# FOSTERING GLOBAL COMPETENCIES AND DEEPER LEARNING WITH DIGITAL TECHNOLOGIES RESEARCH SERIES

## IMPROVING GLOBAL COMPETENCIES AND DEEPER LEARNING THROUGH INTEGRATION OF ROBOTICS AND TECHNOLOGY INTO THE CLASSROOM

Research & Development
Toronto District School Board
March 2017
Report No. 17/18-15

**About this Project:**

This report is the result of a collaborative project supported by the Council of Ontario Directors of Education (CODE), Technology and Learning Fund, TDSB Teaching and Learning Department-STEM K-12 and TDSB Research and Development led by Research Coordinator Erhan Sinay.

**TITLE:** Fostering Global Competencies and Deeper Learning with Digital Technologies Research Series: Improving Global Competencies and Deeper Learning Through Integration of Robotics and Technology into the classroom

**AUTHORS:** Erhan Sinay, Thomas G. Ryan, Ashley Nahornick & David Sauriol



**Cite as:** Sinay, E., Ryan, T. G., Nahornick, A., & Sauriol, D. (2018). *Fostering global competencies and deeper learning with digital technologies research series: Improving global competencies and deeper learning through integration of robotics and technology into the classroom.* (Research Report No. 17/18-15). Toronto, Ontario, Canada: Toronto District School Board.



Research & Development
Toronto District School Board
1 Civic Centre Court, Lower Level
Etobicoke, ON M9C 2B3
research@tdsb.on.ca



R02(STEM\2016-17\Deep Learning and GC Reports\Research Series 3\GC Research Series)es.1485

# Acknowledgements

We would like to thank and acknowledge the support of TDSB Leadership Team:

**Antonio Santos**, Central Coordinating Principal, Toronto District School Board

**Roula Anastasakos**, Executive Superintendent, Research, Organizational Design and Information Service, Educational Partnerships

**Beth Butcher**, Executive Superintendent, LC 1 Leadership-School Effectiveness

**Manon Gardner**, Executive Superintendent, Teaching and Learning, Alternative, International Education

We would like to thank and acknowledge the support and contributions of the following research team members in this study:

**Kamini Jaipal-Jamani**, Associate Professor, Science Education, Department of Teacher Education Brock University. Faculty of Education

**Margaret Douglin,** Researcher Coordinator, Research & Information Services, Toronto District School Board

**Tammy Tse**, Researcher, Research & Information Services, Toronto District School Board

**Cosmin Marmureanu**, Researcher, Research & Information Services, Toronto District School Board

**Sarah Walter,** Researcher, Research & Information Services, Toronto District School

**Dimitris Graikinis,** Researcher, Research & Information Services, Toronto District School

**Ashkan Safari,** Researcher, Research & Information Services, Toronto District School

We would like to thank and acknowledge the following academics granting us permissions to use all or part of their survey tool on teacher engagement:

**Jason Ravitz,** Education Outreach Evaluation Manager, Google

**Robert M. Klassen,** Department of Education, University of York, York, United Kingdom

**Sündüs Yerdelen,** Middle East Technical University, Ankara, Turkey and Kafkas University, Kars, Turkey

**Tracy L. Durksen,** Postdoctoral Fellow, The University of New South Wales, Sydney, Australia

**Trevor P. Robinson,** Utah State University

**Stephen H. Whitehead,** California University of Pennsylvania

**Punya Mishra,** Associate Dean of Scholarship & Innovation, Professor, Leadership & Innovation Mary Lou Fulton Teacher's College, Arizona State University

**Peggy A. Ertmer,** Professor of Learning Design and Technology, Purdue University, College of Education

**Ahmad Khanlari,** PhD Candidate, University of Toronto

**Kaye Ebelt,** The Greene School, Florida

**Carol Goodenow,** Tufts University

**Margaret Blanchard,** Associate Professor of Science Education, North Carolina State University, College of Education

# Contents

## List of Figures

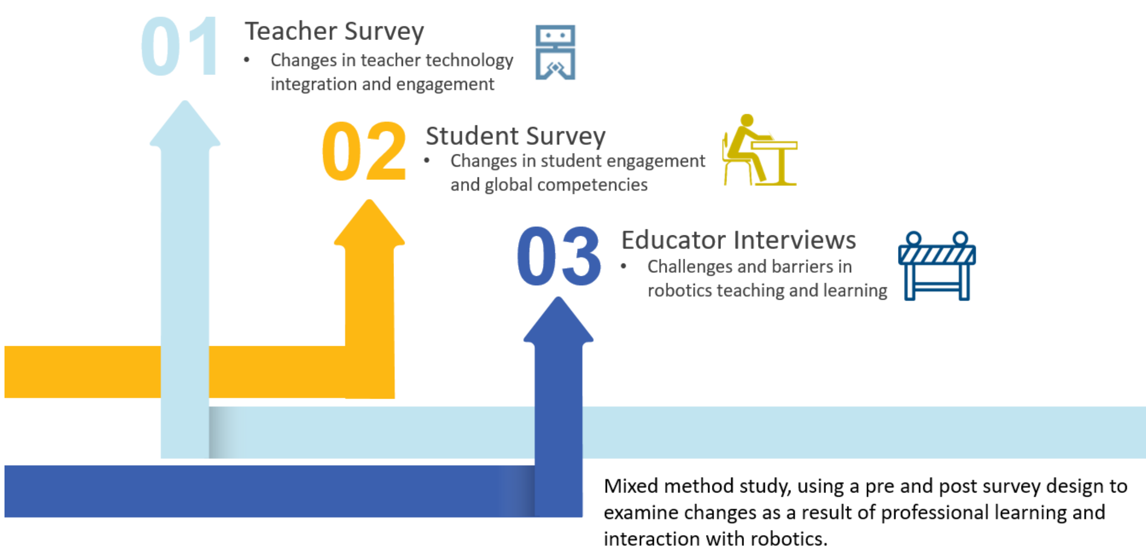
## List of Tables

## Executive Summary

We are living in a technologically advanced world, yet schools are lingering in the past as the 21st century society unfolds (Robinson, 2016). Robotics education is part of Science, Technology, Engineering, and Mathematics (STEM), a global movement in education, that focuses on using robotics to engage students, teachers and society; and at the same time a means to advance pedagogy and learning via creative challenges (English & Gainsburg, 2016b).

During 2015-2016, Toronto District School Board (TDSB) conducted a mixed methods study, involving the triangulation of quantitative and qualitative data sources on robotics in the classroom. Specifically, a pre and post survey design was used to examine changes that occur in teachers and students as a result of professional learning and interaction with robotics in the classroom. Additionally, interviews were conducted with 11 teachers and administrators at 6 randomly selected TDSB schools that were integrating robotics into their teaching and learning activities. This study allowed the TDSB to document changes in: (1) teacher technology integration (2) teacher engagement, (3) student engagement, (4) global competencies and skill growth in students along with (5) challenges and barriers in robotics teaching and learning. Figure 1 presents an overview of the current study.

***Figure 1: STEM Robotics Study Overview***




Overall, results suggest that professional learning in robotics and teaching with robotics reduced barriers experienced by teachers using technology in the classroom and the robotics initiative while increasing engagement and global competencies of students. A summary chart of key findings for the STEM robotics concerning with integration of robotics and technology in the classroom is shown in Table 1.

*Table 1: Key Findings in STEM Robotics Study*

| Teacher Technology Integration |
|---|
| ✓ Increased understanding and ability to connect robotics to other technologies.<br>✓ Improved confidence in choosing the most appropriate pedagogical approach to teach students about robotics.<br>✓ Improved confidence in their ability to help students when they have difficulty with robotics. |
| **Teacher Engagement** |
| ✓ More dynamic and learner focused teaching.<br>✓ Increased co-teaching and co-planning among teachers.<br>✓ High levels of teacher emotional and social engagement when teaching. |
| **Student Engagement** |
| ✓ Increased student engagement.<br>✓ Increased self-esteem.<br>✓ Increased student perseverance. |
| **Global Competencies and Skill Growth in Students** |
| ✓ Increased abilities with collaboration, inquiry/problem-based learning, creativity and innovation. |
| **Challenges and Barriers in Robotics Teaching and Learning** |
| ✓ Lack of teacher buy-in for robotics teaching and learning.<br>✓ Barriers in terms of available resources. |

Robotics has been associated with improvements in elementary students' academic achievement and learning skills as measured in report cards and standardised tests. In terms of report cards, more robotics integration in the classroom was associated with a greater likelihood of student receiving level 3 or 4 achievements in reading, writing, math and science. Additionally, evidence showed improvements in responsibility, organization, independent work, collaboration, initiative and self-regulation of learning skills and habits as graded by their teachers.

Robotics also improved students' scores on both the grade 3 and 6 EQAO tests, however, longitudinal research is necessary to further examine this association and its long-term impact[1]. From the results of this research, a number of recommendations are given here in order to provide the best opportunity for robotics programs to propagate and grow within the school board as the following:

- It is important that teachers do not duplicate their efforts concerning robotics-related activities and sharing resources. Lesson planning, creating robotics-oriented activities and assessing student learning outcomes can be done with other teachers both face-to-face and online.

[1] For details on achievement and skill development please see the detailed findings of this report. Unlike the report card, there is not a clear link between increased robotics and improved results on standardized tests.

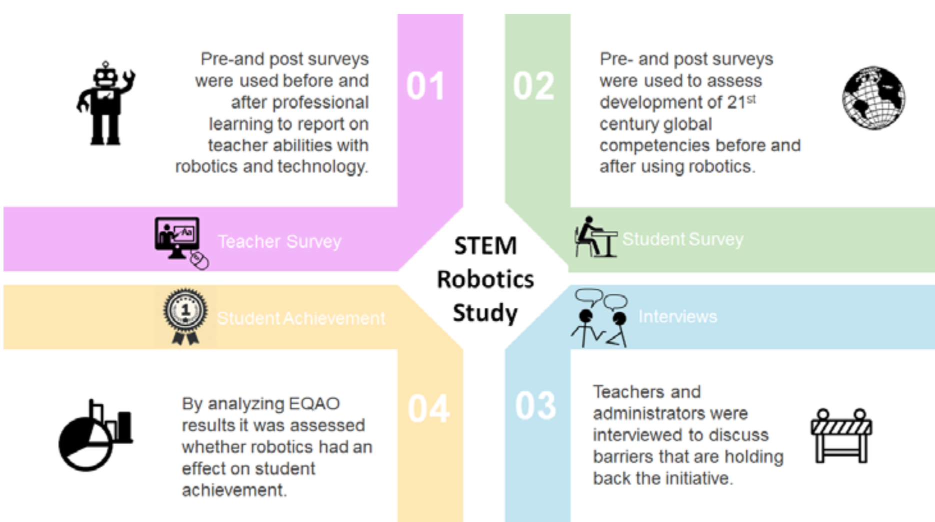
- Time is always of the essence for teachers as they are often in need of more of it. Release time given by administrators is of great importance. Having a teacher who is willing to lead the robotics initiative at a school can greatly improve buy-in.
- Generating buy-in and having teachers feel comfortable using robotics and STEM is of paramount importance. It is recommended that schools move slowly to implement robotics and encourage teachers to lead the initiative for integration of the robotics activities the classrooms. To accomplish this:
    - Administrators need to provide tailored help for individual teachers to support them in gaining efficacy and comfort with robotics implementation.
    - Establishing school-wide learning communities that allows teachers to lead the initiative, leading to improvement of teacher engagement, efficacy and buy-in.

## Introduction

In conjunction with the STEM and "*Fostering Global Competencies and Deeper Learning with Digital Technologies Research Series*", this report on the topic of robotics integration within the TDSB (Toronto District School Board) looks to provide a holistic portrait of STEM within the board. Robotics is an area that exists, along with coding within the broader category of STEM[2]. The areas within this report, which are examined using mixed methods design, include changes in *teacher engagement* and *ability to use technology* which impacts *student engagement* and *global competencies*. The *Technological, Pedagogical, and Content Knowledge (TPACK) framework* was used to examine teachers' abilities to teach with robotics and technology. This framework quantifies the changes in the abilities of teachers who need to interweave technology and robotics into their pedagogy. Therefore, pre and post-surveys were conducted to document the changes in these aptitudes. Building upon changes in teachers' pedagogical practices with robotics, students similarly were provided an opportunity to complete pre and post surveys. The surveys completed by students assessed their development of 21st century global competencies. The areas researched in this study were: 1) collaboration, 2) inquiry/problem-based learning, 3) creativity and innovation, 4) communication/ sociability, 5) perseverance and 6) confidence, before and after using robotics. The findings are compared and contrasted with teachers' perceptions of changes in students' ability within the same global competencies.

Student achievement data have also been compared with students' level of participation with robotics in the classroom. In addition, interview data has been used to generate a list of barriers that are presently holding the initiative back. Through both additional interview findings and researcher recommendations, ways to overcome these barriers are suggested as a blue print of how to best continue implementing robotics across the board. Figure 2 shows main components of the current study.

***Figure 2: STEM Robotics Study Components***




[2] See the related research series in this area in: http://www.tdsb.on.ca/research/Research/Publications/Technology-and-Innovation-in-Education

# Background and Rationale

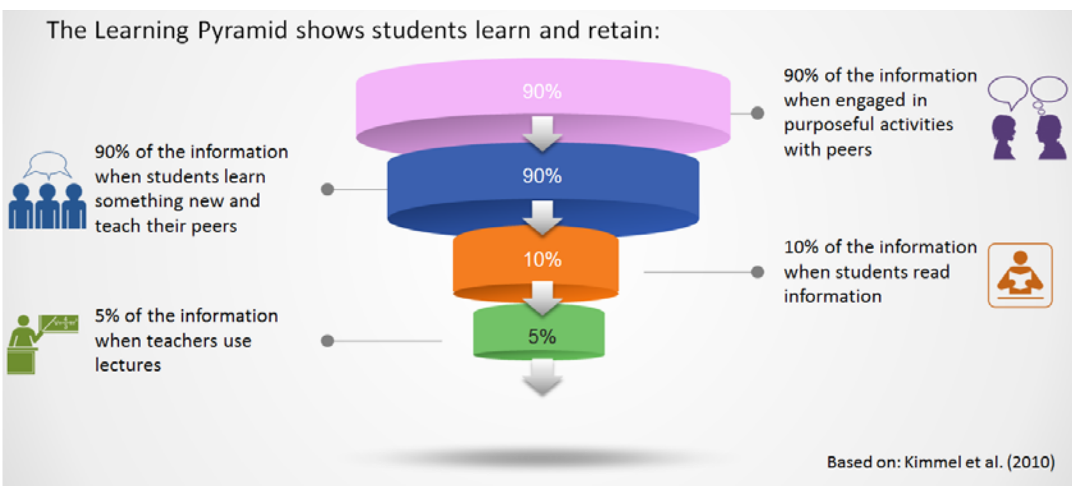
## Robotic-based Learning

Robotics education is part of the Science, Technology, Engineering, and Mathematics (STEM) movement in education which is currently foundational, and a critical step in the continued evolution and sustainability of our world (Thomas & Watters, 2015). STEM has many iterations, definitions and identities which infuse our educational landscapes (Bybee, 2013; English & Gainsburg, 2016b).

What is clear to educators is that we are living in a technologically advanced world, yet schools are lingering in the past as the 21st century society unfolds in a manner that is somewhat unpredictable and yet demanding (Robinson, 2016). Robinson (2016) suggested that schools need “innovation and higher order problem solving …. design thinking and engineering [as it] develops creative confidence through hands on projects and engineering …. to solve real life problems” (p. 6). Possibly more important is that:

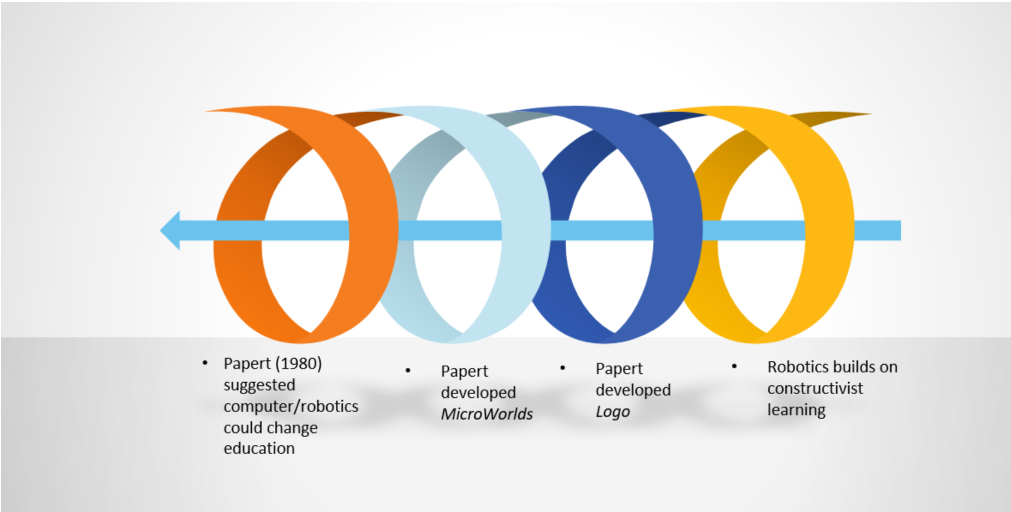
> …the Learning Pyramid shows that students learn and retain 90% of new knowledge when they are engaged in purposeful activities with their peers. When they learn something new and then teach their peers, they are likely to retain 90% of the information. In difference, only 5% is learned when teachers use lectures, and 10% is retained when students read the information (Kimmel, Carpinelli, Burr-Alexander, Hirsch, & Rockland, 2010, p. 57) (see Figure 3).

***Figure 3: Learning Pyramid***




Robotics in education is historically linked to Seymour Papert’s *MicroWorlds* software and *Logo* computer language (Rieber, 1992). Papert suggested new technologies (computers/robots) could change the landscape of learning in schools and education as early as the late 1960s (MIT News, 2016). Early robotics was built upon *MicroWorlds* which draws on the constructivist learning approach of Piaget (1983), associated with cognitive design (Papert, 1980) as depicted in Figure 5. Constructivism involves learner understanding via developmental stages and is a process of thinking and learning (Killen, 2007). Within constructivism it is the belief that learners will create their own knowledge, regardless of teaching approach or style (Piaget, 1983) that draws attention and praise. Robotics education therefore is not so much about teaching approach as it is a means to focus on learning through robotics (Catlin, 2012).

***Figure 4: Background in Robotics Education***



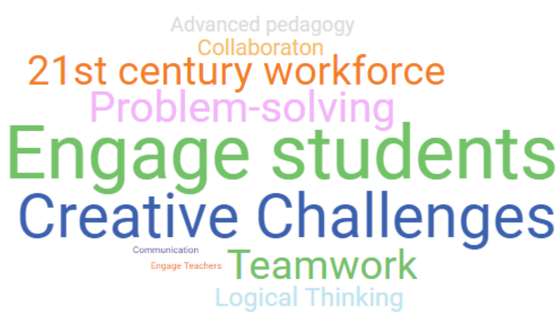

## Robotics and 21st Century Workforce

Robotics within STEM is a means to engage students, teachers and society and at the same time, a means to advance pedagogy and learning via creative challenges (English & Gainsburg, 2016b). Immersion within STEM is balanced to enhance each learner's abilities in problem solving, collaboration, and logical thinking (Han, 2012; Khanlari, 2016) (see Figure 5).

A recent report entitled, *STEM: Building a 21st century workforce to develop tomorrow's new medicines* by the Battelle Technology Partnership Practice (2014) concluded,

> China and Singapore have developed and implemented strategies specifically aimed at gaining a competitive edge in STEM fields, making major investments in improving the state of STEM education to increase the number of scientists, engineers, and other STEM graduates overall. As a result of their investments, they have the highest rates of science and math literacy among Organization for Economic Cooperation and Development (OECD) countries. (p. i).

***Figure 5: Robotics within STEM***



A current Canadian researcher suggests, “twenty-first century education systems should create an environment wherein students encounter critical learning components (such as problem-solving, teamwork, and communication skills) and embrace lifelong learning” (Khanlari, 2016, p. 320). Indeed, the very design of integrative STEM needs to be grounded in the social interactions of students, educators and community members (Honey, Pearson, & Schweingruber, 2014).

### Enticements

It is not a question of where to begin since teachers know that “a child’s psychological profile, learning style, and social/cognitive developmental stage play essential roles in his/her educational process” (Keren & Fridin, 2014, p. 411). As children play, they learn how to solve problems and it is this learning to play creatively that is educational (Resnick, 2003). While using robotics, there is ample opportunity to play as students creatively engage with meaningful tasks that personally challenge students within a classroom of peers who are looking carefully and deeply into robotics (Bers, Flannery, Kazakoff, & Sullivan, 2014). Often these tasks include “. . . tangible interfaces, defined as concrete, physical manipulatives that can directly impact a digital environment” (Strawhacker & Bers, 2014, p. 240). Children can be presented with basic tangible problems to solve such as stacking blocks or sequencing items and as students creatively pursue solutions, they discover, explore and deeply learn how to solve problems (Highfield, 2010) (see Figure 6).

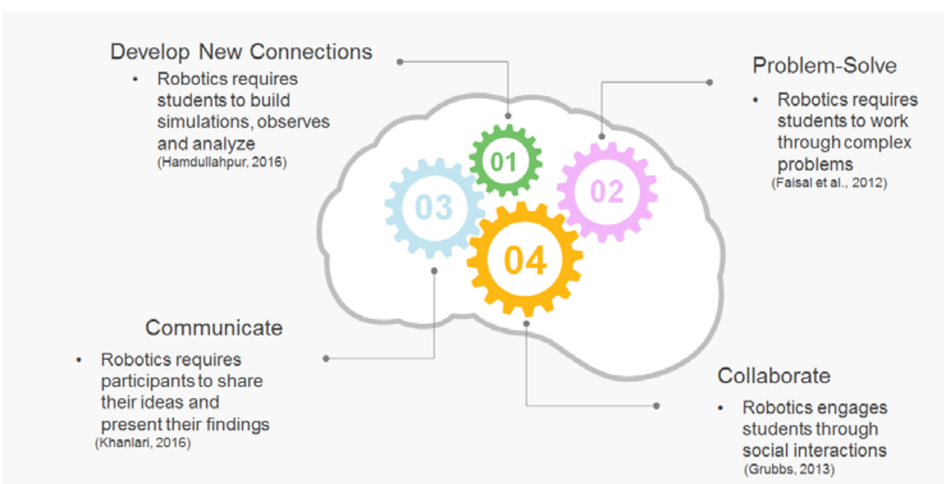
***Figure 6: Enticements***


“Tangible (hands-on) programming interfaces are especially well-suited for introducing young children to programming as they can match their developmental skill-set” (Strawhacker & Bers, 2014, p. 241). Overall, “technology curriculum in primary schools can play a significant part in supporting students to develop technology literacy, but also literacy capabilities more broadly configured” (Chandra, 2014, p. 29). From a developmental standpoint, the introduction of STEM at an early age can help students within their own educational constructivist development (Piaget, 1983). While investigating constructivism and STEM (Robotics), Gura (2012) found “robotics helps students to improve skills which are difficult to learn through traditional classes but are ‘key scientific and engineering practices’” (p. 16). Gura’s findings support Khanlari (2016) whose recent Canadian research effort determined,

> …robotics elegantly and authentically integrates STEM in hands-on experiences and can increase students' engagement, creativity, teamwork, communication, authentic research and information gathering, information evaluating, decision-making, problem-solving, and understanding of subject areas such as engineering and computing, [while]. . . utilising basic skills in real-world applications. (p. 322)

STEM (robotics) can prompt neuroplasticity which is the brain's ability to develop new connections and this can be invigorated by having students "tackle a challenge that requires them to build simulations . . . observe, analyze and compile data they get from whatever they have built . [and]. . teach others what they have observed and learned. Through this process of learning, fundamentals get addressed" (Hamdullahpur, 2016, p. 1). Indeed, whether a learning object or learning tool, robotics (Alimisis & Kynigos, 2009) can "encourage students to grow and actively research using problem-solving, communication, and collaboration skills" (Faisal, Kapila, & Iskander, 2012, p. 14). Robotics engages students via negotiation and social interaction requirements based on communications, and helps students learn to function in society (Grubbs, 2013). Khanlari (2016) claims "robotics has positive effects on students' lifelong learning skills . . . [such as] . . . interpersonal relationship building" (p. 328). Further, robotics has the ". . . potential to improve students' collaboration and teamwork abilities [and] robotics was also perceived by participants to have positive effects on students' communication skills, their abilities to share their ideas with others, and presenting their findings to audiences" (Khanlari 2016, p. 328). It is these skills, processes and capacities that are needed in the near future according to the World Economic Forum who suggested that by 2020, employers will be looking for people who are complex problem solvers, critical thinkers, creative, people managers, and coordinators with emotional intelligence, judgment and decision making skills who are service-oriented, negotiators with cognitive flexibility (Gray, 2016; Sinay et al., 2016) (see Figure 7).

***Figure 7: Effects of Robotics on the Brain***



## Robotics: An International View

STEM education is a global movement, for instance the "British government began a new computing subject including coding lessons for children as young as five" (Dredge, 2014, p. 1). Not to be outdone within North America, ". . . the U.S. coding education programs are continuously expanding as the IT job market flourishes. . . and Belgium, the Czech Republic, Estonia, Finland, and Hungary have started to invest in information technology education" (Innwoo et al., 2015, p. 1). In Asia, the Korean Ministry of Education announced it would boost IT (software learning) at both elementary and secondary levels to move with new trends (programming languages) in learning (Korean Ministry of Education, 2014, p.1). In the Southern Hemisphere, Chandra (2014) reported that the Australian Curriculum, Assessment and Reporting Authority was planning to move forward with enhancing technologic literacy involving students " . . .listening to, reading, viewing, speaking, writing and creating oral, print, visual and digital texts, and using and modifying language for different purposes in a range of contexts" (p. 24). To further develop their technological literacy skills, "classroom activities and assessments need to be designed so they can enable them to learn the importance of listening, talking and discussing technological processes, especially in articulating, questioning and evaluating ideas" (Australian Curriculum, Assessment and Reporting Authority, 2014, p. 24). Due to this evidence of global activity in STEM, English (2016a) suggests that:

> "given the global importance accorded to STEM achievements as measured by national and international assessments, it is not surprising that many nations are questioning the quality of their curricula and the strategic actions needed to enhance the STEM disciplines. If we are to advance STEM integration and lift the profile of all of its disciplines, we need to focus on both core content knowledge and interdisciplinary processes. Nations that enjoy high international testing outcomes as well as strong STEM agendas have well-developed curricula that concentrate on twenty-first century skills including inquiry processes, problem-solving, critical thinking, creativity, and innovation as well as a strong focus on disciplinary knowledge (p. 3).

STEM has really moved beyond borders. For example, a recent cross continent robotics competition involving remote programming and video streaming feedback, entitled R2T2, included ($n$ = 110) children from Europe and Africa and required participants to engage in collaborative space rescue. This inclusive enterprise demonstrated an approach to global collaboration via robotics and problem-solving skills found within engineering (Mondada, Bonnet, Davrajh, Johal, & Stopforth, 2016, p. 1). It is about the development of new skills for eventual employment in STEM related industry that prompted Innwoo et al., (2015) to investigate the effect of robotics on a total of 27 third-grade students at an elementary school in Korea. The study found that creativity and class satisfaction improved significantly for students who participated in a robotics treatment for 12 weeks. In each of these studies, various student skills and abilities have been enhanced providing the necessary incentives for educators to wade deeper when presented with STEM opportunities in schools and classrooms.

## Robotics Education at the TDSB

The aim of this study was to examine the effect of a system-wide, robotics professional learning pilot initiative on teacher self-efficacy, knowledge, and teaching practices (teaching STEM with robotics). This initiative was implemented by one of the largest and most diverse school districts in Canada. Prior to presenting the method and results of the current study, a brief summery of previous research findings are presented.

### Research Questions

The following research questions have been addressed in this study:

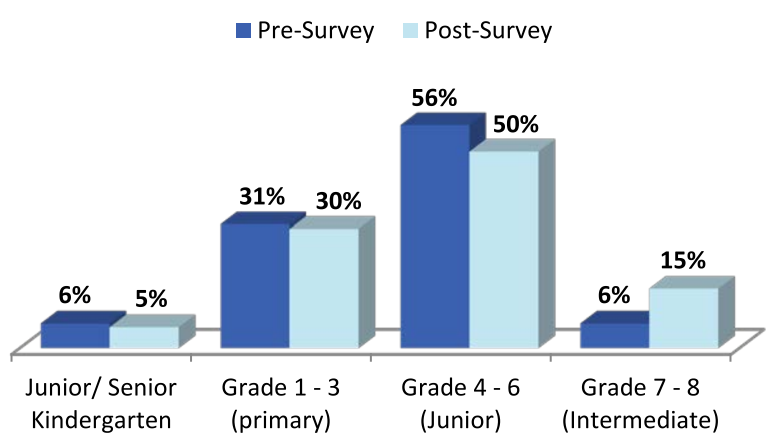
1. Did elementary teachers' knowledge of TPACK, application of technology at higher levels based on the SAMR model, and self-efficacy change after participation in robotics professional learning?
2. What were elementary teachers' perceptions of how engagement in robotics learning impacted student learning and engagement?

### Previous Findings

The TDSB is moving in the direction to foster educational environment where students could develop critical learning components and embrace lifelong learning, required as 21st century skills. As noted in a recent 2015-2016 professional learning survey of the Toronto District School Board (TDSB) 46% of teachers (*n* = 26) indicated that they used Lego Mindstorms ev3 and 50% of them (*n* = 28) used LEGO WeDo robotics kits. The majority of these grade school educators (57%, *n* = 32) signalled that robotics sessions mostly occurred at the secondary level (grade 10) compared to the elementary level (12% at Primary level; 18% at Junior level), suggesting that changes need to be made to further engage elementary students in STEM (Robotics) activities.

As shown in Figure 8, that survey also revealed that most teachers, involved in robotics professional learning, mainly taught at the Junior level and not the Primary level, therefore there is a need to engage more primary teachers.

***Figure 8: Taught by Grade Participants***



## Methods

The methods used for this research involved triangulation of quantitative and qualitative data sources and an overview of this study research design is depicted in Figure 9. A pre and post quasi-experimental survey design was used to look at changes that occurred in teachers and students as a result of teacher engagement with professional learning and interaction with robotics in the classroom. Participants in this study included 100 elementary school teachers and students from a total of 66 elementary schools, from kindergarten to grade 8. They participated in robotics professional learning from October 2015 to May 2016.

The qualitative phase unfolded within seven schools via stratified random sampling which involved semi-structured interviews. Data were collected from students, teachers, and administrators for triangulation purposes. Semi-structured interviews were conducted with participating teachers to further explore their use of robotics in classroom teaching and its effect on student learning. Interviews were conducted at several robotics schools with a school administrator and one of the lead robotics teachers. Stages of interviewing process are shown in Figure 10.

Teachers received 3 full days of intensive professional learning (PL) with Lego WeDO, spread over a six month period, facilitated in collaboration with a University of Toronto Engineering Department. Teachers were surveyed prior to taking a robotics professional learning course at the University of Toronto. The same teachers were then revisited 4 months later, after they had the opportunity to implement elements of what they had learned within their classroom. Teachers also received their initial training from the school board. Thereafter, all teachers were supported by coaches throughout the year. Pre- and post questionnaires, developed from previously validated STEM surveys, were administered to teachers before and after the PL.

In total, 91 teachers and 1646 students responded to the surveys. Overall, there were 65% and 85% return rates for teacher and student surveys respectively based on the expected number of students from each classroom (elementary classes have 20 or less students). In this report pre and post results were reported on the teachers and students who were participated into the professional learning and the robotics program.

Figure 9: STEM Robotics Study Overview

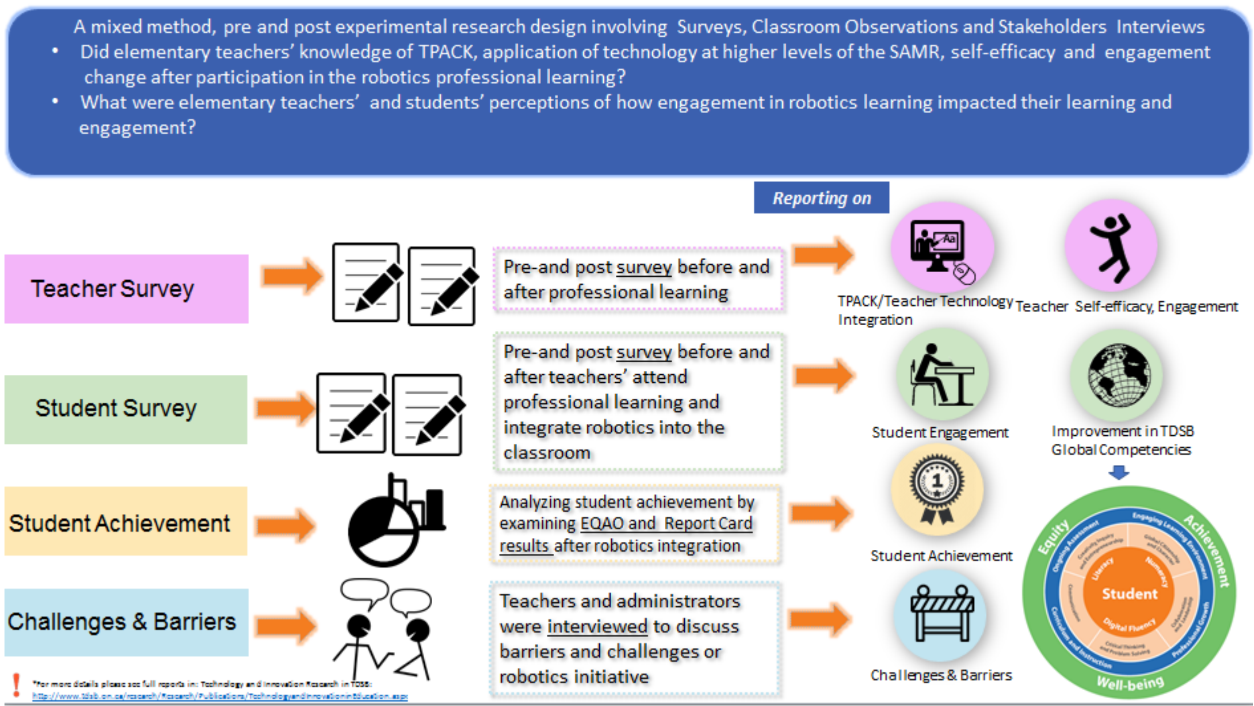
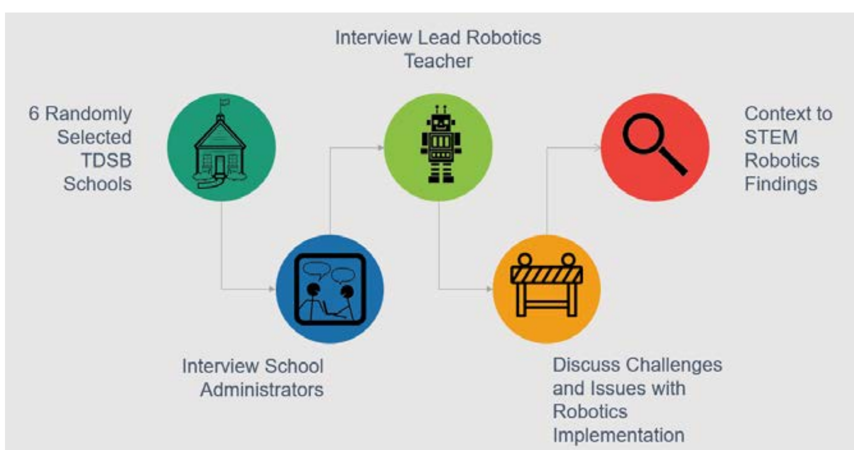


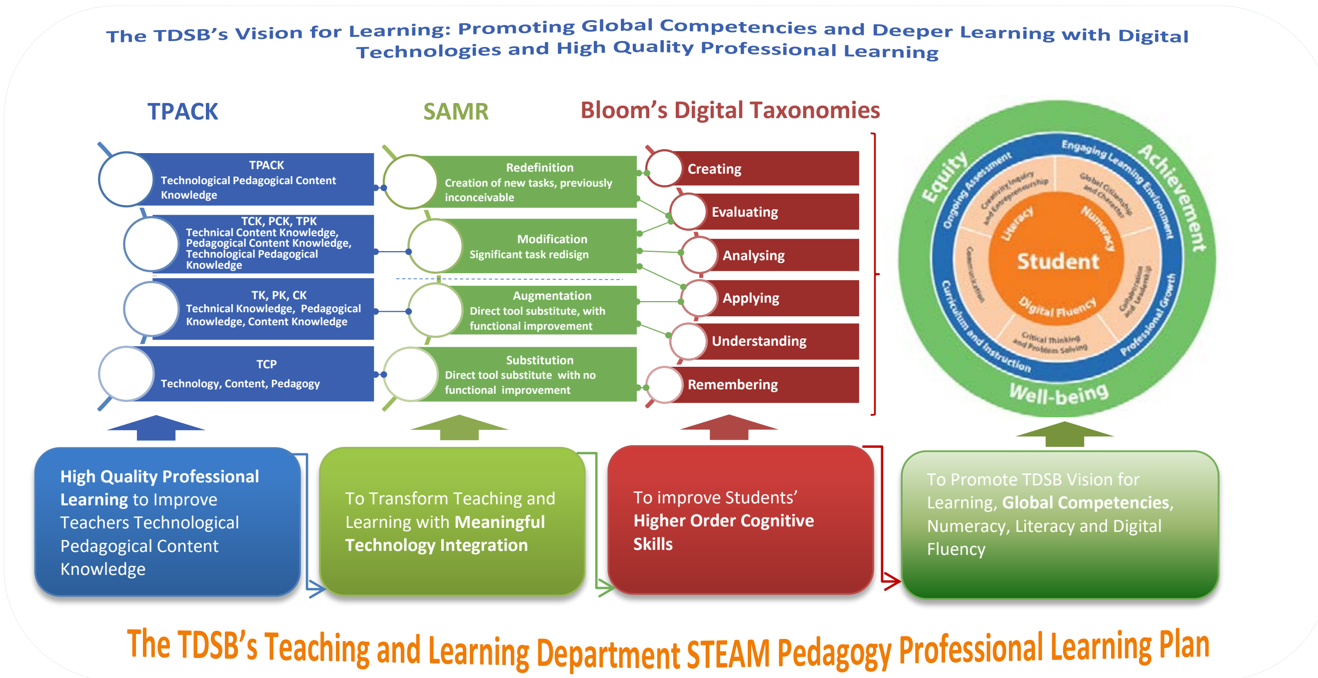

Figure 10: Interviews with Teachers and Administrators




## Theoretical Framework: Teacher Technology Integration

Professional learning for STEM and Robotics was designed according to two technology integration models: 1) Technological Pedagogical and Content Knowledge (TPACK) model (Mishra & Koehler, 2006), and 3) Substitution, Augmentation, Modification, and Redefinition (SAMR) model (Puentedura, 2014) as depicted in Figure 11. According to this 3-stage PL model, as teachers improve their proficiency in technology integration and gain TPACK knowledge, they begin to move from one STEM Integration level and SAMR level to the next in the sequence (e.g., progress from Augmentation to Modification) enabling them to design tasks promoting students' higher-order cognitive skills and improving student learning and global competencies.[3]

***Figure 11: Fostering Global Competencies and Deeper Learning Through STEAM Education and High-Quality, Effective Professional Learning***




*Note: STEM-TPACK Model based on Mishra, M. & Koehler, M.J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. Teachers College Record, 108(6), 1017-1054.; Inspired from Sinay, E. (2014). Global learning and teaching with educational technology in the Toronto District School Board (Research Report No. 14/15-01). Toronto, Ontario, Canada: Toronto District School Board; STEM Integration Levels are based on (Vasquez, 2014, p. 13).*

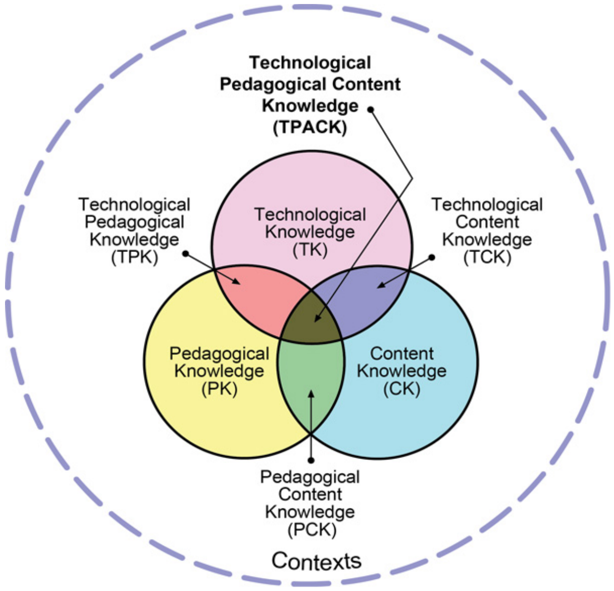
## TPACK Model

The Technological, Pedagogical, and Content Knowledge (TPACK) framework was used to examine teachers' abilities to teach with robotics and technology. The TPACK model developed by Mishra and Koehler (2006) inter-relates three types of knowledge: technological, content, and pedagogy as depicted in Figure 12. It is proposed that combinations of all three types of knowledge are essential for integrating educational technology into teaching practice successfully. These knowledge areas interact to produce the Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and the Technological Pedagogical Content Knowledge (TPACK) as depicted in Figure 12.

---

[3] STEM Professional Learning model started with TPACK and SAMR and then integrated STEM Integration levels from Vasquez, 2014, p. 13. STEM Strategy also evolves into STEAM over time and used interchangeably in this report. For details on each of these models please see Sinay, E., Jaipal-Jamani, K., Nahornick, A., & Douglin, M. (2016). STEM teaching and learning in the Toronto District School Board: Towards a strong theoretical foundation and scaling up from initial implementation of the K-12 STEM strategy. Research Series I. (Research Report No. 15/16-16 Toronto, Ontario, Canada: Toronto District School Board.

*Figure 12: TPACK Model*



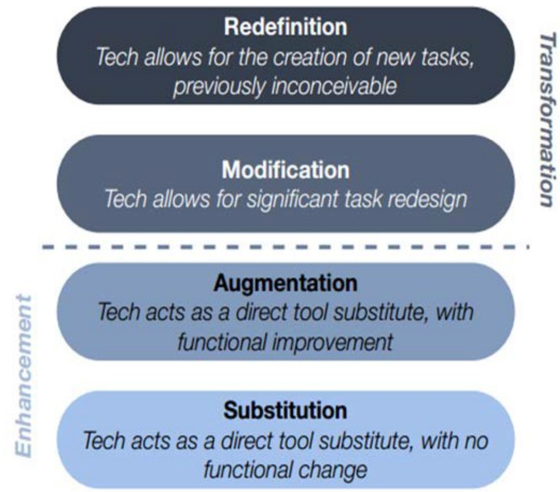

***Source:*** Koehler and Mishra, 2009 (p. 67); Reproduced by permission.

The teacher survey largely focused on technology usage and integration into the classroom using the TPACK framework while also looking at teacher engagement and an assessment of student global competencies. These interviews looked at larger systemic issues of robotics such as implementation while also addressing alterations in teaching practises and development of skills and global competencies in students brought on by the initiative. The results found within these areas are used to provide context and to expand upon results of the TPACK and student skills surveys. Further, they provide much of the data about barriers impeding implementation of robotics and recommendations for both overcoming these barriers and scaling up robotics in general.

## SAMR Model

Teachers also saw increases in terms of the level of technological complexity of work they had students complete for them in their classrooms. The SAMR model framework is used to detail the increases in the level of technological sophistication within teachers' classrooms, as depicted in Figure 13. The SAMR model provides a lens for technology integration, which resembles earlier models detailed by Green (2014). The SAMR model is viewed as a continuum, starting from a Substitution level, evolving to the Augmentation and Modification levels, and ending at the Redefinition level. The first two levels in the process are viewed as enhancement and the last two are viewed as transformation. As users move along the curriculum, technology appears to take a significant part in teaching and learning, but at the same time, is integrated seamlessly within it (Green, 2014).

*Figure 13: Substitution Augmentation Modification Redefinition (SAMR) Model*




***Source:*** Puentedura, 2014, p.1; Reproduced by permission of the author.

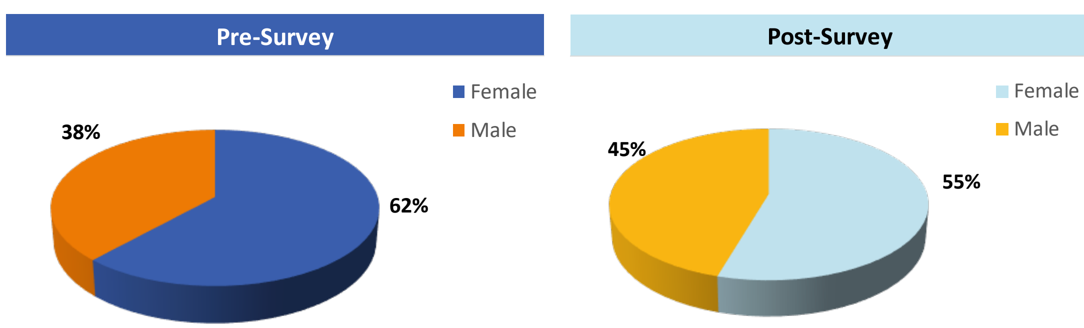
## Study Demographics

In total, 91 elementary teachers participated in the PL, in which 30 and 35 educators responded in the pre- and the post-survey respectively. Participants were assured of anonymity before completing their survey and no potential incentives were provided.

## Gender Distribution

As shown in Figure 14, 62% of the participants were female and 38% were male in the pre-survey. In the post-survey, participants (who only attended PL) were similarly represented by gender.

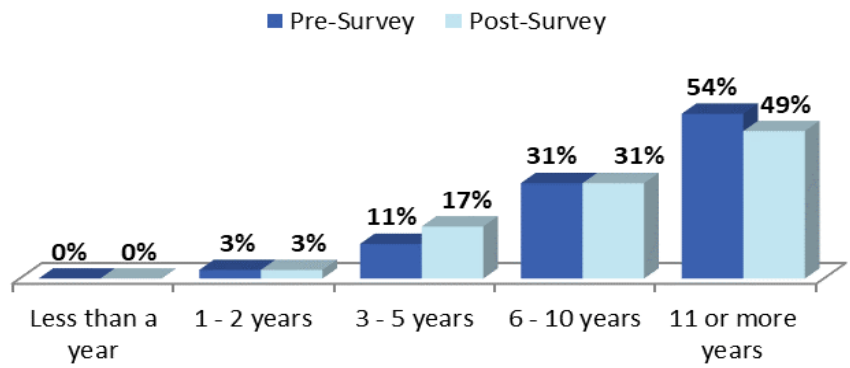
*Figure 14: Gender Distribution of the Educators*



### Teaching Experience

More than half (54%) and almost half (49%) of teachers, who participated in pre- and post-surveys respectively, have been teaching for 11 or more years while only 3% have been teaching for 1-2 years as noted in Figure 15.

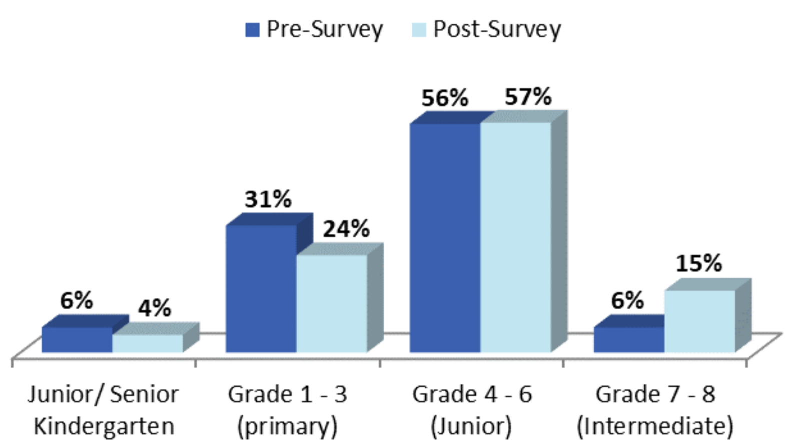
*Figure 15: Teaching Experience*




### Grades Taught

Educators were also asked on both pre- and post- surveys to indicate the grades they instructed. As illustrated in Figure 16, more than half of the participants (56%) taught Grades 4 to 6, while lower proportions taught Grades 1 to 3 (31%) and Grades 7 to 8 (6%) in the pre-survey. Similar trend was found in the post-survey, more than half of the participants (57%) taught Grades 4 to 6, while 24% and 15% taught Grades 1 to 3 and Grades 7 to 8 respectively (see Figure 16). This current study also revealed that most teachers, involved in robotics PL, mainly taught at the Junior level.

*Figure 16: Grades Taught by Educators*



# Results: Pre and Post Professional Learning

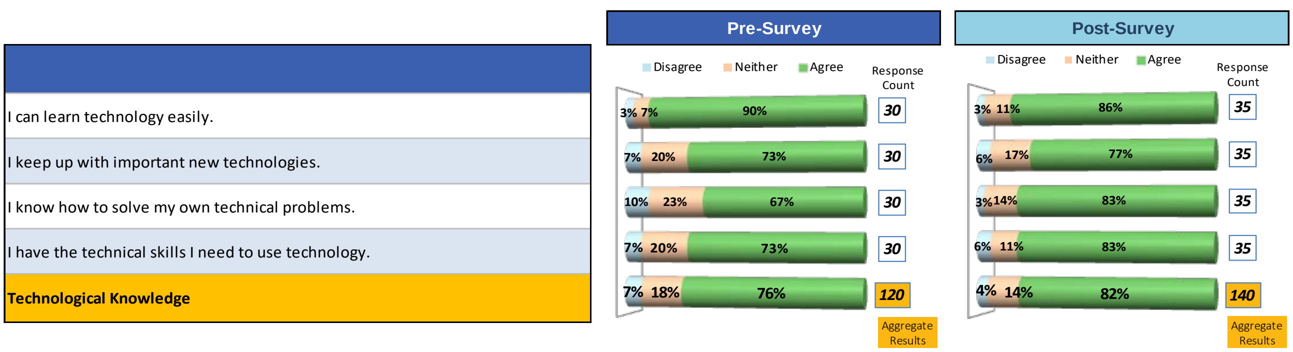
## TPACK Results

The following charts detail the opportunities that teachers need to weave technology and robotics into their pedagogical practice using TPACK model before and after receiving PL associated with robotics. Teachers' answers identify whether they agree or disagree that they have the skills listed. It should be noted that percentages in the charts may not add up to 100% in some cases due to rounding counts across the bars represents counts of responses.

## Technological Knowledge

Figure 17 details teachers' self-perceptions of their *knowledge using technology* following the robotics PL. Many of the teachers agreed that they had *knowledge of technology* and *technical skills* before PL which was further increased after PL. Additionally, teachers agreed that *learning technology* may not be as easy as they initially thought as agreement response rate dropped by 4%.

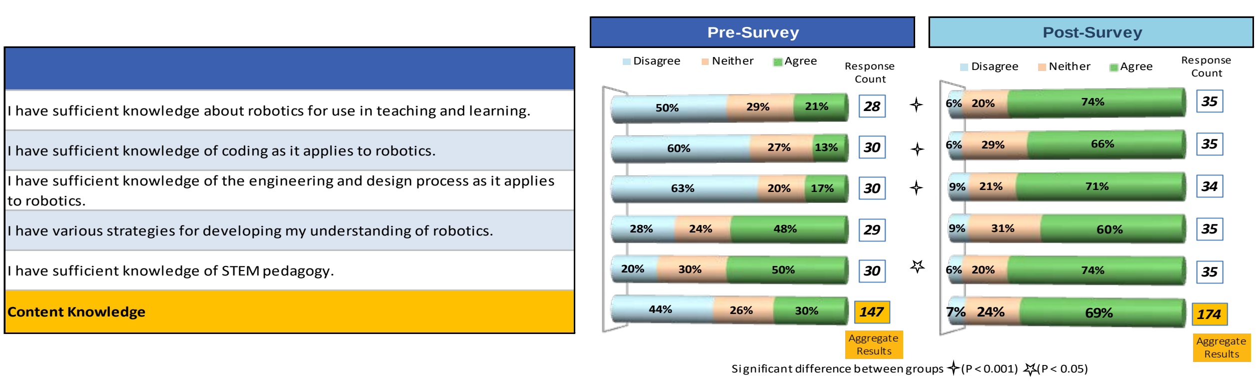
*Figure 17: Technological Knowledge*




## Content Knowledge

As can be seen in Figure 18, teachers' robotics content knowledge (as it applies to robotics) rose significantly. Sufficient knowledge of *robotics in teaching and learning*, *coding, engineering/design process,* and *STEM pedagogy* increased significantly by 53% (from 21% to 74%), 53% (from 13% to 66%), 54% (from 17% to 71%) and 24% (50% to 74%) respectively. They also agreed that their *ability for various strategies to develop robotics understanding* rose to a lesser extent by 12% (from 48% to 60%).

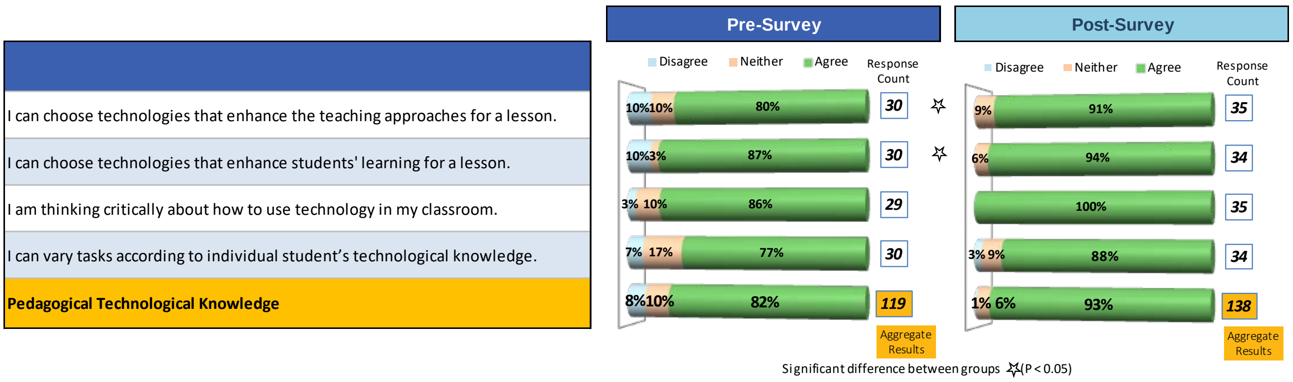
*Figure 18: Content Knowledge*



## Pedagogical Technological Knowledge

As depicted in Figure 19, *teachers' abilities to teach using technology* in the classroom also grew after PL. It was found that the choice of technologies that enhance *the teaching approach for a lesson* and *students' learning for a lesson* rose by 11% (from 80% to 91%) and 7% (from 87% to 94%) respectively. In addition, teachers agreed that their abilities for *critical thinking about how to use technology in my classroom* and *varying tasks according to individual student's technical knowledge* also increased by 14% (from 86% to 100%) and 11% (from 77% to 88%) respectively.

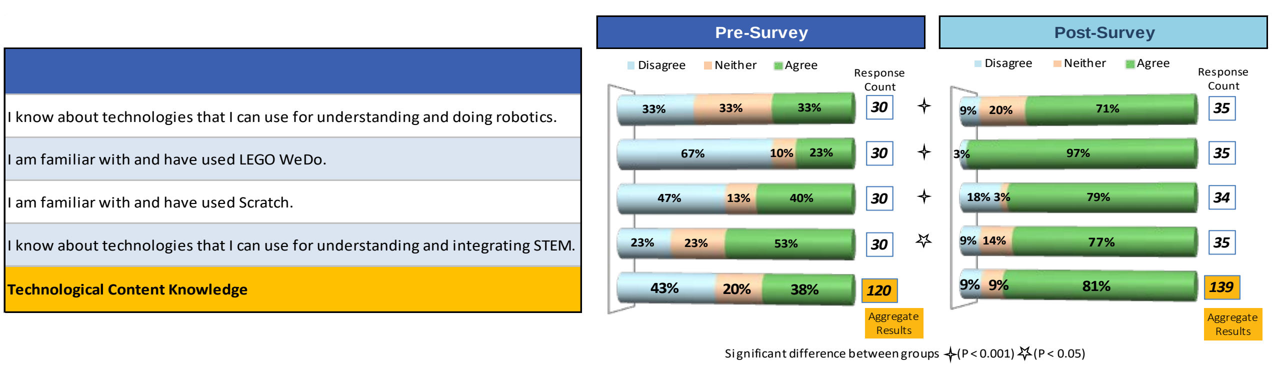
*Figure 19: Pedagogical Technological Knowledge*




## Technological Content Knowledge

Additionally, PL provided large changes in self-reported abilities that teachers had in finding and using technologies that relate to robotics (see Figure 20). Teachers reported that their knowledge about technologies that can be used for *understanding and doing robotics* and *understanding/integrating STEM* rose significantly by 38% (from 33% to 71%) and 24% (from 53% to 77%) respectively. Additionally, they indicated that they became more familiar and used *LEGO WeDo* and *Scratch* as agreement response rate increased notably by 75% and 39% after the PL.

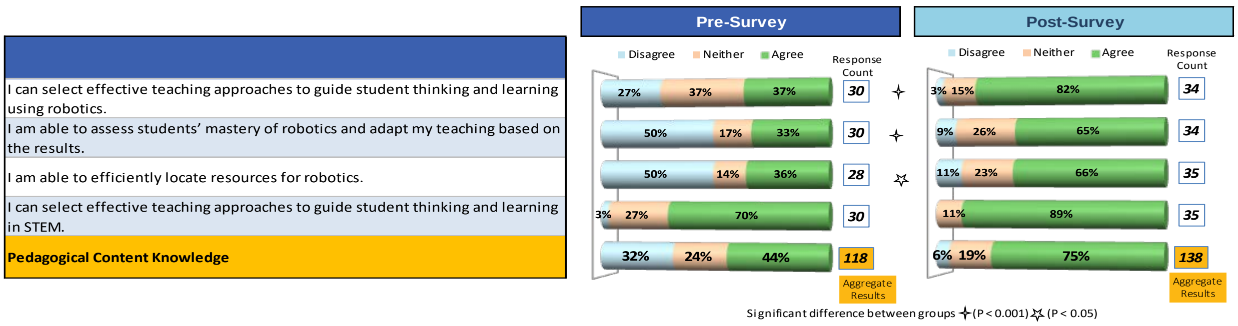
*Figure 20: Technological Content Knowledge*



## Pedagogical Content Knowledge

As illustrated in Figure 21, PL also resulted in large increases in *teachers' ability to generate and teach lessons centred on robotics*. Teachers reported that after PL their abilities in *selecting effective teaching approaches* that guide students' thinking and learning using *robotics* and *STEM* increased by 45% (from 37% to 82%) and 19% (from 70% to 89%) respectively. Teachers' ability in *assessing students' mastery of robotics and adapt teaching methods based on results* as well as *efficiently locating resources for robotics* were also increased by 32% (33% to 65%) and 30% (from 36% to 66%) respectively.

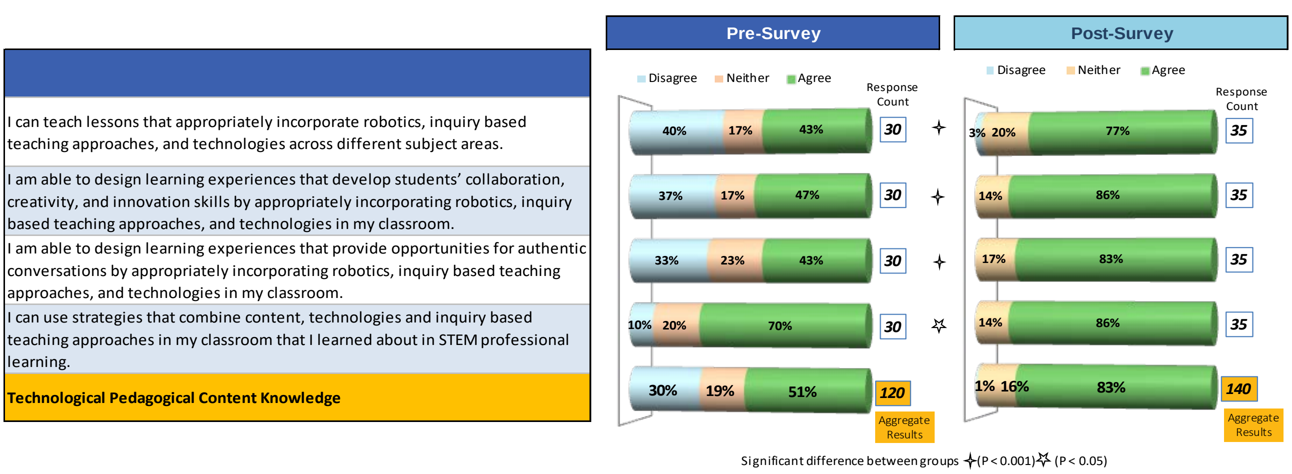
*Figure 21: Pedagogical Content Knowledge*




## Technological Pedagogical Content Knowledge

The final TPACK descriptor is TPACK itself, which combines all the elements into one dimension. Again, attending robotics PL had a significant effect on *teachers' self-reported views about their TPACK knowledge* (see Figure 22). It was reported that after PL teachers' abilities in design learning experiences in the classroom that *developed students' global competencies (collaboration, creativity & etc)* and *inspired authentic conversations* increased by 39% (from 47% to 86%) and 40% (from 43% to 83%) respectively. Also, as depicted in Figure 22, teachers agreed that *the ability in teaching lessons that appropriately incorporate robotics, inquiry-based approaches, and technologies across different subject areas* rose from 43% to 77% as well as 16% increase in being *able to apply the strategies that combine content, technologies, inquiry-based teaching approaches learnt from STEM PL* (from 70% to 86%).

*Figure 22: Technological Pedagogical Content Knowledge (TPACK)*



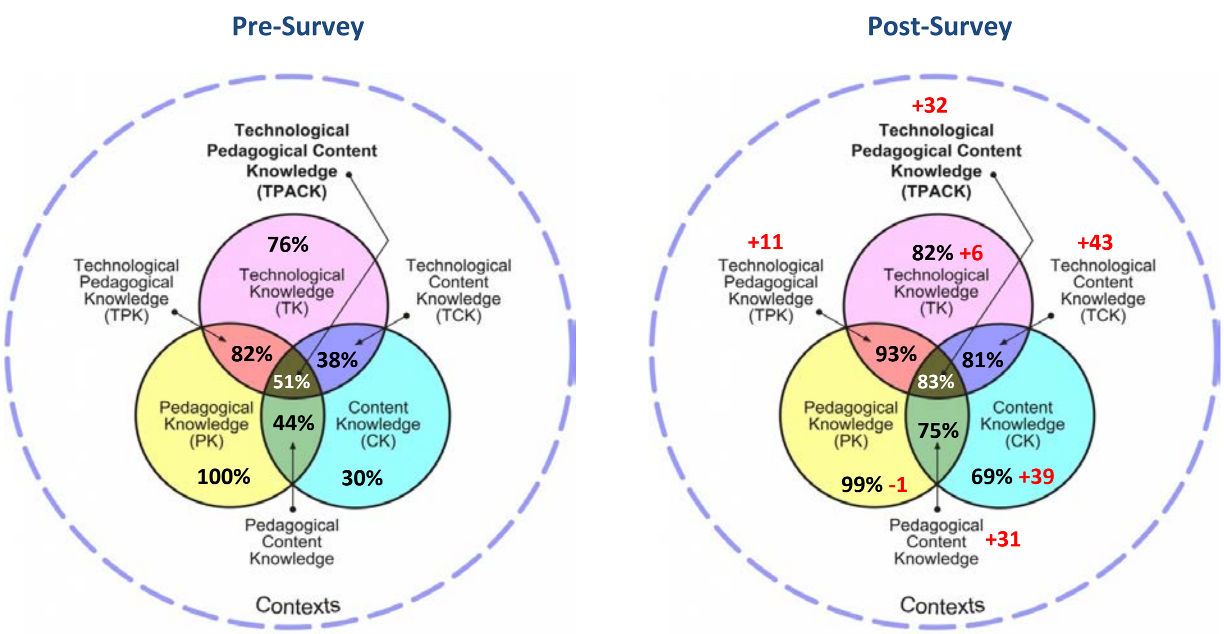
Even before teachers reach in-service teaching positions there is awareness in pre-service that “effective technology integration involves the use of technological tools to enhance the teaching and learning of content. This also includes the use of technology to support higher-level thinking and extending beyond only using technology to develop basic skills” (Polly & Rock, 2016, p. 336). If however this pre-service technology emphasis is absent in pre-service the probability that teachers will move into STEM (robotics) when they secure in-service teaching positions is diminished and the result is a “shortage of teachers with the specialist skills and knowledge to teach subjects like (Picciano & Steiner, 2008), robotics and other technology subjects, especially in rural areas” (Dunn, 2014, p. 1).

## Aggregate TPACK Results

Figure 23 provides an overall view of changes of TPACK components after PL with robotics, indicating the most components rose within a moderate (6% in TK; 11% in TPK) to large (39% in CK, 43% in TCK and 31% in PCK) rates while only one dimension slightly decreased (1% in PK). 51% of teachers agreed on possessing technological, pedagogical and content knowledge (TPACK) before PL and following PL, this number increased to 83%.

Based on this finding, professional learning is clearly essential in enhancing teacher’s robotics/STEM knowledge for their teaching practices.

***Figure 23: Aggregate Percentages for Each TPACK Component***



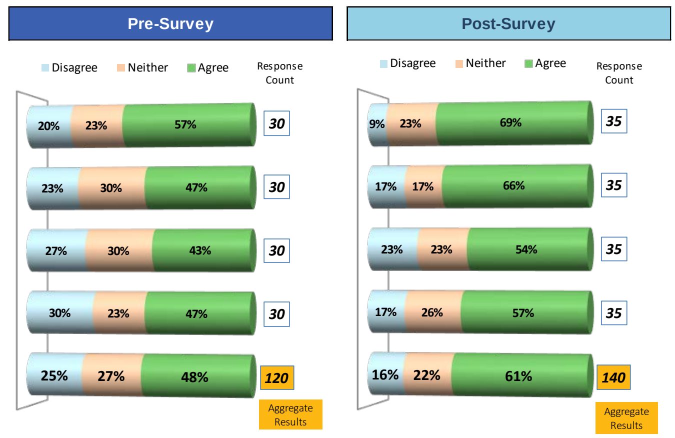

***Source:*** Koehler and Mishra, 2009 (p. 67); Reproduced by permission.

## SAMR Results

The pre and post survey results highlight changes in technology integration as teachers are further exposed to robotics. The modified version of the SAMR model for technology integration at TDSB classrooms is previously shown in Figure 24. Compelling results can be seen in the transformation elements of the model as teachers' reports of students using substitution, augmentation, modification, and redefinition rose by 17%, 15%, 12% and 6% (see Figure 24).

*Figure 24: Student Application of The SAMR Model*

| |
|---|
| Students substitute tools, including technologies, to complete tasks (e.g., student submitting an assignment in a Word document rather than handing it in on paper). |
| Students use technologies to augment their learning and improve how they are doing tasks (e.g., students use the text-to-speech function on a word processor to help the writing process). |
| Students modify their learning and task completion using technology (e.g., students place their essay on an online discussion board to seek feedback from classmates). |
| Students use technology to completely redefine their learning and task completion (e.g., students submit a short documentary using Windows Movie Maker instead of an essay). |
| **SAMR Model** |

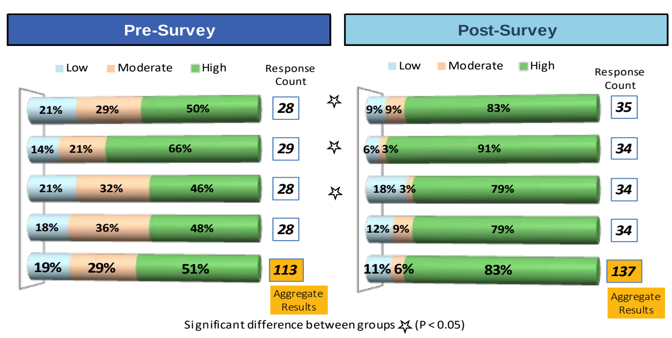



## Teacher Confidence with Technology

Both the experience of professional learning and having the opportunity to work with robotics in their classrooms raised teacher confidence teaching with robotics significantly (see Figure 25). Teachers agreed that the confidence level in *ability in engaging students to participate in technology-based projects* and *helping students who may be having difficulty with robotics* grew by 25% (from 66% to 91%) and 33% (from 46% to 79%) respectively. In addition, after PL teachers agree that they felt being more confident in *having the necessary skills to use robotics for classroom instruction* (33% increase) and about *teaching students using the LEGOWeDo/ EV3* (31% increase).

*Figure 25: Teachers' Technology Confidence*

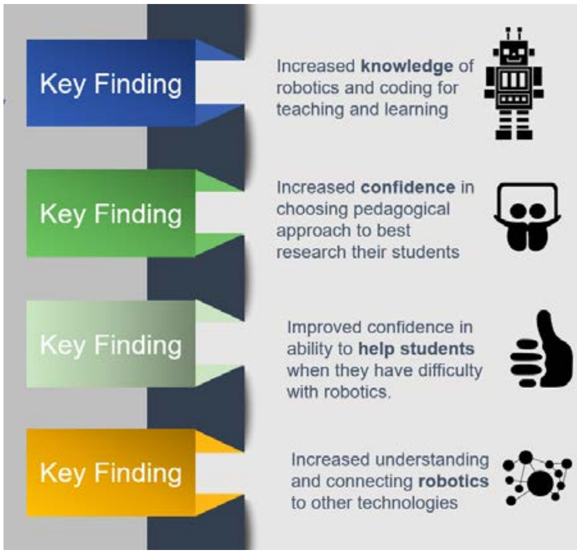
| |
|---|
| I feel confident that I have the skills necessary to use robotics for classroom instruction. |
| I feel confident that I can engage my students to participate in technology-based STEM projects. |
| I feel confident that I can help students when they have difficulty with robotics. |
| I feel confident about teaching students using the LEGO WeDo/ EV3 |
| **Technology Confidence** |



## Key Findings in Teacher Technology Integration

Overall, there were many important findings related to teacher technology integration. A main highlight was through professional learning and robotics integration in the classroom where teachers reported increased understanding and confidence with robotics in education. Figure 26 presents summary of key findings for this section.

*Figure 26: Overall Teacher Technology Integration Findings*




## Teacher Engagement

An analysis of interviews conducted with educators at schools, who took part in robotics professional learning, revealed several commonalties about how teaching with robotics affected their teaching practices. Both teachers and principals discussed how robotics in the classroom had a positive effect on teacher engagement. They felt that robotics affected their teaching in the many ways as discussed in the following section.

## Creating a More Dynamic Teaching Style

The largely cited impact change in teaching practice was due to teachers taking on a multi-modal approach to teaching (Thomas & Watters, 2015). This learner-based approach is a dynamic process that helps teachers to improve teaching practice. A teacher described changes in the style of teaching in the following way:

> *You can't veer too far away from the curriculum that you're supposed to teach, and although most of our curriculum is in this inquiry-based….it's still relatively regimented in the topics that you choose. It's really what we've discussed about….these robotics allow you to continue to teach the same curriculum, but allow you to engage students in a different way and provide them with opportunities to problem solve and learn in different ways.* - Teacher

## Co-teaching and Co-planning

The robotics program also led to an increase in co-teaching and co-planning. This has been true even among teachers who did not traditionally engage in these practices. Not only is co-teaching found between teachers, it is also found between students and teachers. One of the interviewed administrators discussed the process of how co-teaching and co-planning started to take shape at her school as such:

> *It began from let's say a STEM activity in one classroom and then it morphed towards a collaborative approach where then there was team teaching happening. And what was interesting is we had let's say, the Gr 6 teachers start off with robotics and then the Gr 3 teachers joined on that.* - Administrator

The potential effects of robotics on teacher engagement have also been assessed using surveys. The post-survey results showed that 61% of teachers always felt *emotionally engaged* while teaching (see Figure 27). In 67% of the cases teachers always displayed *positive social engagement with their colleagues* (see Figure 28). Similarly, 67% of surveyed teachers were always *cognitively engaged with their work* (see Figure 29). A higher proportion of teachers showed *positive social engagement with their students* by always *caring about their student problems* (79%) and by *being empathetic to their students* (83%) (see Figure 31).

***Figure 27: Teachers' Emotional Engagement***

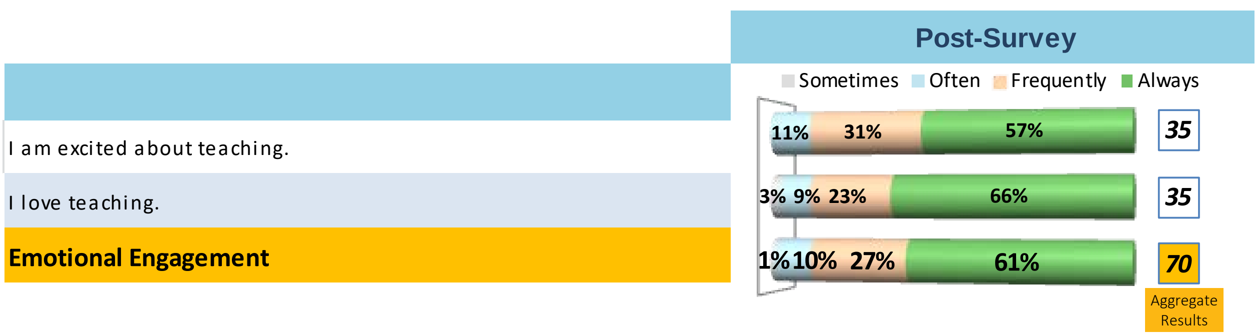



***Figure 28: Teachers' Social Engagement with Colleagues***

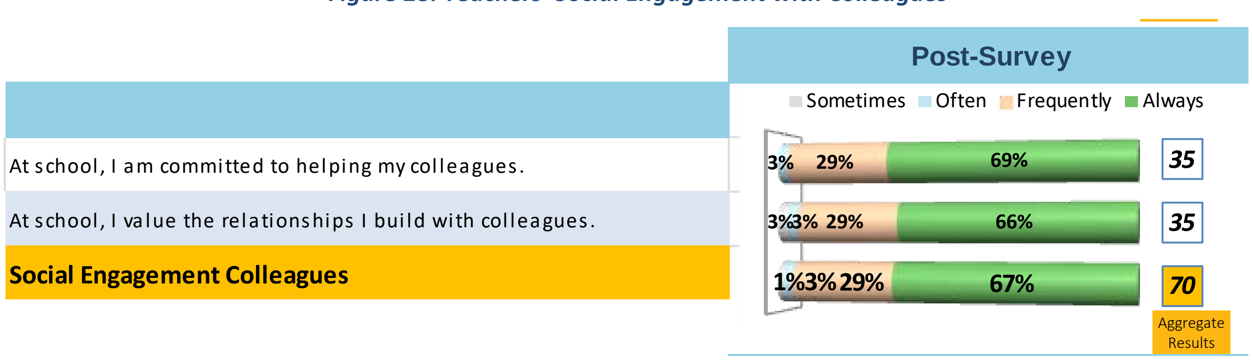


*Figure 29: Teachers' Cognitive Engagement*

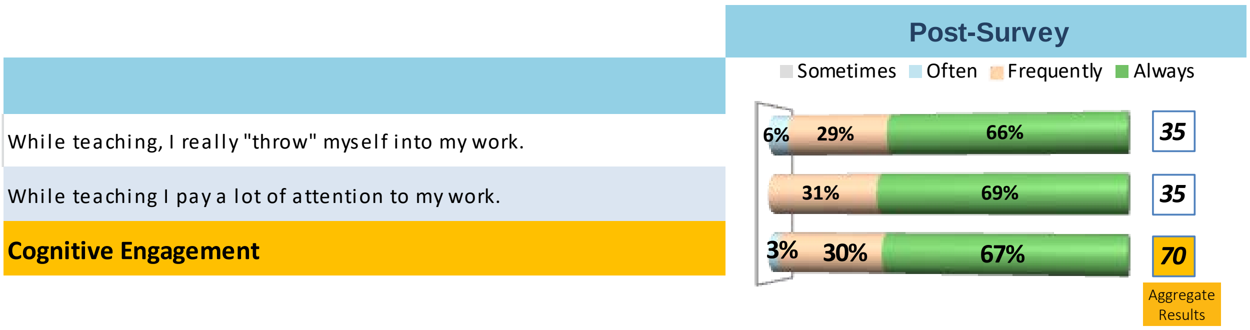
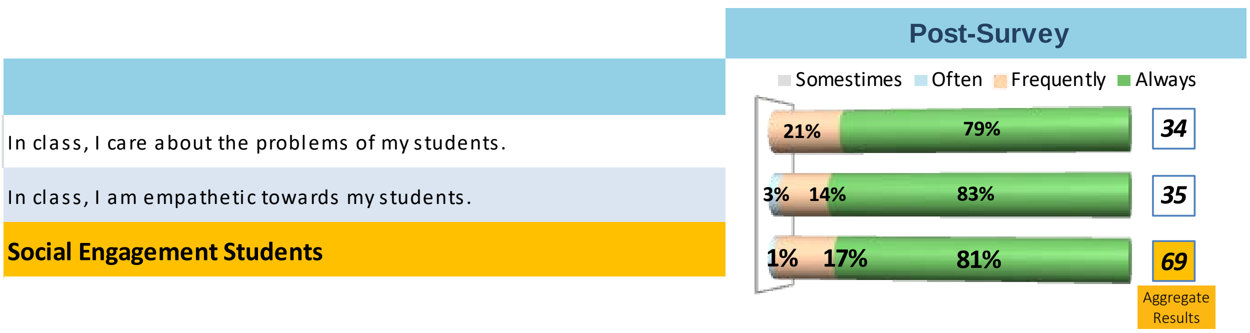


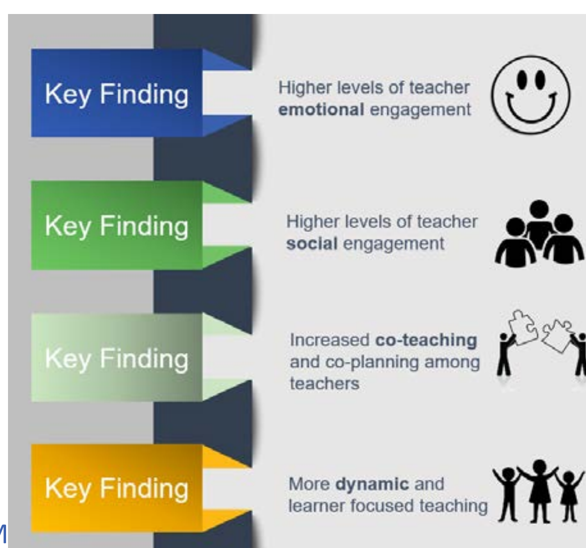

*Figure 30: Teachers' Social Engagement with Students*




## Key Findings in Teacher Engagement

Overall, there were many important findings related to teacher engagement. The main findings included: (1) more dynamic and learner focused teaching, (2) increased co-teaching and co-planning and (3) higher levels of teacher emotional and social engagement when teaching. Below is a summary table highlighting the key findings for this section (see Figure 31).

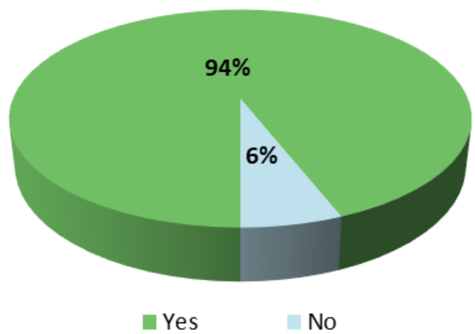
*Figure 31: Overall Teacher Engagement Findings*



## Student Engagement

A positive impact on student engagement was also documented as the vast majority, 94%, of teachers indicated that they noticed a change in student engagement due to robotics activities (see Figure 32).

*Figure 32: Teachers' Observed Increased Student Engagement*




Information collected from interviews with teachers and administrators helped detail these survey findings in a more nuanced way. A common thread found throughout was positive student engagement being cited as one of the most common successes. Students have been very receptive to the robotics initiative. This engagement manifested itself in students being open to try new things and to continue to persevere regardless of early setbacks. One of the school administrators described the increase in engagement at his school:

> *I would say the biggest success has been the total lack of… total engagement of the students, not lack of engagement. I mean out of a scale of 1 to 10 of students being totally engaged and not engaged at all in what they're doing, I would say it's like 10 out of 10.* - Administrator

With an increase in student engagement there were increases in student initiative and self-esteem. Robotics hands-on approach has provided an opportunity for students with different learning styles to take on leadership roles. This is particularly true for students who have not fared as well in traditional learning style classrooms, as a teacher explains:

> *We have our problem solvers. . . they feel very good. Their self-esteem is over the moon. They may not be strong in other areas, but this is the one they do well. They feel it gives them a little bit of… positive attention as well. It's great for their self-esteem. It also shows others that they have skills in so many different ways within the classroom. It's been positive that way.* - Teacher

A frequently reported impact was the increase in engagement for students with special educational needs who traditionally have been harder to engage. Important to note herein that when these students are more engaged, fewer behavioural issues are reported and an opportunity arises to build confidence, pride and comradery with their fellow students:

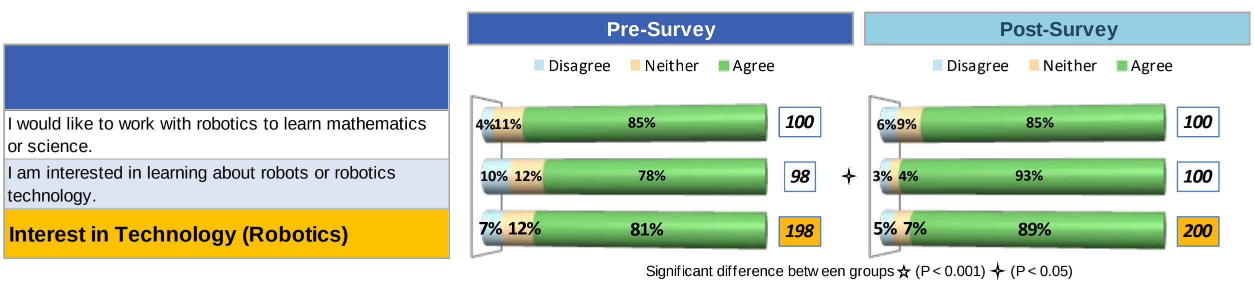
> *They're working very nicely in the room and uh, the students who usually have issues focusing and staying on task are, are more engaged…* - Teacher

With an increase in student engagement and self-esteem, several students began feeling more confident voicing their opinions whereas in the past, they may have remained silent.

> *"Student voice, huge, because they talk about their designs, they share opinions about what to do, they try different things out if it's not working."* - Administrator

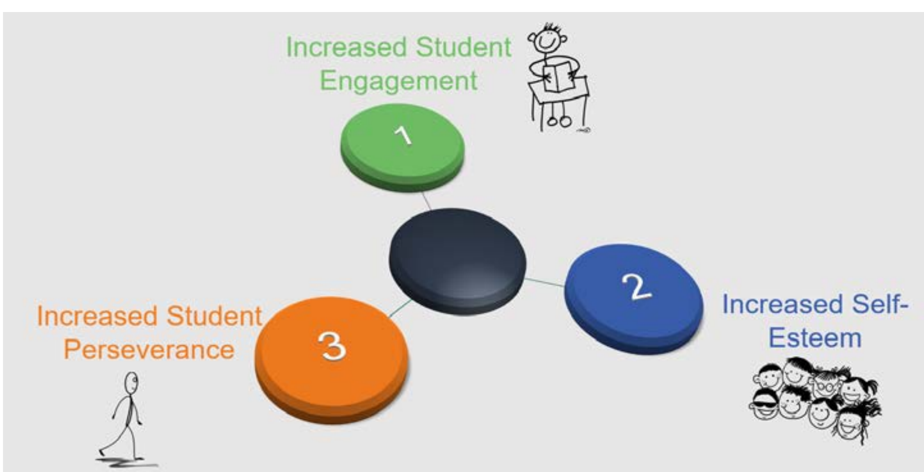
A strong indicator of increased student engagement/interest was understood from the results given in Figure 33. As can be seen in this figure, survey results show a significant increase in *students' interest in learning about robotics* by 15% (from 78% to 93%) while their *interest in working with robotics to learn mathematics or science* did not change after students had the opportunity to experience robotics in their classroom.

***Figure 33: Students' Interest in Robotics***




Overall, there were many important findings related to student engagement. The main findings included: 1) increased student engagement, 2) increased self-esteem, and 3) increased student perseverance. Figure 34 below highlights these key findings.

***Figure 34: Overall Findings on Student Engagement***



## Students’ Global Competencies

The need to begin robotics education in primary grades benefits students in many diverse ways, for instance, Bers et al. (2014) found “. . . kindergartners were both interested in and able to learn many aspects of robotics, programming, and computational thinking” (p. 145). Introducing technology in primary schools can support students developing technology literacy and broaden literacy skills (Chandra, 2014). In addition, interpersonal (social skills) are skills which can be nurtured as Hwang and Wu (2014) found that “. . . working together, learners had to figure out how to reduce conflicts, which was both a benefit to the completion of their collaborative tasks and an important skill for their socialization” (p. 431). When robotics is offered in classrooms, Julià and Antolí (2016) determined that STEM work resulted in “positive change in spatial ability of the participants in the robotics course [which] was greater than change evident in the students who did not join the course” (p. 185). Educators can design activities and assessment tasks which draw upon a range of literacy skills. . . [leading] to the deep understandings of technology, solving problems and communication” (Chandra, 2014, p. 29).

Evidence of the perceived student competencies growth via robotics within STEM is demonstrated via the 2015-2016 professional learning survey of the TDSB as noted in Figure 35. This figure illustrates and supports what research has determined including: robotics within STEM nurtures problem solvers, critical thinkers, creativity, managers, coordinators, emotional intelligence, judgment and decision makers, who are service oriented, negotiators with cognitive flexibility (Sinay et al., 2016).

***Figure 35: Teachers’ Perspectives on Student Skill Growth***

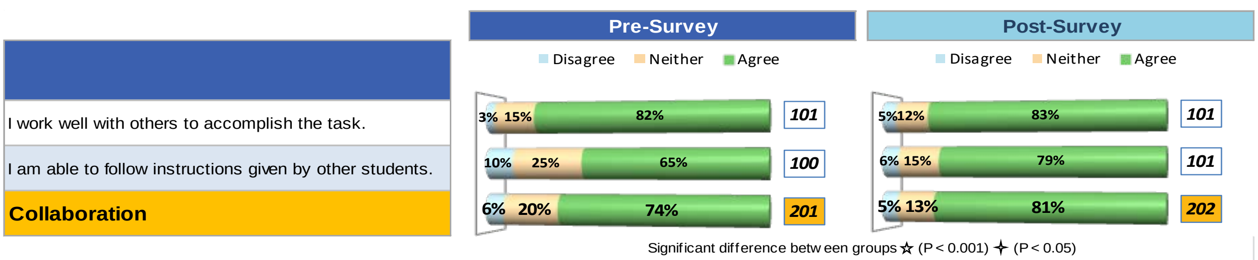
| **Student Skill Growth** | |
|---|---|
| Collaboration | 94% |
| Communication | 74% |
| Computational Skills | 51% |
| Confidence | 60% |
| Creativity | 74% |
| Innovative Thinking | 77% |
| Inquiry-based Learning | 66% |
| Perseverance | 91% |
| Problem-based learning | 77% |
| Other | 3% |

Moreover, the 2015-2016 professional learning survey of the TDSB revealed evidence of student skill development as noted in Figure 36. Teachers’ perceptions of their *students’ abilities to collaborate* showed significant levels of improvement due to robotics. More specifically teachers indicated that students showed moderate to high improvement in both *working well with others to complete the tasks* (68%) and *ability in following instructions given by the other students* (69%).

These results correlated with students' self-reporting of their *growth in collaboration* as illustrated in Figure 37. Students reported that their *ability to follow instructions given by their classmates* increased from 65% to 79% after robotics was introduced in their classroom.

*Figure 36: Teachers' Perspectives on Student Collaboration*


*Figure 37: Students' Perspectives on Collaboration*




The robotics initiative provides an environment where collaboration between students is not only encouraged, but also generates the best results in terms of the projects that students can create.

> *At its very nature, the design process, this robotics piece, is a collaborative effort; it's successful… it probably finds the most success when there's two or three minds working together. Not to say that the lone wolf, the student by themselves can't be successful, but from my observation . . . here, the students have been most successful when they're working together, when there's 3 or 4 heads working together towards a common goal.* - Teacher

On an individual level, collaboration appears in several ways. For instance, students who may not have been engaged in other classes had the opportunity to take on different roles within their robotics work group. This helped students generate confidence, and this effect is further increased when students collaborate with different groupings of peers. Generating positive results with varied groups helps students build additional confidence.

> *Kids that don't normally work together were able to get together and create things. So that was neat to watch. Like I had an ESL child that had no English at all and another student who has multitudes of learning issues and they were able to come together and create things and they*

*got robots doing things far quicker. So they came up with this almost their own communication how to work together and solve problems.* - Teacher

The initiative also can cultivate an environment where students are engaged in co-teaching of their peers and with their teachers.

*I felt like I was completely removed from the thing because they were teaching me and they were looking through and being the investigators.* - Teacher

Han (2012) and Khanlari (2016) claimed that immersion within STEM is balanced to enhance each learner's abilities in problem solving, collaboration, and logical thinking. Findings relating to teachers' perceptions of students' skill improvement in problem-based learning and inquiry in the 2015-2016 professional learning survey of the TDSB as noted in Figure 38, displays that within these skillset domains, teachers perceived students to have enjoyed moderate to high improvement in both *asking questions to better understand the problem* (68%) and *trying out various possibilities to solve the problem* (85%). Students were also asked the same questions in the STEM surveys that were administered in 2017. A statistically significant improvement was shown in the *ability of students to experiment with different possibilities to solve problems*, as it rose from 56% to 69% (see Figure 39).

***Figure 38: Teachers' Perspectives on Students Inquiry/Problem Based Learning***

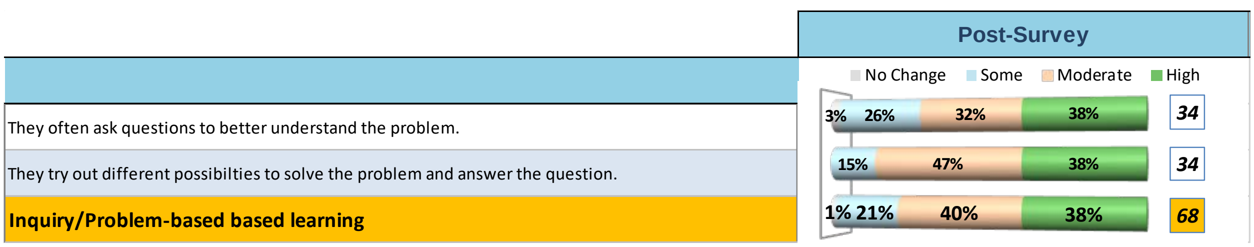
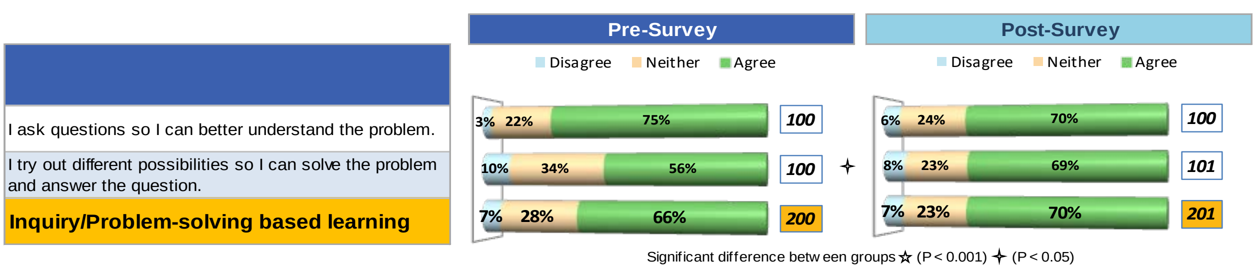



***Figure 39: Students' Perspectives on Inquiry/Problem-Based Learning***




Khanlari (2016) stated that ". . . authentically integrates STEM in hands-on experiences and can increase students' engagement, creativity, teamwork, communication . . ." (p. 322). Figure 40 illustrates teachers' perceptions of students' skills improvement in *creativity and innovation*. It was observed that *students coming up with their ideas to solve problems*, *testing out different ideas to improve them*, and *discovering new ways of doing things* were moderately to highly improved (79%, 80%, and 78% respectively) after the introduction of robotics.

When two of the three questions above were directed towards students', interestingly different results emerged. The corresponding results can be seen in Figure 41. More specifically, in comparing the pre- and post-test results, a higher proportion (76% vs. 66%) of students agreed to *testing different ideas to improve them after engaging with robotics*.

*Figure 40: Teachers' Perspectives on Student Creativity and Innovation*

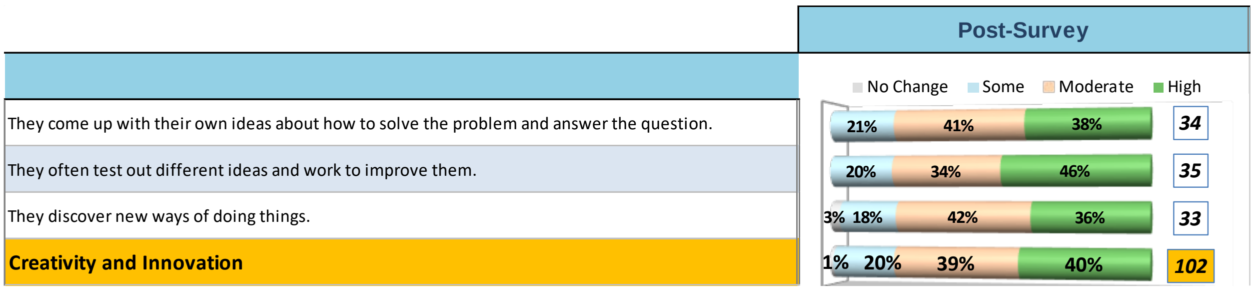
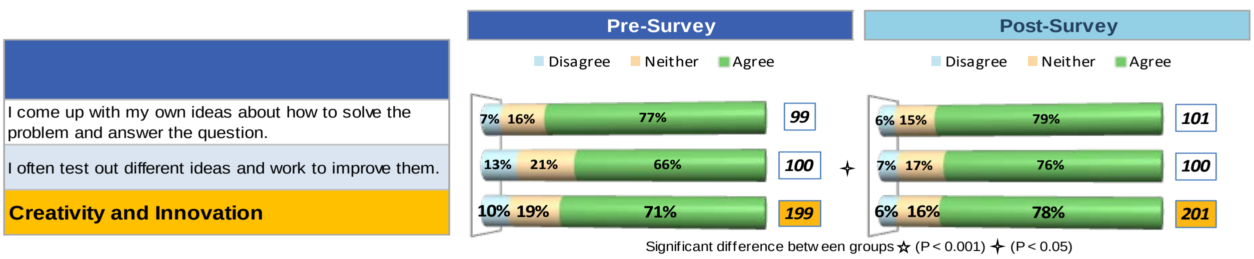



*Figure 41: Students' Perspectives on Creativity and Innovation*




Researchers have reported that interpersonal abilities are cultivated within robotics work and while ". . . working together, learners . . . figure out how to reduce conflicts, . . . both a benefit to the completion of their collaborative tasks and an important skill for their socialization" (Hwang & Wu, 2014, p. 431). Indeed, robotics engages students via negotiation and social interaction requirements based on communication, and helps students learn to function in society (Grubbs, 2013).

The survey in the present study shows perceived student skill improvement in communication and sociability. As presented in Figure 42, teachers also reported moderate to high improvement in students' skills in the following areas: *sharing ideas with others* (77%), *giving feedback to others* (53%), *listening to feedback from others* (52%), and *helping students who need assistance* (64%). These improvements connect with the idea that introduction of robotics in the classroom could lead to high levels of collaboration and teamwork amongst students.

*Figure 42: Teachers' Perspectives on Students' Communication/ Sociality*

| | Post-Survey (No Change / Some / Moderate / High) | |
|---|---|---|
| They share my ideas with others. | 23% 46% 31% | 35 |
| They give feedback to others. | 9% 38% 29% 24% | 34 |
| They listen to feedback from others. | 9% 38% 26% 26% | 34 |
| They help students who need assistance. | 3% 32% 35% 29% | 34 |
| **Communication/Sociality** | 5% 33% 34% 28% | 137 |

*Student perseverance* was another area that teachers reported improvement in students. Teachers felt 72% of students showed moderate to high improvement In *continuing to work at a problem until it is fully solved* as illustrated in Figure 43.

*Figure 43: Teachers' Perspectives on Students' Perseverance*

| | Post-Survey (No Change / Some / Moderate / High) | |
|---|---|---|
| They work on the problem until it is solved | 3% 15% 50% 32% | 34 |
| **Perserverance** | | |

Robinson (2016) reported that schools need to inspire and provide opportunities for "innovation and higher order problem solving…design thinking and engineering [as it] develops creative confidence through hands-on projects and engineering . . . to solve real life problems" (p. 6). As displayed in Figure 44, 64% of teachers reported that students showed a moderate to high improvement in *feeling confidence to solve the problems* after robotics was introduced.

*Figure 44: Teachers' Perspective on Students' Confidence*

| | Post-Survey (No Change / Some / Moderate / High) | |
|---|---|---|
| They feel confident about their ability to solve the problem. | 3% 32% 32% 32% | 34 |
| **Confidence** | | |

The overall hands-on approach to robotics helped students better retain information. There was an improvement in math skills through the use of coding. Students also saw connections to the real world, which helped the learning process, as they were able to put theory into practice. It improved thinking skills and student learning as they learned different ways to problem solve as noted within this excerpt from an interviewed teacher.

*[I] feel that it is a lot easier for kids to understand Math concepts if they are engaged, and, and focused more when using [the] Robotics program than just standing there and doing a lesson on the smart board and give them follow-up activity sheets or some nonsense like that.* - Teacher

Overall, there were many important findings related to global competencies and skill growth in students. The main findings included increased abilities with: collaboration, inquiry/problem-based learning, creativity and innovation, as illustrated in Figure 45.

***Figure 45: Overall Findings of Global Competencies and Skill Growth in Students***


## Enriching School Communities Robotics

Additionally, there were other examples of robotics improving the culture of schools and connecting parents deeper with their child's learning. Through both robotics clubs and competitions, schools have had their cultures expand to make robotics a dynamic and regular part of their daily learning experience.

Administrators stated during interviews that they saw robotics create a different culture of learning in their schools. There was greater engagement and collaboration for instance, one administrator suggested:

*So once you walk into a room and you just see people teaching people regardless of what their roles are or their grades are or whatever, that's a huge benefit because now you've created a culture of learning within your classrooms and quite frankly that will morph itself towards your school.* - Administrator

The prevalent success of the program at the school level was cultivating a sense of purpose for the school as a whole. The initiative has brought a sense of identity to the school as one administrator observed:

*…it has really brought a synergy to the school and a sense of purpose, an identity. As they really see themselves as a STEM school now.* - Administrator

One of the central ways that robotics can generate enthusiasm and connection among students and teachers is through various robotics competitions hosted in Toronto and around the province, as suggested by one administrator:

*....we brought our own robotics competition. Again, our coach was instrumental in launching it last year so next year will be our second one. We have a lot of… you know, the Etobicoke guardian came and the kids were in the paper and it was really exciting for them. So it really brought a sense of community to the school, because of the way that we were able to mobilize it.* - Administrator

Furthermore, participation in these competitions, and robotics and STEM in general help students feel more engaged in school, as illustrated in the following quote:

*I think they were not interested in athletics or the dance club… so there are kids who traditional who weren't engaged in something that are now.* - Administrator

Students in special education, as one administrator mentioned, are also using robotics as a means to engage themselves both with the subject area and with the school as a whole more.

*Most of our students that are in special education classrooms are kinesthetic learners plus the motivation; they like to have that end product right away but I have found that they are really taking the time to really figure it out. I find that most of them are the ones that are actually being the leaders. {…} They are coming out and signing up for lunchroom club and they are integrating with other kids that they don't really talk to on the playground. They are the ones who are stepping up and being the leaders and teaching others.* - Administrator

Another success was the parental exposure to the initiative. The initiative has energized the parent community as well as one teacher reported:

*Another success is parents were exposed to it during our STEM night. Their kids were not doing it yet in their classrooms or in the school but they had exposure. That was my whole intent of bringing it there, kind of entice the kids to show up to the club and be interested in the classroom.* -Teacher

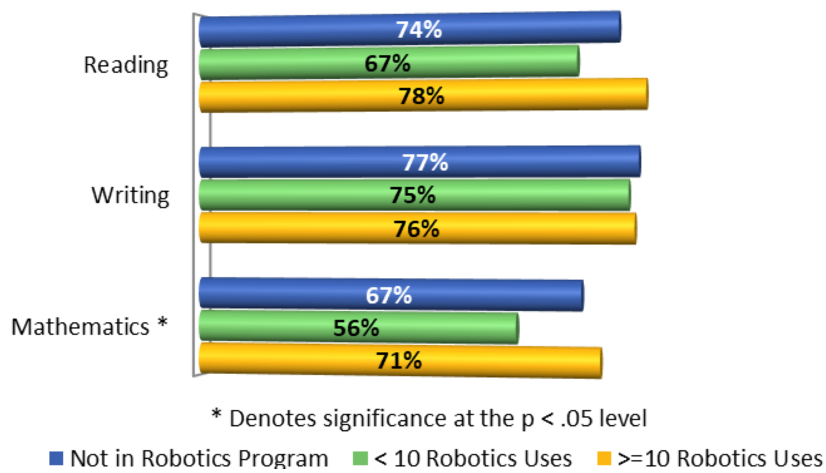
## Improvement in Academic Achievement, Learning Habits and Skills

In this section, the effects of robotics on students' academic achievement, EQAO results, learning habits and skills will be discussed. Robotics has been shown to have a positive effect across all of these areas of elementary education. Participating in robotics, at various levels, depending on the involvement in the initiative, leads to improved EQAO results as well as improvements in reading, writing, science and mathematics for students as measured in student's Report Cards. Additionally, and potentially being the cause of these improvements, robotics improved students' learning skills and study habits. Please note that for ease of reading, 10 or more sessions in robotics has been classified as "several" robotics sessions while 10 or fewer robotics sessions has been classified as "some" sessions.

## EQAO Results

Of all the achievement-oriented results collected, the EQAO results for Grade 3 students presented the most uneven findings. Although a higher proportion of students who participated in several robotics sessions achieved a Level 3 or 4 on reading, writing and mathematics, the results were not as strong for students who took part in some robotics sessions. More specifically, compared to students who were not in a robotics program, a higher proportion of students who attended more than 10 robotics sessions achieved a score of Level 3 or 4 on their reading (78%), writing (76%), and mathematics (71%). However, when students' achievement in these three assessments is compared between students not in a robotics program vs. those who attend less than 10 robotics sessions, a lower proportion of the latter group achieved scores in Level 3 or 4 on reading (67%), writing (75%) and mathematics (56%) (see Figure 46).

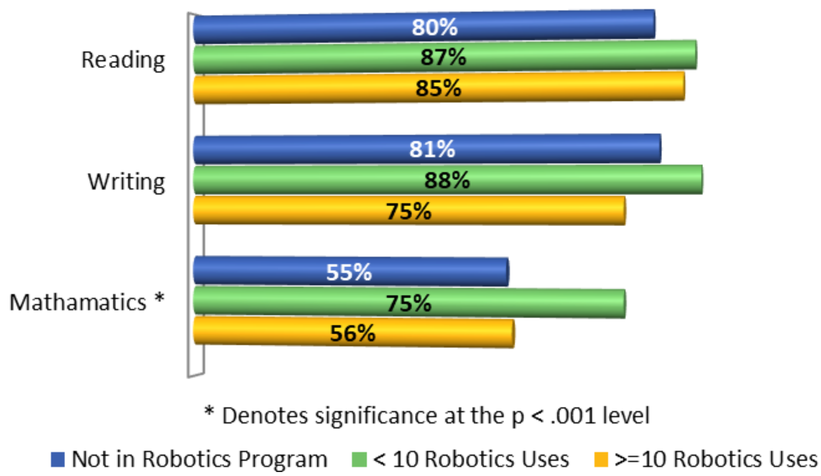
*Figure 46: EQAO Grade 3 Results at level 3/4*




.

The EQAO results for Grade 6 students demonstrate that in all cases except for the writing test, being part of the robotics program improved their results. Unlike the Grade 3 EQAO results, these results showed stronger performance in EQAO areas by students who had taken some robotics sessions compared to several sessions. Comparing all 3 areas, a higher proportion of students in robotics who were taking some sessions achieved scores in Level 3 or 4 in EQAO's reading (87%), writing (88%) and mathematics (75%). A slightly lower proportion of students who had taken several sessions achieved scores in Level 3 or 4 in these areas: reading (85%), writing (75%) and mathematics (56%) (see Figure 47).

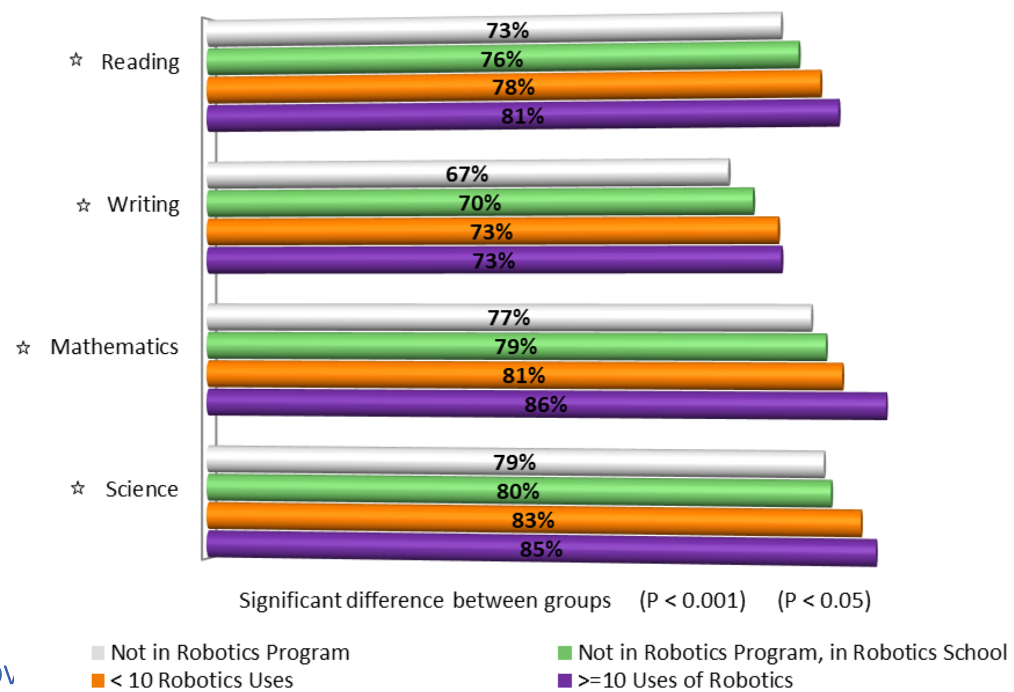
*Figure 47: EQAO Grade 6 Results at level 3/4*




## Elementary Report Card Results for Academics

Results in subject areas on elementary report cards trend up depending on the amount robotics are used by students in their classrooms. Looking at reading, writing, mathematics and science and the percentage of students who achieved Level 3 or 4 in these areas, having had several robotics sessions led students to have the best result. More specifically, across the domains mentioned, high proportions of students (73% to 86%) reached that threshold. With the exception of writing, a slightly lower proportion (73% to 83%) of students who took some robotics sessions achieved these results. The lowest proportion (67% to 79%), while a slightly higher proportion (70% to 80%) of students attending schools with a robotics, but not directly participating in robotics, scored Level 3 or 4 on all domains (see Figure 48).

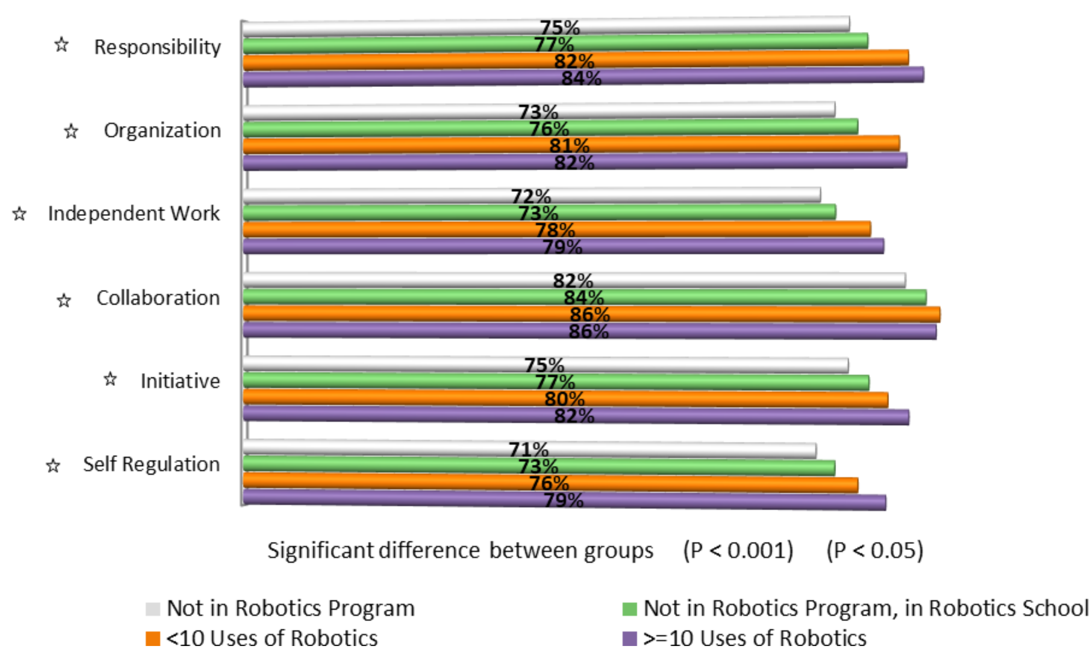
*Figure 48: Elementary Report Card Academics (Reading, Writing, Math, Science); Student at level 3/4*



## Elementary Report Card Results for Learning Skills

Similarly, to report card results for academics, the report card for learning skills demonstrated higher results when students have participated more in robotics. Learning skills are reported as students having achieved a *good* or *excellent* rating from their teacher. For students who have had several robotics sessions, they reached that standard 84% of the time in responsibility, 82% in organization, 79% independent work, 86% in collaboration, 82% in initiative and 79% in self-regulation. Looking at the same areas, 76% to 86% of students who had some robotics sessions had *good* or *excellent* learning skills. The lowest proportion of students who were not at a robotics school (71% to 75%) received such high ratings on their learning skills (see Figure 49).

*Figure 49: Elementary Report Card Learning Skills: Student at Good/Excellent Level*



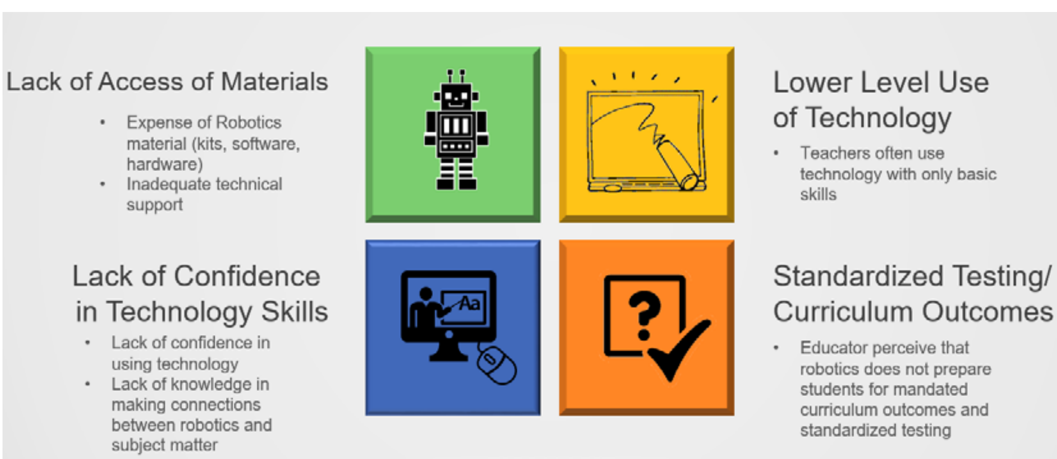
## Challenges and Barriers

Khanlari (2016) suggested that "the most challenging factor that may prevent primary/elementary teachers from using robotics technology in their teaching activities is the lack of access to supporting materials and inadequate technical support…lack of confidence in their technology skills, and their lack of knowledge in making connections between robotics and the subject matter are also major obstacles" (p. 328). According to the same author, even with the "benefits for teachers and students in Robotics education, the workload and lack of preparation time and instructional support" is considered another barrier.

The expense of robotics materials (kits, software, and hardware) is a barrier which prevents schools from offering robotics in STEM classrooms (Catlin, 2012). Hwang and Wu (2014) found collaboration unavoidably involves conflicts. Therefore, educators should be proactive to prevent conflicts and teach social skills. By working together, learners have to figure out how to reduce conflicts, which is both a benefit to the completion of their collaborative tasks and an important skill for their socialization" (p. 431).

One serious complaint from educators is that "robotics does not prepare students for the many mandated outcomes and tests. Therefore, primary/elementary teachers may be reluctant to integrate robotics into their teaching activities because they perceive robotics as an unnecessary topic (Khanlari, 2016, p. 328). These are not the only barriers and concerns to be considered; another is the extent to which any technology is used in schools. For example, Polly and Rock (2016) found "teachers used a wide variety of technologies with a large dependence on Internet-based technologies, interactive whiteboards, and iPad applications [yet] further analyses found that most of the technology uses were lower-level and focused on only basic skills" (p. 336). With a lack of professional learning, preparation time, and large-scale provincial testing focussed on other areas of the curriculum, there is little incentive for educators to implement complex STEM programs such as robotics (see Figure 50).

