D., & Ranganath, C. (2014). States of curiosity modulate hippocampus-dependent learning via the dopaminergic circuit. Neuron, 84(2), 486-496.

Hatano, G., & Inagaki, K. (1986).Two courses of expertise. In Stevenson, H., Assume, H., & Hakuta, K. (Eds.), Child development and education in Japan (pp. 262–272).New York, NY: Freeman.

Hayden, K., Ouyang, Y., Scinski, L., Olszewski, B., & Bielefeldt, T. (2011). Increasing student interest and attitudes in STEM: Professional development and activities to engage and inspire learners. Contemporary Issues in Technology and Teacher Education, 11(1), 47-69.

Kwon, H. (2017). Effects of 3D Printing and Design Software on Students' Overall Performance. Journal of STEM Education: Innovations and Research, 18(4), 37-42.

Lambert, P. (2017). Hard focus on "soft" skills. Future Frontiers background. A paper commissioned by the NSW Department of Education. Retrieved from https://cica.org.au/wp-content/uploads/Hard_focus_on_soft_skills_Dr_Phil_Lambert.pdf

Liu, J., Hu, S., & Pascarella, E. T. (2019). Are non-native English speaking students disadvantaged in college experiences and cognitive outcomes? Journal of Diversity in Higher Education. Advance online publication. https://doi.org/10.1037/dhe0000164

Martin, L. (2015). The promise of the maker movement for education. Journal of Pre-College Engineering Education Research (J-PEER), 5(1), 30-39.

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. Computers & Education, 70, 29-40.

Namdar, B., & Shen, J. (2015). Modeling oriented assessment in K-12 science education: A synthesis of research from 1980 to 2013 and new directions. International Journal of Science Education, 37(7), 993–1023.

Okita, S.Y., & Schwartz, D. L. (2013). Learning by teaching human pupils and teachable agents: The importance of recursive feedback. Journal of the Learning Sciences, 22(3), 375-412.

Papert, S. (1993). The children's machine: Rethinking school in the age of the computer. New York: Oxford University Press.

Ramachandran, A., Huang, C. M., & Scassellati, B. (2019). Toward Effective Robot--Child Tutoring: Internal Motivation, Behavioral Intervention, and Learning Outcomes. ACM Transactions on Interactive Intelligent Systems (TiiS), 9(1), 1-23.

Scoular, C., & Care, E. (2018). Teaching Twenty-First Century Skills: Implications at System Levels in Australia. In Assessment and Teaching of 21st Century Skills (pp. 145-162). Springer, Cham.

Wade, S., & Kidd, C. (2019). The role of prior knowledge and curiosity in learning. Psychonomic bulletin & review, 26(4), 1377-1387.

World Economic Forum. (2016). The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution. Retrieved from Geneva: http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf