Classroom Robotics and Acquisition of 21st Century Competencies: An Action Research Study of Nine Ontario School Boards

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Dr. Janice Aurini
Department of Sociology & Legal Studies
University of Waterloo
jaurini@uwaterloo.ca

Dr. John McLevey
Department of Knowledge Integration
University of Waterloo
john.mclevey@uwaterloo.ca

Dr. Allyson Stokes
Department of Knowledge Integration
University of Waterloo
a2stokes@uwaterloo.ca

Dr. Rob Gorbet
Department of Knowledge Integration
University of Waterloo
rob.gorbet@uwaterloo.ca

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1 Acknowledgments

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2 Executive Summary

This Action Research Study examines the use of robotics in nine school boards in Ontario. The report addresses the following key issues:

- **Current Practices**: We provide an overview of how robotics is currently being used to support student learning.
- **Benefits of Robotics**: We document how robotics is used to develop 21st century competencies, support engaging classroom teaching, and enable positive classroom dynamics.
- **Challenges**: We detail the challenges of integrating and supporting robotics in elementary curriculum.
- **Considerations and Next Steps**: We offer practical strategies for supporting robotics teaching and learning, using robotics as a tool to develop 21st century competencies, and integrating robotics across the curriculum.

The findings detailed in this report are supported by interviews and focus groups conducted between January 2017 and June 2017 with 169 teachers and students, 19 video-recorded classroom observations, and 201 surveys completed by teachers.

We found that teachers are using robotics in a variety of creative ways to support mathematics, literacy, science, and awareness of environmental or social issues. Robotics can encourage student collaboration, communication, and problem-solving. Robotics is also credited with reducing behavioural issues and supporting positive student interactions.

Despite the potential benefits of robotics, challenges remain. Currently, robotics initiatives are not firmly embedded within schools and school boards; this is largely due to insufficient curriculum and assessment integration, resources and professional development, and support. Further, opportunities to engage robotics are not equitably distributed across and within schools. These challenges greatly limit the expansion and development of robotics.

To support robotics, this report details 8 key considerations:

> **Consideration 1**: Prioritize professional development and support teachers in their efforts to learn more about robotics and coding.
>
> **Consideration 2**: Integrate robotics, coding, and computational thinking into curriculum documents and make these documents equally available to all schools across the province.
>
> **Consideration 3**: Continue the work begun in the Phase 1 Discussion Paper on assessment of 21st century competencies (MOE 2016), support teachers in the transitions related to assessment, and revise report cards to ensure that these skills are seen to be valued and worth committing time and energy to in the classroom.
>
> **Consideration 4**: Provide funding and support to increase the equitable distribution of robotics, coding and other technological learning within and across school boards.
>
> **Consideration 5**: Ensure that all students in the province of Ontario have an opportunity to be exposed to robotics, coding and technological learning at some point during their

elementary school career.

Consideration 6: Centralize and facilitate the tender process by offering a list of pre-approved kits.

Consideration 7: Provide teachers with adequate space and time to meaningfully engage robotics teaching and learning.

Consideration 8: Encourage and facilitate the development of strategic collaborations and partnerships.

3 About the Action Research Study

Ministries of education are increasingly using technology to support student engagement and learning. Ontario is no exception. In 2014, the Ontario Ministry of Education (MOE) launched a technology and learning fund. This investment – which is part of a larger initiative to enhance 21st century competencies – is intended to support the meaningful integration of technology in the classroom and help students "become more technologically savvy" (Ontario Ministry of Education, 2014:1). In addition to tablets, smartboards, and other devices, MOE purchased over 5,300 robotics kits. These kits were distributed to every school board in the province. In some cases, school boards used these kits to support an already thriving robotics and technology program. In other cases, the investment made by MOE afforded school boards the opportunity to introduce robotics for the first time.

This Action Research Study examines the use of robotics in nine of these school boards. Drawing on qualitative and quantitative data collected between January 2017 and June 2017, the report addresses the following key issues:

- **Current Practices**: We provide an overview of how robotics are currently being used to support student learning.
- **Benefits of Robotics**: We document how robotics is used to develop 21st century competencies, support engaging classroom teaching, and enable positive classroom dynamics.
- **Challenges**: We also detail the challenges of integrating and supporting robotics.
- **Considerations and Next Steps**: We offer practical strategies for supporting robotics teaching and learning, using robotics as a tool to develop 21st century competencies, and integrating robotics across the curriculum.

As researchers, we naturally started this project with a healthy amount of skepticism. Are teachers able to make meaningful connections to the curriculum using robotics? Beyond student engagement, is there evidence that robotics produce tangible academic and social benefits? Do teachers see robotics as a viable tool to support 21st century competencies? Or do teachers see robotics as a 'fad' with little pedagogical value?

We have now conducted focus groups and interviews with 169 teachers, administrators, and students; surveys with 201 teachers and administrators; and video-recorded observations in 19 classrooms. In analyzing these data, we have been struck by teachers' overwhelming enthusiasm for robotics. Teachers (particularly those with substantial classroom experience) told us that robotics readily supports several curriculum expectations. They are finding a variety of creative ways to integrate mathematics, literacy, science, and awareness of environmental or social issues into assignments using robotics. The nature of robotics assignments also encourages students to collaborate, communicate their ideas, problem-solve, and work through a variety of challenges. Students also have an opportunity to play a variety of roles including designing the robot, coding, documenting, graphing or journalling, and presenting their results orally or in written format. Robotics is also credited with reducing behavioural issues and supporting positive student interactions. In short, when used strategically, teachers told us that robotics really 'works.'

In this report, we document the results of the Action Research Study. We first describe the data collection and the robotics kits. We then turn to the main findings. This section outlines the main benefits of classroom-integrated robotics, while also laying out the key challenges in adoption. We conclude with an explanation of eight considerations based on our extensive empirical research.

This report draws on qualitative and quantitative data collected between January and June 2017. Active consent was used throughout the data collection process. Administrators, teachers, and students volunteered to participate in the Action Research Study. Only children who had permission from a parent and who signed an assent letter participated in a video-recorded observation and student focus group.

3.1 Data Collection

We used a variety of data collection methods for this report, including focus groups with teachers and administrators, focus groups with junior and intermediate students, interviews with teachers, video-recorded classroom observations, and a sample survey of teachers and administrators. We also coded and analyzed data from reports that school boards submitted to CODE about the kits they purchased, and how kits are being used in their board.

- **Focus groups with administrators and teachers involved in the robotics program**: We gathered information about current board practices and the benefits and challenges of doing robotics. Participants were also asked for suggestions to enhance the integration and impact of robotics.
- **Focus groups with junior intermediate students in classrooms doing robotics**: We asked students to reflect on their experiences with and perceptions of robotics, including the benefits and challenges of doing robotics in the classroom.
- **Interviews with teachers, video-recorded observations and post-observation interviews**: We included teachers currently doing robotics ("robotics teachers") and teachers currently not doing robotics ("non-robotics teachers"). A comparative approach allowed us to systematically examine whether there are observable differences between classrooms with and without robotics (e.g., student engagement).[1] Non-robotics teachers also provided valuable insights into the perceived barriers to introducing robotics. Video recording allowed us to record various dimensions of 21st century competencies, including evidence of collaboration (e.g., negotiating ideas), flexibility (e.g., openness to alternative perspectives), creativity (e.g.,

[1] Moreover, we recognize that teachers are successfully developing 21st century competencies without the aid of robotics or other technologies.

expressing a new idea), problem solving (e.g., developing a plan) and mathematics or science literacy (e.g., use of appropriate computation strategies). In our post-observation interviews, robotics and non-robotics teachers were able to reflect, often together, on the perceived value of robotics or other technological aids in the context of developing 21st century competencies and achieving curriculum goals.

- **Sample survey with teachers**: We designed and conducted a sample survey of teachers from six school boards. Each of these boards provided us a list of teachers within their board who are doing robotics in their classrooms, and a list of administrators who were involved in helping get robotics into their schools. This resulted in a list of 350 teachers and administrators. Our response rate for teachers and administrators involved in classroom-integrated robotics was 57% (201 completed surveys).[2]
- **Administrative Reports to CODE**: Finally, we coded and analyzed reports that school boards submitted to CODE about the kits they purchased with CODE funds, and how the kits are being used in their boards. These reports include quantitative information about the number of kits purchased, the types of kits purchased, the number of schools that received kits, and the number of kits in general circulation. The reports also included some open-ended responses to questions from CODE about professional development for teachers, teacher preparation, connections to curriculum, and student engagement.

Table 1: Overview of data and participants

Data Collected	Participants	Notes
10 focus groups	95 participants	Administrators and teachers
6 student focus groups	46 participants	Junior and intermediate students
38 teacher interviews	38 participants	Administrators and teachers
19 video-recorded observations	19 classrooms	11 classrooms with robotics, 8 without
Teacher and administrator survey	201 participants	Response rate 57% from 6 boards
Reports to CODE	64 school boards	Multiple types of data

3.2 The Kits

Ontario boards were given the opportunity to purchase robotics kits, through CODE, from a menu of six possible selections from four manufacturers: VEX, LEGO, fischertechnik, and Tetrix. The available kits span a range of technical intricacy and capabilities, from the construction or demonstration of simple machines (fischertechnik), to the design and construction of more complicated remotely operated machines (Tetrix), all the way to programmable autonomous robots. Given this range, decisions about which kits to purchase depend on the grade levels and subjects they will be used in. As shown in Figure 1, these kits are overwhelmingly being used in elementary math, science, and tech-

[2] In addition, we worked with each board to secure a probability sample of elementary and secondary teachers who were not doing robotics in their classrooms. Our response rate for teachers not doing robotics in the classroom was too low to use in any quantitative data analysis, but we did analyze the responses to open-ended survey questions to develop a better understanding of why some interested teachers do not use robotics in their classrooms.

nology classes. However, as we will discuss below, many teachers are also integrating robotics into their elementary language and arts courses.[3]

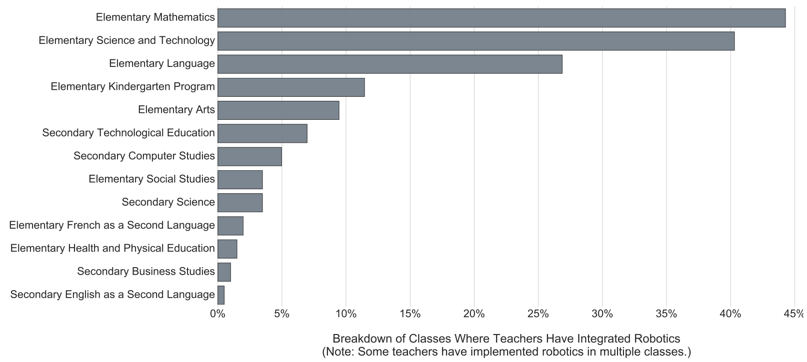

Figure 1: Breakdown of classes where teachers have integrated robotics.

The LEGO WeDo kit (shown in Figure 2) is targeted at Grades 2-5, and uses the familiar LEGO block construction system. Free curriculum and standards alignment grids are available.[4] A programmable controller block allows control of up to two motor or sensor blocks. The system is programmable and controllable over bluetooth from Windows, MacOS, Chromebook, as well as iOS and Android tablets.

Figure 2: LEGO WeDo Construction Set (www.education.lego.com).

LEGO EV3 Mindstorms (Figure 3) use LEGO's more advanced Technic construction system. Mindstorms include a central "brain" which connects to proprietary motors and sensors. Up to four motors and four sensors can be connected at once. It is targeted at Grades 6-8 and free curriculum and standards grids are available. Mindstorms can be programmed in the proprietary LEGO EV3 software using a computer or tablet/smartphone, or using a range of other third-party platforms including Scratch and ROBOTC.

VEX IQ (Figure 4) is a snap-together kit similar to LEGO Mindstorms. It is targeted at grades K-8 and includes free curriculum as well as a standards mapping grid. The robots are programmed from

[3]Data come from the teacher survey, not from reports to CODE, which listed grade numbers but not subject areas. The bars represent the percentage of teachers who reported doing robotics in the relevant subject. In other words, more than 40% said they had integrated robotics into their Elementary Math class, slightly more than 40% said they integrated robotics into the Elementary Science and Technology class, etc. Note that teachers can use robotics in more than one subject, so the percentages sum to more than 100%. Some of the teachers we surveyed have taught secondary classes. We have included those classes in the graph, even though the CODE support was for elementary.

[4]Note that references to curriculum and standards alignment grids in this section are to US standards such as the Next Generation Science Standards (NGSS, http://ngss.nsta.org/) and ITEES Standards for Technological Literacy (STL, https://www.iteea.org/39197.aspx). To the extent that the Ontario curriculum is similar, these can likely be remapped to the provincial standards.

Figure 3: LEGO EV3 Mindstorms Core Set (www.education.lego.com).

a computer, using VEX's proprietary Modkit drag-and-drop language or the third-party software, ROBOTC. The "brain" can control/respond to up to twelve motors or sensors in any combination. There is a competition framework, the VEX IQ Challenge, which allows teachers and students to build towards a goal outside of the curriculum.

Figure 4: VEX IQ Super Kit (www.vexrobotics.com/vexiq).

VEX EDR (Figure 5) is a more complex construction kit with metal parts and traditional fasteners. It is targeted at grades 6-12 and includes free curriculum as well as grids and an online standards mapping tool. The robots are programmed from a computer, using easyC or ROBOTC. The "brain" is very advanced–similar to what one might encounter in a real industrial robot–and can control/respond to many motors or sensors in any combination. There is an international competition framework, the VEX Robotics Competition, which allows teachers and students to build towards a goal outside of the curriculum.

Figure 5: VEX EDR Classroom & Competition Super Kit (www.vexrobotics.com/vexedr).

The fischertechnik Introduction to STEM 1 kit (Figure 6) uses a twist-lock assembly mechanism that allows the construction of 40 different predefined models of simple machines. It is targeted at Grades 2-4 and is a more constrained kit than the programmable ones available from LEGO or VEX. Standards-based curriculum is available on registration with fischertechnik.

Figure 6: fischertechnik Introduction to STEM I Kit (www.fischertechnik.biz).

The Tetrix Prime Starter Set (Figure 7) uses a combination of plastic and metal parts which connect using traditional fasteners. Out of the box it is operated using a remote controller, but is not directly programmable. An expansion pack allows the use of Arduino-based programming, which elevates the complexity closer to the VEX EDR kit. Programmable Tetrix kits are used in the FIRST Tech Challenge, an international competition similar to the VEX Robotics Competition. Standards-based curriculum is available with the more expensive whole-classroom kits (e.g., the Remote Control STEM Unit, which comes with 12 Prime Starter Kits).

Figure 7: Tetrix Prime Starter Set (www.tetrixrobotics.com).

The variation in capabilities in the specific kits made available via the CODE grant program suggests that careful thought should be given to the definition of "robotics." We suggest there are two aspects: the ability to physically assemble or reconfigure component parts to develop a machine that can carry out a task, and the ability to program (and re-program) these machines in order to accomplish different tasks.

The fishertechnik STEM I kit allows the construction of a limited number of simple machines, but does not include motors or permit programming of any kind; we do not consider this a "robotics" kit. The Tetrix Prime kit allows the open-ended design of complex machines including arms, motors and wheels, but these machines are remotely controlled by the students rather than programmed and functioning autonomously. Both fishertechnik and Tetrix do have more advanced kits which permit reprogrammable behaviours, but these were not made available via the CODE purchasing program. It is important to note also that our study recruitment was not limited to those teachers using kits purchased through the CODE program. Hence, we also saw in our observations in schools, examples of programmable robots that were suitable even for very young ages (e.g., BlueBot from Terrapin, Dash and Dot from Wonder Workshop, and Sphero).

Figure 8 shows the breakdown of which kits were purchased by boards across the province. LEGO is certainly the most popular vendor, although this is partly due to its popularity with larger school boards. (Most boards commonly purchase all their kits from the same vendor.)

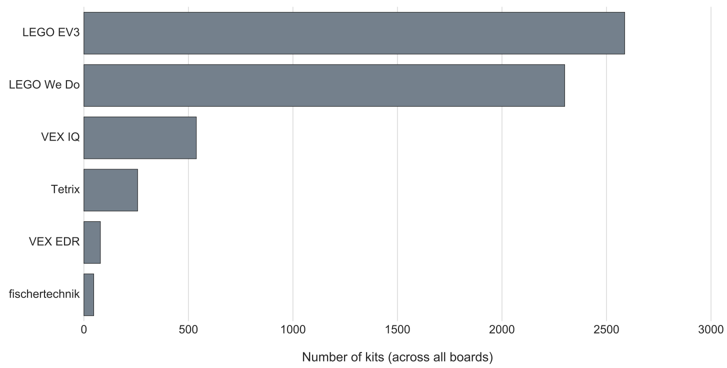

Figure 8: Breakdown of kits purchased through CODE.

4 Action Research Study: Main Findings

4.1 Current Practices

In this section, we document current pathways to robotics and provide examples of how teachers are integrating robotics into their classrooms. This discussion sets the context for several of the benefits and challenges associated with robotics, documented later in the report.

Currently, the development of robotics initiatives rests on a handful of 'trail blazers'. Typically, these individuals champion robotics to their colleagues, and seek out resources or support. Of course, access to and uses of robotics varies between and within the nine school boards. Not all schools have robotics kits, and not all teachers have access to robotics kits or a sufficient number of robotics kits and supporting technology, even within schools that have kits. (See Figures 15 on page 27 and 16 on page 28.) Teachers who do have access to robotics kits use them in a variety of creative ways to make connections to the curriculum.

4.1.1 Pathways to Robotics

4.1.1.1 School Pathways

The most common pathway to doing robotics within schools is through a "champion" or "trailblazer." These teachers go "above and beyond" to bring robotics into a school or classroom. The following is a quote from a grade seven and eight teacher who describes his passion for coding and how, with one other teacher, he took the initiative to bring coding and robotics into his classroom.

> I've always been a hands-on tech computer coding kind of guy. … As I got into teaching and became an elementary school teacher, I always wondered why people weren't making good use of all of the available technology. As [name of teacher] joined the school with me, we were able accomplish more. We got kids looking at electronics, taking things apart, looking at how they work. We started teaching coding…and we got some extra robotic kits in addition to the few that we had in the building. The robotics initiative kept growing and growing…

A supportive principal or vice-principal is critical to the introduction of robotics; they are instrumental in accessing the robotics kits for their school, identifying potential robotics teachers, and providing various kinds of support or training opportunities. As one robotics teacher explained, her principal "believes in the use of technology" and "encourages it in everyone's classroom." However, it also became clear that sustainable integration requires support beyond the school level. As one teacher explained, "[W]e were given permission from up high; [names redacted] made it very clear board-wide on several occasions that you have permission to explore, to learn, to inquire as a teacher." A senior administrator in her school board promoted the value of "trailblazers" and stressed that it was the job of central staff to "pave those paths so that more would follow." School boards that have made robotics a priority and offer consistent support are more advanced and satisfied with the integration of robotics.

> Our board did an excellent job launching the robotics effort. They took us to a robotics company, to visit the plant. It was very engaging for us to see the robots in action. Then we had time to explore the LEGO EV3 robots, and LEGO representatives were there. We came away from that with a very good feeling, although it was a bit overwhelming because it was our first look at the EV3. How do we get a culture like this in the school? In our case, it was made very clear board-wide on several occasions that as teachers we have permission to explore, to learn, to inquire, and whether it be with robotics or whatever, that's part of our job. … Having Board permission didn't completely remove the barriers, but it certainly gave some impetus for people to take on the risk of doing things a bit differently.

The particular pathways that champions and schools take vary, but include: fundraising (or asking a parent council to fund-raise); taking part in robotics competitions; and, through funding from CODE. For many teachers and students, Hour of Code (https://hourofcode.com/ca) was an entry point into robotics and coding.[5]

4.1.1.2 Teacher Pathways

When we asked teachers how they came to use robotics, several themes emerged. A background in robotics (or technology) helped teachers recognize the potential of robotics. These teachers were also

[5] Interestingly, there were differences in perceptions about how robotics kits were being distributed, with some teachers claiming that their board used CODE funding and followed CODE's suggestions to prioritize distribution according to need (e.g., socioeconomic data of a school), while others claimed that kits were distributed to those most likely to make robotics a success (i.e., those with the most passion and existing skill or training). Still others thought that all schools in Ontario had been given kits. Some noted that before CODE funding existed, it was up to individual schools and school boards to prioritize robotics.

less fearful of robotics. Teachers also felt more comfortable using robotics if they have colleagues to collaborate with or share ideas with. For example, one teacher said that:

> I spent 25 years in IT at some of the big banks before I even came to the school board. So, I have an advantage in understanding the concepts and practice of coding. It was nice to actually team up with [name redacted], because together we converted what used to be a computer club more into the robotics side.

For those without a background in robotics or technology, the process can be mysterious and daunting. For these teachers, networks are very important to developing a pathway to implementing robotics. Being connected to someone within or external to the school who has expertise in robotics makes it much easier for teachers to try robotics.

> We have a family friend who is principal at one of the leading technology schools. They have tons and tons of these little circuits that you connect to things. The kids made posters, I don't even know on what. But if you take the little circuit and it touches 'right here,' it will tell you facts about that thing. Or, if you program it with potatoes, it'll play musical instruments. So, it's completely open ended what you can get these things to do. That's my next step – to get my hands on our friend who is the principal to bring in all these new things.

For some teachers, finding the right expert to help in the classroom means looking in places you may not have thought about. Established high-school robotics clubs are a valuable resource for several robotics teachers, especially in the feeder schools. It's a win-win situation: the elementary students and teachers benefit, and over time these partnerships are a recruiting tool for the participating high schools, which supports the sustainability of their competition teams. One elementary teacher, for example, invited members from the high school robotics competition team to talk about their experiences, show videos, and experiment with the robotics kits. As she explained, "I like to find the experts who can bring their knowledge into the classroom to get them started, to kick it off."

In other cases, teachers who lack the technological background can become inspired by a compelling experience or PD activity. With the right support for this initiative from the school and board, these teachers can start their own programs with simpler robotics kits. Matching the specific kit capabilities and complexity to the level of both the teacher, students, and material is crucial to avoid overwhelming teachers who are new to robotics.

> At our school, we didn't have any robotics kits. I was actually at a library workshop and another librarian was showing me a video of what her robotics club kids were doing with Dash.[6] I thought, 'Well, that's kind of neat, we should do that at our school.' So I asked if we could get some and we've built up to four complete Dot and Dash kits with the accessories. They get kept in the library and are maintained there. We have a booking system so each class can check out a kit and they use it in their classrooms.

Another pathway to robotics for some teachers is through their own children. Teachers with children interested in robotics, or who had bought a robotics kit for their child, came to realize the utility of robotics in their own classrooms.

[6] Dash and Dot are robots from the Wonder Workshop, which target grades K-5 and are some of the easiest programmable platforms in terms of novice access. https://education.makewonder.com/

4.1.2 Examples of How Robotics are Used to Support Student Learning

In schools with robotics, some classrooms have their own dedicated kits. At one school, for example, the teacher is able to borrow a large number of kits from a professor she knows from a nearby college. Others applied and received a grant to purchase robotics kits for their classroom or for a maker space that has a focus on robotics. In most cases, however, robotics kits are accessed for a period, a set number of weeks, or a term. Some schools create a maker space in the library that includes robotics kits that can be accessed by the entire staff. Other schools have a robotics cart that includes the kits and any additional resources (e.g., Chromebooks, iPads) that can be signed out. In some cases, teachers have liberal access to the robotics kits simply because few if any other teachers in their school currently use them.

At the classroom level, teachers use robotics kits in a variety of ways to connect to mathematics, science, literacy, art, or social studies. One junior teacher, for example, uses Dash and Dots and Spheros to teach students perimeter, angles and measurement. Using strips of paper and tape, students create a box or pathway with shapes or angles and code the robot to follow the road map they create. (See Figure 9.)

Figure 9: Grade 4 students exploring perimeter with Dash and Dot.

Teachers at the junior and intermediate level are able to develop more elaborate assignments that connect to more than one subject. One Grade 5/6 teacher developed a series of assignments that builds toward student teams parallel parking their robot. Students create a roadway for the robot to travel, they have to graph their progress at various stages of the project (e.g., distance, speed, successes or failures) and they must journal their progress and respond to questions. They also address several challenges and must adjust their approach along the way (e.g., the teacher introduces a cross-walk). Some example materials from this assignment are shown in Figure 10.

In another class, students design a land rover, tying the robotics to their unit on space. They research a planet and then design a robot that can operate on its unique surface and climate conditions. They keep track of all their steps and develop a 'pitch' to sell the land rover to NASA.

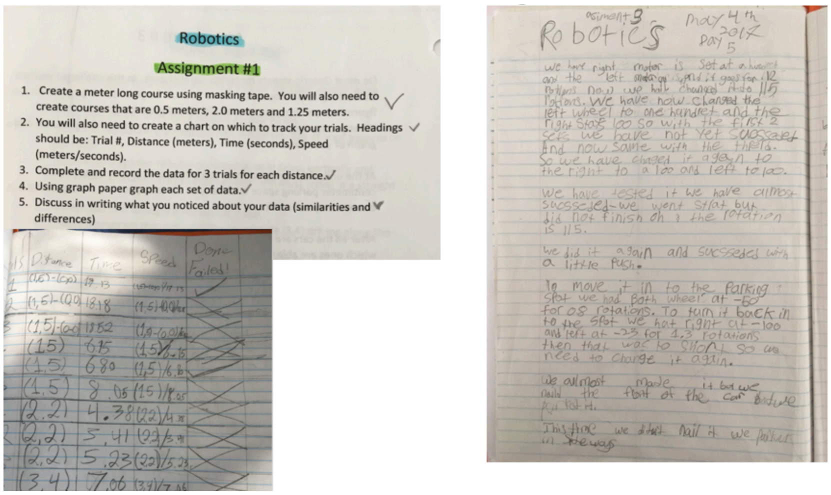

Figure 10: Grade 5/6 work on a project for math class.

One grade 4 teacher integrated robotics in a novel assignment in which students worked in small groups to design a robot that addresses a social justice issue. (See Figure 11.) In addition to designing and building the robot, part of the assignment includes researching the social justice issue and journaling their progress in a reflective journal.

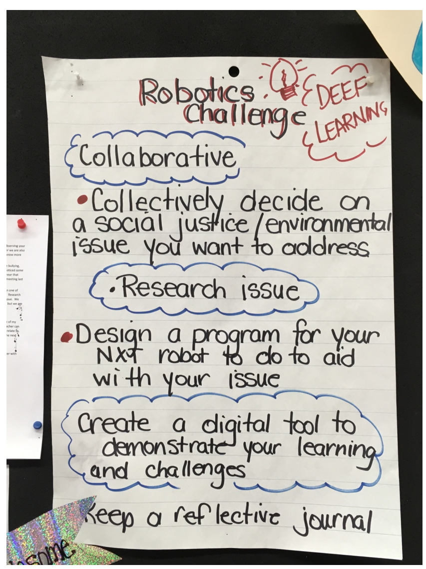

Figure 11: Grade 4 assignment integrated in language arts.