*Figure 50: Challenges to Robotics*



## Barriers to Implementing Robotics

Interviews with administrators and teachers uncovered additional barriers to the implementation of robotics at the TDSB. Several of the areas, though not all, tied into issues related to teachers connecting with the robotics initiative such as a lack of teacher confidence, time and use of technology. Other barriers include lack of financial resources, lack of material resources, computer technology issues, and student engagement (see Figure 51).

*Figure 51: Barriers to Implementing Robotics*


## Teacher Confidence

The most important factor is buy-in with teachers and confidence in their individual abilities to use robotics and the STEM pedagogy to teach (see Figure 52). For varied reasons, many teachers voiced reservations about trying something new. The STEM pedagogy involves taking risks as a teacher and ceding elements of classroom control to other teachers and in some cases, students. In particular, the use of inquiry-based teaching techniques, many of which cede control of the assignment to the class as a whole and do not end with a pre-designed goal being fulfilled, can lead to teacher anxiety. An administrator had the following to say in this regard.

> *I think for many adults, many teachers, educators, not knowing where you're going to end up can be very anxiety causing.* - Administrator

The same administrator noted that many of the teachers in his school who resist robotics do so because of what he calls a closed mind set. He suggested:

> *There's a lot of artificial barriers that some of the teachers put up. It's just a closed mindset, not this sort of growth mindset.* - Administrator

He further mentioned that it is the fear of the unknown and the reluctance to try something new that leads to this closed mind set, as illustrated in the quote below:

*They're [the teachers] often very quick to say with the children that they're teaching, 'I just need you to try.' But the teachers don't often practice that themselves.* - Administrator

*Figure 52: Teacher Confidence*


## Lack of Time

Teachers further expressed concern finding adequate time to teach with robotics. Although they agreed that inquiry-based learning centred on robotics was a more effective teaching pedagogy, they noted it was also time-consuming (see Figure 53). As one teacher reflected:

*I guess because I wasn't comfortable with it, it made it hard to plan and teach the time tabling of it, trying to allocate enough time for them to make the changes that they needed because I always found I was rushing them.* -Teacher

*Figure 53: Lack of Time*




## Using Technology

An additional area of robotics that generated significant apprehension with a sub set of teachers was having to use technology (see Figure 54). At several of the schools that expressed difficulty implementing robotics and STEM, a lack of understanding and in some cases a resistance, to using technology were mentioned as reasons to why implementation did not happen smoothly. As one administrator reported:

> *From my experience, the reason why teachers are reluctant usually is because they don't want others to see them as inadequate.* - Administrator

These words give some possible explanation of why so many teachers avoid using new technologies when they perceive the possibility of embarrassing themselves. For this reason, availability of training, and even just having access to the very technology itself, is imperative.

However, having the technology on site does not guarantee that teachers will use the technology unless explicit modeling is further provided. One administrator discussed how technology brought into schools often will go unused without any one to model their usage to the staff.

> *We have amazing kits in our science lab that are untouched.* – Administrator

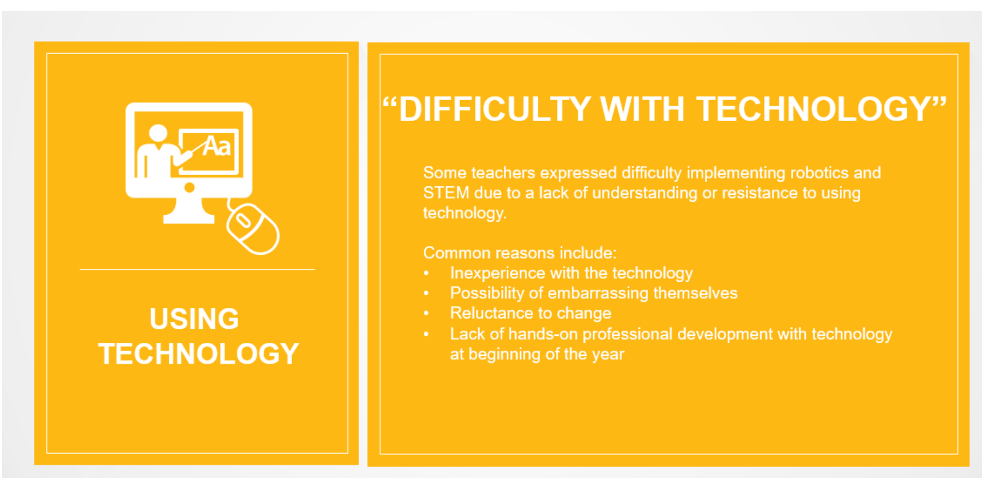
Furthermore, a teacher commented on not fully understanding the robotics kits she was using which prevented her from successfully implementing them in her classroom.

> *My lack of knowledge was a big one, planning it, in such a way that the kids understood what they needed to do. I guess because I wasn't comfortable with it, it made it hard to plan and teach, the time tabling of it.* - Teacher

This same teacher mentioned later in her interview that being provided with a workshop on how to properly use robotics in the classroom would have better enabled her to better implement them in her class:

> *If there was a workshop at the beginning where they could have shown us the kind of things the robots would have been able to do, and even taken me through all of the different functions and…keys and find things within the computers. It was mostly trial and error. I want to do this, but I don't know how, so let's keep pushing buttons.* -Teacher

***Figure 54: Using Technology***



## Resources and Supports

Figure 55 suggests the main resources and supports that both administrators and teachers require to successfully implement robotics. Resistance towards the implementation of the robotics strategy occurred when teachers and administrators felt that they were not receiving adequate resources and supports. Although it was only a portion of the sample that reflected these views – often from schools that had significant issues seeing their robotics programs thrive – this issue was a large one when it arose.

The lack of resources came in the form of not enough technical supplies to do STEM – often this occurred in schools that were running robotics programs – and limited opportunities to be supported by STEM coaches and STEM Digital Lead Learners. One of the administrators expressed the latter suggesting:

> *More support for the staff. Like staff as a whole, right? So even though we're a pilot STEM school, we don't have sufficient support in my opinion to be able to help teachers to build their capacity to be able to continue with STEM in their classroom when the coach is no longer here. It's kind of hit and miss. You know little bit then you're off, right. It's not enough. We need more focused, structured, maybe opportunities to visit other classrooms…* - Administrator

Commenting further on limited external support being provided, one school administrator had the following to say in regards to how much they have access to their STEM coach.

> *Yes, we have one but we have I don't have her for focused periods of time where I can really benefit from her. It's just very surface and it's not enough to be able to get STEM truly going in this school.* - Administrator

The central issue administrators kept coming back to was the availability of funds available for them to run their programs. An administrator articulated this claim:

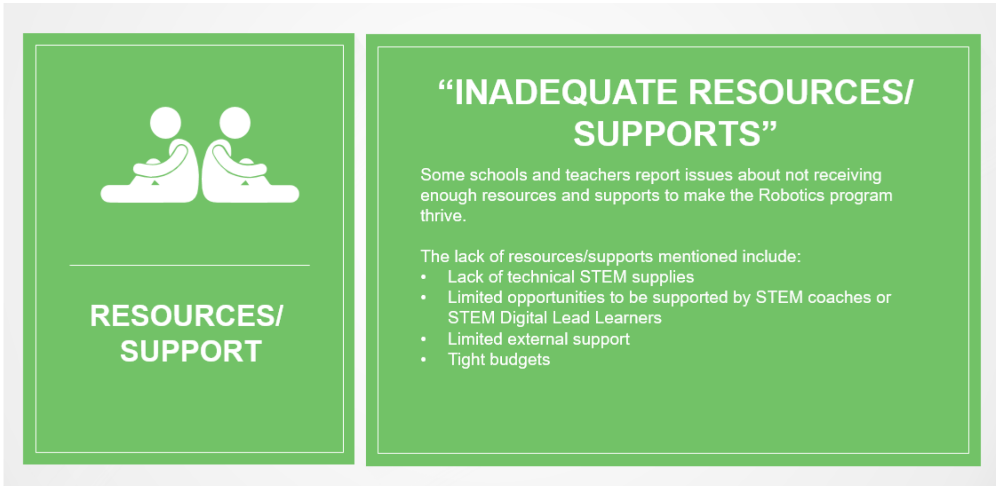
> *Money is always…money always seems to be….we never have enough money to do the things we want." A lack of funds leads some schools to not be able to purchase the amount of STEM equipment that they need or want. These realities force schools to make difficult choices in terms of buying new equipment, providing release time for teacher co-planning and sending teachers to professional learning.* - Administrator

In regards to professional learning and the importance of choosing wisely what they send their teachers to attend, one principal reflected:

> The worst thing is to send a teacher to a day of PL and they walk away with nothing that they want to come back or excited about. It needs to be something that's meaningful, relevant to what they do on a day-to-day basis. - Administrator

Statements like these further illustrate the need to maximize resource usage in order to generate enthusiasm for robotics and avoid some barriers.

*Figure 55: Resources & Supports*




## Lack of Financial Resources

Lack of financial resources was another major challenge that reduces the possibility of co-teaching (see Figure 56). In order to provide time for co-teaching, administrators need to provide their teachers with adequate release time, which cannot be done with insufficient funding. As one administrator mentioned:

> *More funding. Yeah, because release time…will help facilitate the co-planning that's necessary and [establish] PLCs…I think definitely cash… funding…[is needed].* - Administrator

*Figure 56: Lack of Financial Resources*

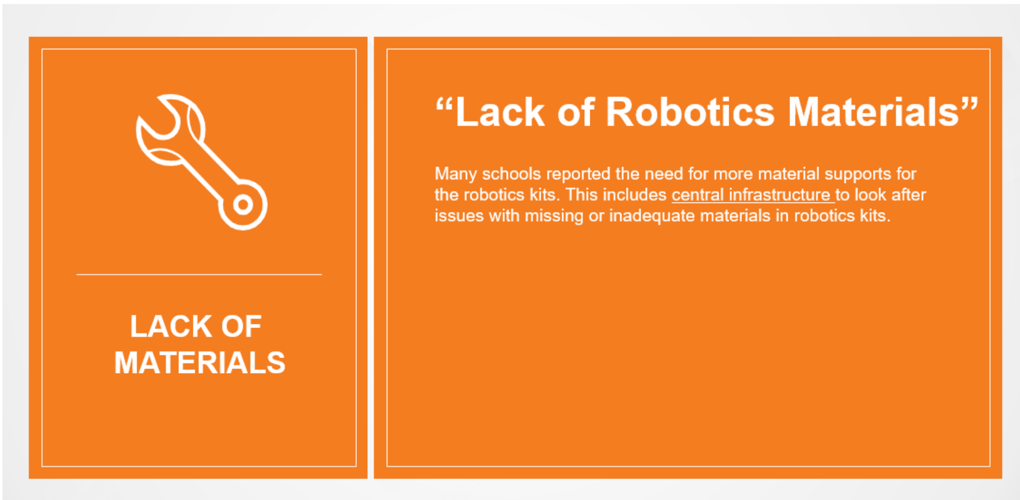



## Lack of Robotics Material Resources

As reported, many schools wanted more material support, equipment and kits (see Figure 57). A practical concern was support for kits if pieces were missing or went missing. If pieces go missing, then these kits are useless which presents a need for a central infrastructure that looks after these issues. An administrator discussed this concern at his school.

*Grade 1's, they lose pieces all the time. What if some of these pieces go missing? Is it even worth starting? Because if they go missing, who's going to pay for it? . . . So I think that…there has to be, if this is something that whether Model Schools wants their Model Schools to be implementing fully,…then there has to be support pieces around sustaining the actual kits.* - Administrator

***Figure 57: Lack of Materials***




## Lack of Computers

Another big issue was the lack of computers. In many schools, computers are only accessible in labs; so then it becomes a scheduling issue because you have to book well in advance. It was suggested that if lab times were scheduled in at the beginning of the year, then this method of booking would be successful. Otherwise, this form of booking computer labs often prevents the successful implementation of STEM in the classroom or the incorporation of technology into learning. In cases where there are limited computers and a big group of students are at one computer, the students who are not in front of the computer lose focus. This is especially problematic in classrooms with behavioural issues. Insufficient equipment also leads to unequal time in which students get to use the robotics kits (see Figure 58). The need for hardware to be accompanied by the appropriate software was addressed by one teacher:

*If you're really pushing STEM, you have to give schools more support with it. I don't understand why we are going to workshops and doing all these new initiatives that we don't have the hardware to support. You can give all the software in the world, and we can have all the apps in the world, if you don't have the hardware to access them…* - Teacher

*Figure 58: Lack of Computers*




## Planning and Administrators’ Commitment

Figure 59 depicts the commitments suggested by administrators to address barriers in successful STEM/robotics implementation in the classroom. For instance, one area of improvement for the development of robotics cultures within schools was the range of planning which needed to be done by administrators to execute their robotics/STEM strategy. Noting the starting point for the successful implementation of STEM being the administrators themselves, one administrator detailed varied barriers that arose with STEM programs.

> *So you need an advocate that would be a barrier for schools without it, you need that key teacher… if you don’t have it, I think that would be a barrier. You need support from outside of the school… that would be a barrier. Getting the materials needed… that would be a barrier.* - Administrator

Specifically, as echoed across the majority of administrators linked with STEM, a long-range plan is central to success with STEM at its individual sites. One administrator concluded:

> *If you are expecting people to come together without putting a plan in place, that’s usually where things falls apart.* - Administrator

These quotes above demonstrate the complexity of STEM and robotics as there are a variety of structures required for the initiative to succeed. Opportunities for growth mentioned in interviews included the development of buy-in with teachers about the initiative, budgeting for essential technologies, allocating release time for planning and co-planning, and finding quality professional development related to STEM. Simply put by one administrator in regards to developing STEM at her school, *“You have to know the destination before you get on the train.”*

An additional barrier to adequate planning by administrators is their lack of adequate knowledge on the topic of STEM and robotics. In the view of one administrator, this was one of the key barriers to success of the STEM initiative. He placed these thoughts in the following quote:

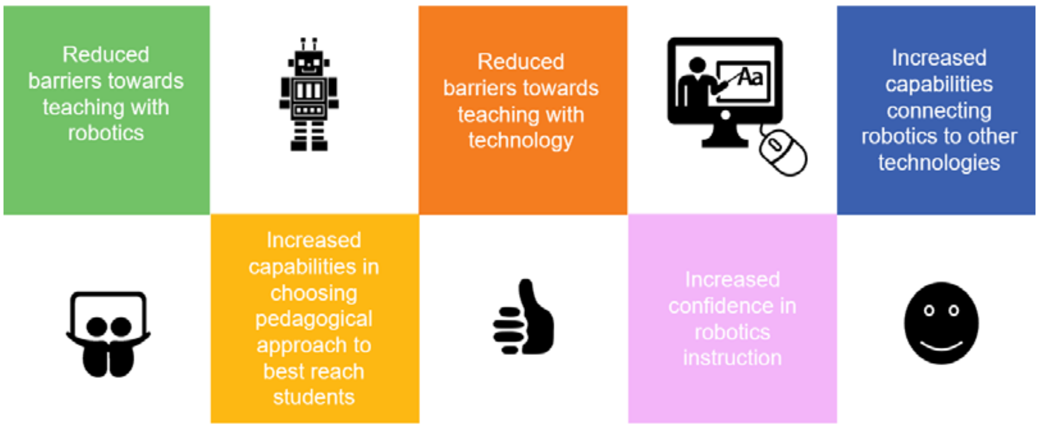
*[I] think [a better] understanding and a lot of administrators may require a better understanding behind the pedagogy and then how to integrate it into their school.* - Administrator

***Figure 59: Planning & Administrator Commitment***

## Discussion, Recommendations and Conclusion

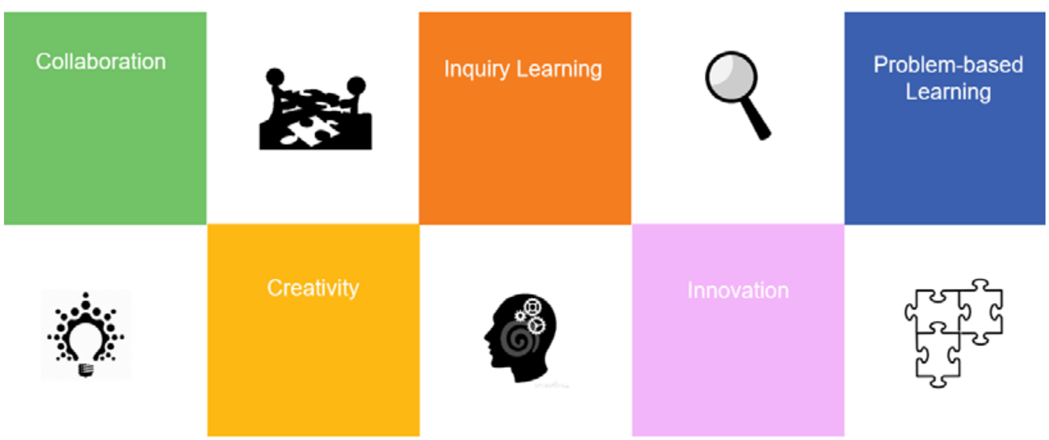
Professional learning in robotics leads to reduced barriers for teachers in teaching with robotics and technology in general. This is evident from seeing increases in the post TPACK survey. Specifically, teachers become much more capable of understanding and connecting robotics to other technologies they have available to them and choosing a pedagogical approach that will best serve their students within that context (see Figure 60).

*Figure 60: Conclusions from Teacher Findings*




Students showed improvement across a number of global competencies after they had longer exposure with robotics, specifically in their competencies of collaboration, inquiry/problem-based learning, creativity and innovation. Improvements in these competencies are central in terms of nurturing youth who will have the ability to step forward into the types of knowledge economy positions becoming more prevalent in contemporary society (see Figure 61).

*Figure 61: Conclusions from Student Findings*




Students showed increases in the following global competencies after exposure to robotics.

In addition, students showed improvement in their achievement and learning skills by participating in the robotics program. In most cases additional exposure to robotics correlated with increases in EQAO results, report card achievement and learning skills. The conclusion which can be reached is that robotics does have a positive effect across other areas of students' education. More specifically, the 21st century skills and global competencies which engagement in robotics helps to develop are useful attributes in almost all areas of students' school and academic lives.

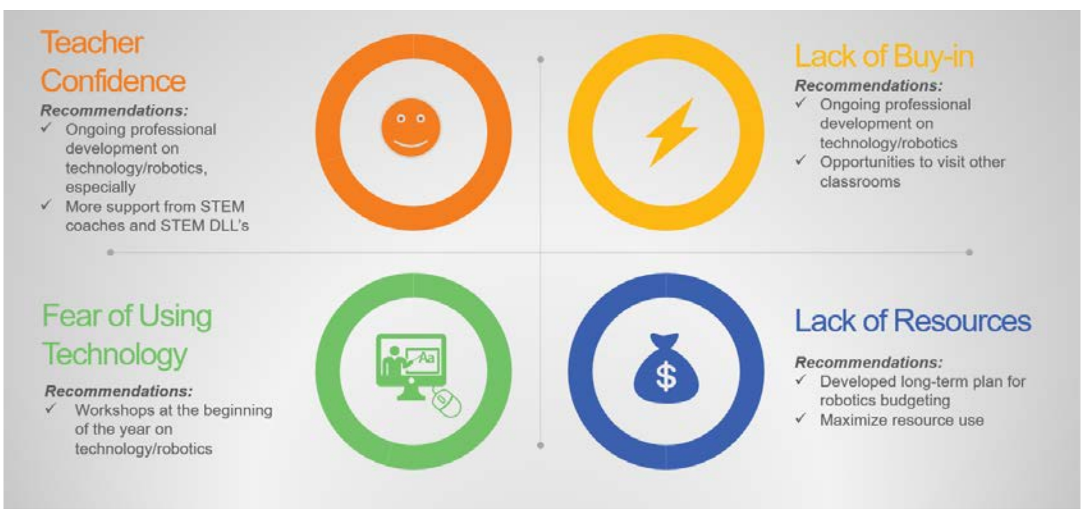
Despite all the positive effects of robotics for both teachers and students, there are still several barriers, which hinder further implementation (see Figure 62). Both teachers' confidence in teaching with robotics and their overall fear of using technology are the two largest concerns. These are areas where the following recommendations could potentially be applied:

- Ongoing and continuous professional learning on technology/robotics,
- More on-site support from STEM coaches and STEM Digital Leader Learners,
- Workshops at the beginning of the year on technology/robotics,
- Opportunities to visit and model exemplary teachers' classrooms.

Additionally, beyond those two areas mentioned, there are still barriers in terms of available resources for implementing robotics as well. This is a rather sizeable barrier, which requires coordination between teachers, administrators and central leadership. Recommendations to address this barrier include:

- Administrators developing a long-range plan for robotics with a focus on budgeting for necessary robotics resources,
- Administrators maximizing resource usage to generate enthusiasm for robotics,
- Administrators focusing on good budgeting techniques.

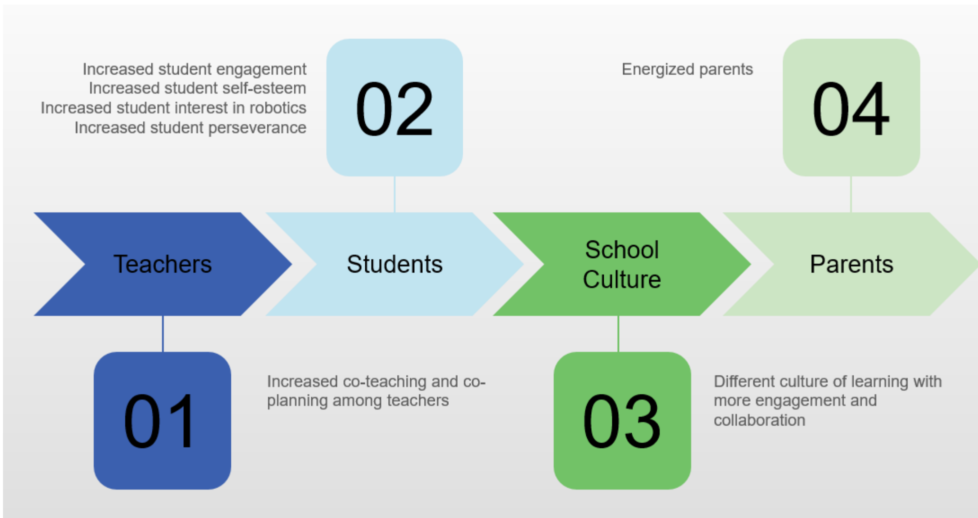
***Figure 62: Barriers and Recommendations to Implementation***




Although there were areas hindering the additional scaling up of robotics, there were also several areas where success was evident (see Figure 63). These successes occurred with students, teachers and across schools doing robotics themselves. These successes with robotics include:

- **Teachers increased:** co-teaching and co-planning among teachers.
- **Student increased:** student engagement, self-steem, and interest in learning about robotics; perseverance; and opportunities for HSP students.
- **School increased:** cultures of learning for students; purpose and identity for schools; robotics competition opportunities that bring the school together; and strong connection between the parent community and their children's school.

***Figure 63: Additional Successes***




## Recommendations for Teacher Engagement

- **Resource sharing networks:** There is a need to build networks (both physical and digital) with other schools doing robotics. Teachers suggested building learning networks and connecting with other schools. One way to do this is through classroom visits (virtual or face-to-face) at other schools to see how the initiative is being carried out. Having teachers online uploading videos and resources that they used could help show how they are implementing the program and grading it would be practical and informative. One administrator suggested that *"I think like anything, we have to find schools who are like-minded with this vision and we have to create some kind of learning hub, some kind of connection."* - Administrator
- **Release time:** The Board was encouraged to provide release time for staff in schools that are capable to teach other teachers. To support this position one administrator argued, that *". . . the board should build in some release time for your own staff that are capable of doing some coaching as well".*
- **Teachers need to be made to feel comfortable with STEM:** Teachers need to be encouraged to try something new and explaining it is acceptable to struggle with a STEM lesson plan is beneficial. The program needs to be started with interested teachers. This is the only way for robotics to proliferate within schools. Teachers need to experience a new vision of education

and how robotics can be a vehicle towards this vision. There is a need to tailor support for teachers based on their backgrounds and comfort level. Teachers need directions on how the program can be linked to curriculum expectations. Instead of implementing STEM at every school at the same time, it was suggested that it should be rolled out slowly, starting with schools that are interested. There is no point investing if teachers are not on board first to carry it out. A suggestion was made for the initiative to be run as a club and once they feel comfortable with it they would be able to incorporate it into their classroom. One administrator reflected upon his or her experiences in one school where, *"the teachers who were teaching grade… even kindergarten, Grade 1 and 2, they were the most apprehensive and had a hard time really changing their perception of what STEM can be in a classroom until they had actually seen it."*

- **Generating Buy In:** Moving robotics slowly across the board and allowing teachers to see it in action are essential elements of generating buy in towards robotics with teachers. As teachers see their peers using robotics, and the tremendous successes they have engaging their students with them, many will be willing to take a risk and try doing it themselves. *The teachers have to have buy-in, [in] order for them to bring it to their classroom. "They have to have evidence. They are seeing the kids wanting to come out to the LEGO club. They are seeing them build something and bringing it to show them and them being self-advocates and saying"; "Hey, we want this as well."* - Teacher
- **Finding a Robotics Lead Teacher:** An important component of generating school wide buy-in is by finding a teacher who already has a natural propensity towards technology and robotics and allowing them the chance to generate enthusiasm with other teachers. Getting connected peer to peer with an initiative can have a strong effect on a teacher's interest in initiatives such as robotics. "*I think if you have one teacher who totally enjoys doing this and can get their kids enthralled with working with robotics, I think they'd be able to also get others on board in the school."* - Administrator
- **Modeling Robotics for Teachers:** By providing teachers with the chance to visit classrooms already doing STEM and robotics, many of the fears individual teachers have can often be overcome. When teachers are given the opportunity to see the enthusiasm that robotics can generate in the classroom, it can go a long way in availing their anxieties. "*The teachers who were teaching grade… even kindergarten, Grade 1 and 2, they were the most apprehensive and had a hard time really changing their perception of what STEM can be in a classroom until they had actually seen it."* - Administrator
- **Building a Learning Community**: When an initiative such as robotics truly gets off the ground, teachers can literally drive the initiative themselves by banding together to further their knowledge and enthusiasm towards the subject area. A learning community can be infectious in terms of pushing an entire school's culture towards embracing an initiative such as robotics. "*It acts as a vehicle to create a learning community because when you're working with robotics, there's a sense of excitement. There's certainly engagement and there's a perception from others of wow, that's really interesting, I want to be a part of that."* - Administrator

## Referencies


Alimisis, D., & Kynigos, C. (2009). Constructionism and robotics in education. In D. Alimisis (Ed.), *Teacher education on robotics-enhanced constructivist pedagogical methods* (pp. 11-26). Athens, Greece: School of Pedagogical and Technological Education.

Australian Curriculum, Assessment and Reporting Authority. (2014). The Australian Curriculum: Technologies. Retrieved from http://www.heia.com.au/resources/documents/Designandtechnologies2014.pdf

Battelle Technology Partnership Practice. (2014). *STEM: Building a 21st century workforce to develop tomorrow's new medicines.* Report prepared for the Pharmaceutical Research and Manufacturers of America provided by Battelle Technology Partnership Practice. Columbus, Ohio. Author. Retrieved from http://phrma-docs.phrma.org/sites/default/files/pdf/stem-education-report-2014.pdf

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. doi:10.1016/j.compedu.2013.10.020

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. National Science Teachers Association, NSTA Press, Arlington, Virginia.

Catlin, D. (2012). *Maximising the effectiveness of educational robotics through the use of assessment for learning methodologies*. Paper Presented at the Conference: 3rd International Workshop Teaching Robotics Teaching with Robotics, At Riva del Garda, Italy.

Chandra, V. (2014). Developing students' technological literacy through robotics activities. *Literacy Learning: The Middle Years*, *22*(3), 24-29.

Dredge, S. (2014). Coding at school: A parent's guide to England's new computing curriculum. *The Guardian*. Retrieved from http://www.theguardian.com/technology/2014/ sep/04/coding-school-computing-children-programming.

Dunn, K. (2014). *Learning robotics online: Teaching an online robotics course for secondary school students.* Unpublished Master's Thesis, University of Christchurch, New Zealand. Retrieved from http://ir.canterbury.ac.nz/bitstream/handle/10092/10281/thesis_fulltext.pdf?sequence=1&isAllowed=y

Ebelt, K. R. (2012). The effects of a robotics program on students skills in STEM, problem solving and teamwork. Montana State University. Retrieved from: http://scholarworks.montana.edu/xmlui/bitstream/handle/1/1216/EbeltK0812.pdf

English, L. D. (2016a). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, 3 (3). Retrieved from https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-016-0036-1

English, L. D., & Gainsburg, J. (2016b). Problem solving in a 21st-century mathematics curriculum. In L. D. English & D. Kirshner (Eds.), *Handbook of international research in mathematics education* (3rd ed., pp. 313–335). New York: Taylor & Francis.

Faisal, A., Kapila, V., & Iskander, M.G., (2012). Using robotics to promote learning in elementary grades. (pp. 1-14) Paper presented at the 19th American Society for Engineering Education (ASEE) Annual Conference & Exposition, San Antonio, Texas. Retrieved from https://www.asee.org/public/conferences/8/papers/5480/view

Goodenow, C. (1992). Strengthening the links between educational psychology and the study of social contexts. *Educational Psychologist, 27*(2), 177-196.

Gray, A. (2016). *The 10 skills you need to thrive in the Fourth Industrial Revolution*. Reading presented at World economic forum in Switzerland, Davos. https://www.weforum.org/agenda/2016/01/the-10-skills-you-need-to-thrive-in-the-fourth-

Green, L. S. (2014). Through the looking glass: Examining technology integration in school librarianship. *Knowledge Quest*, *43*(1), 36 – 43.

Grubbs, M. (2013). Robotics intrigue middle school students and build STEM skills. *Technology and Engineering Teacher, 72*(6), 12–16.

Gura, M. (2012). Lego robotics: STEM sport of the mind. *Learning and Leading with Technology, 40*(1), pp. 12- 16. Retrieved from https://eric.ed.gov/?q=Lego+robotics%3a+STEM+sport+of+the+mind.+Learning+and+Leading+with+Technology&id=EJ991224

Hamdullahpur, F. (2016). *Education and the 4th Industrial Revolution*. Speech presented at Economic Club of Canada, Toronto, ON. Retrieved from http://www.21stcentech.com/education-4th-industrial-revolution-part-2

Han, J. (2012). Emerging technologies: Robot assisted language learning. *Language Learning & Technology, 16*(3), 1-9. Retrieved from http://llt.msu.edu/issues/october2012/emerging.pdf

Highfield, K. (2010). Robotic Toys as a Catalyst for Mathematical Problem Solving. *Australian Primary Mathematics Classroom,* 15 (2), 22–27. http://eric.ed.gov/?id=EJ891802

Honey, M., Pearson, G., & Schweingruber, A. (2014). *STEM integration in K-12 education: status, prospects, and an agenda for research*. Washington: National Academies Press.

Hwang, W., & Wu, S. (2014). A case study of collaboration with multi-robots and its effect on children's interaction. *Interactive Learning Environments*, *22*(4), 429-443.
doi:10.1080/10494820.2012.680968

Innwoo, P., Donjeong, K., Junghyuk, Oh., Yoonho, Jang., & Keol L. (2015). Learning Effects of Pedagogical Robots with Programming in Elementary School Environments in Korea. Indian Journal of Science and Technology, 8 (26). Retrieved from http://www.indjst.org/index.php/indjst/article/view/80723

Julià, C., & Antolí, J. (2016). Spatial ability learning through educational robotics. *International Journal Of Technology & Design Education*, *26*(2), 185-203. doi:10.1007/s10798-015-9307-2

Keren, G., & Fridin, M. (2014). Kindergarten Social Assistive Robot (KindSAR) for children's geometric thinking and metacognitive development in preschool education: A pilot study. *Computers In Human Behavior*, *35*4-412. doi:10.1016/j.chb.2014.03.009

Khanlari, A. (2013). Effects of robotics on 21st century skills. Retrieved from: http://warse.org/pdfs/2013/icet4esp10.pdf

Khanlari, A. (2016). Teachers' perceptions of the benefits and the challenges of integrating educational robots into primary/elementary curricula. *European Journal of Engineering Education*, *41*(3), 320-330. doi:10.1080/03043797.2015.1056106

Kier, M. W., Blanchard, M. R., Osborne, J. W., & Albert, J. L. (2013). The Development of the STEM Career Interest Survey (STEM-CIS). Research in Science Education, 44(3), 461–481. doi:10.1007/s11165-013-9389-3

Killen, R. (2007). Teaching strategies for outcomes-based education. (2nd ed.). Cape Town: JUTA.

Kimmel, H., Carpinelli, J., Burr-Alexander, Hirsch, L., & Rockland, R. (2010, Spring). Advancing the "E" in K-12 STEM Education. *The Journal of Technology Studies,* 2, 53-63.

Klassen, R. M., Yerdelen, S., & Durksen, T.L. (2013). Measuring teacher engagement: Development of the Engaged Teacher Scale (ETS). *Frontline Learning Research*, *2*, 33-52.

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60-70.

Korean Ministry of Education. (2014). Software education plan in elementary and secondary schools. Seoul, Korea. Ministry of Education. Retrieved from http://asiasociety.org/global-cities-education-network/south-korean-education

Mishra, M. & Koehler, M.J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054.

MIT News. (2016). Professor Emeritus Seymour Papert, pioneer of constructionist learning, dies at 88. Retrieved from http://news.mit.edu/2016/seymour-papert-pioneer-of-constructionist-learning-dies-0801

Mondada, F., Bonnet, E., Davrajh, S., Johal, W., & Stopforth, R. (2016, Sept-Oct). R2T2: Robotics to integrate educational efforts in South Africa and Europe. *International Journal of Advanced Robotic Systems*, 1-13. DOI: 10.1177/1729881416658165

Ontario College of Teachers. (2011, Sept). About more than robots. *Professionally Speaking*. Retrieved from http://professionallyspeaking.oct.ca/september_2011/features/robots.aspx

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.

Piaget, J. (1983). Piaget's theory. In P. Mussen (Ed.). *Handbook of Child Psychology*. Wiley.

Picciano, A. G., & Steiner, R. V. (2008). Bringing the real world of science to children: A partnership of the American Museum of Natural History and the City University of New York. *Journal of Asynchronous Learning Networks, 12*(1), 1-16.

Polly, D., & Rock, T. (2016). Elementary education teacher candidates' integration of technology in the design of interdisciplinary units. *Techtrends: Linking Research & Practice to Improve Learning*, *60*(4), 336-343. doi:10.1007/s11528-016-0059-y

Puentedura, R. (2014, November 12). *SAMR: First Steps* [Presentation slides]. Retrieved from http://www.hippasus.com/rrpweblog/archives/2014/11/13/SAMR_FirstSteps.pdf

Ravitz, J. (2014). *A survey for measuring 21st century teaching and learning: West Virginia 21st century teaching and learning survey* [WVDE-CIS-28]. Retrieved from: http://www.academia.edu/5901608/A_survey_for_measuring_21st_century_teaching_and_learning_West_Virginia_21st_Century_Teaching_and_Learning_Survey_WVDE-CIS-28_

Resnick, M. (2003). Playful learning and creative societies. Education Update, 8(6). Retrieved from http://web.media.mit.edu/wmres/papers/education-update.pdf.

Rieber, L.P. (1992). Computer-based microworlds: A bridge between constructivism and direct instruction. *Educational Technology Research and Development. 40*(1) 93-106.

Robinson, N. (2016). A case study exploring the effects of using an integrative STEM curriculum on eighth grade students' performance and engagement in the mathematics classroom. Unpublished Doctoral Dissertation. Atlanta, GA: Georgia State University. Retrieved from http://scholarworks.gsu.edu/mse_diss/32

Robinson, Trevor P. (2014). The development of an instrument to measure the self-efficacy of students participating in VEX Robotics Competitions. *All Graduate Theses and Dissertations.* Paper 3077.

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological Pedagogical Content Knowledge (TPACK): The Development and validation of an assessment instrument for preservice teachers. Journal of Research on Technology in Education, 42, 123–149. doi:10.1080/15391523.2009.10782544

Sinay, E., Jaipal-Jamani, K., Nahornick, A., & Douglin, M. (2016). *STEM teaching and learning in the Toronto District School Board: Towards a strong theoretical foundation and scaling up from initial implementation of the K-12 STEM strategy. Research Series I*. (Research Report No. 15/16-16). Toronto, Ontario, Canada: Toronto District School Board.

Sinay, E. (2014). *Global learning and teaching with educational technology in the Toronto District School Board* (Research Report No. 14/15-01). Toronto, Ontario, Canada: Toronto District School Board

Sinay, E., & Ryan, T.G. (2017). Global Competencies and Deep Learning: Teaching and Learning with Coding. *Research Series 2*. (Research Report No. 2). Toronto, Ontario, Canada: Toronto District School Board.

Strawhacker, A. L., & Bers, M. U. (2014). "I want my robot to look for food": Comparing children's programming comprehension using tangible, graphical, and hybrid user interfaces. *International Journal of Technology and Design Education, 25*(3). 293-319.

Thomas, B., & Watters, J. (2015). Perspectives on Australian, Indian and Malaysian approaches to STEM education. *International Journal of Educational Development, 45*, 42–53.

Whitehead, Stephen H. (2011). Relationship of robotic implementation on changes in middle school students' beliefs and interest toward Science, Technology, Engineering and Mathematics. *Theses and Dissertations.* Paper 898.

Wang, L., Ertmer, P. A., & Newby, T. J. (2004). Increasing preservice teachers' self-efficacy beliefs for technology integration. *Journal of Research on Technology in Education, 36*(3): 231-250, DOI: 10.1080/15391523.2004.10782414.

Vasquez, J. A. (2014). STEM - Beyond the acronym. *Educational Leadership*, *72*(4), 10-15.