An intermediate classroom teacher has students design a robot that will "make your life easier". (Example materials shown in Figure 12.) Once they select the problem they want to solve, students complete a series of tasks including: developing three designs, breaking down their chosen design into a series of steps, building and testing their design, making improvements and justifying any changes, using appropriate science and technology vocabulary, and documenting and presenting their progress. Working in small groups, students designed everything from a robot that will hold a cell phone to a robot pooper scooper.

Some activities emerged more organically. As one teacher explained, students are "naturally finding

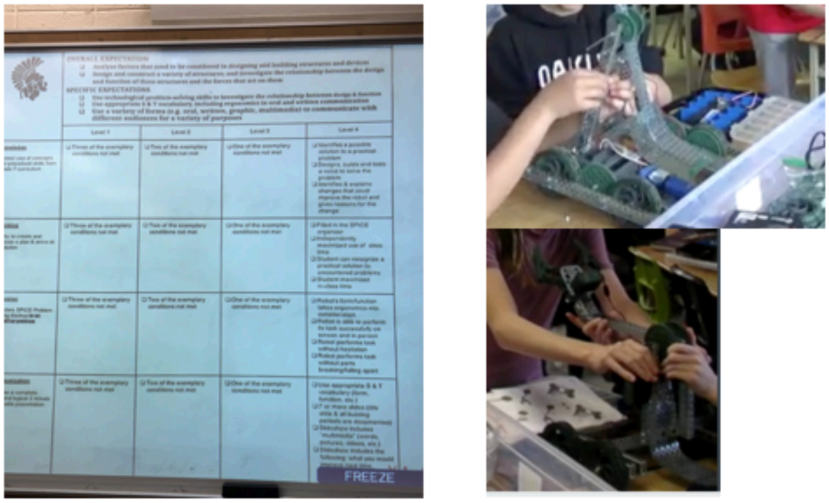

Figure 12: Grade 7/8 assignment in science class. The image on the left is a rubric displayed on a smart board.

ways to integrate [robotics] into other subject matter". She described how two groups of students in her class worked together to build and code a robot to play music they were learning in band class.

> One group two weeks ago, they decided that they would figure out how these sensors work. They wanted to have the robot play a song they were learning in band. One of them was going through her trombone notes and putting in the music while the other ones were building the robot. The cool thing about that project-based idea was that they had to build the robot so that it would do the task that they wanted. It was the two groups working together, which was really cool.

Current robotics teachers and students are finding creative ways to connect robotics to the curriculum and develop 21st century competencies. Robotics are also used in clubs and afterschool programs and some schools have teams that compete at local or regional competitions (e.g., Halton Skills Competition). Cross-curricular integration is evident; teachers and students readily find ways to connect robotics to several subjects and curriculum expectations. We observed students not only developing and designing a robot and coding, but also journaling, documenting and summarizing their results (e.g., writing, graphs and charts, pictures and diagrams), presenting their results to the class using PowerPoint and live demonstrations, and applying science, mathematics, literacy and technology learning.

4.2 Benefits of Robotics

> *I would change the fact that [robotics] is not used in schools a lot. I feel like it would really help people understand some elements of math and overcome challenges. Like earlier how we said some people hate math and they don't like it, but if they tried this and saw that math can be fun...*
>
> *Grade 5 Student*

Teachers who are currently using or supporting robotics in their school board touted the benefits of robotics. Without prompting, many teachers connected robotics to the development of 21st century competencies, particularly problem-solving, critical thinking, collaboration, communication, and perseverance. They also stressed how robotics provides students with technical education and engaging activities (e.g., robotics competitions) that they otherwise would not have access to at home or in their community.

High levels of engagement, improved classroom management, and providing a mechanism for students to shine outside traditional sports or academics were just some of the other benefits teachers discussed. The hundreds of students we observed and spoke to described robotics as fun, interesting, and challenging. We observed students problem-solving, collaborating, and supporting their classmates. They readily used mathematical, scientific, and technical language. They were highly enthusiastic about robotics, and several students told us that robotics has helped them realize the relevance of math and science. They also talked about the importance of developing robotics and coding skills for future employment.

4.2.1 The Development of 21st Century Competencies

> *...it's a hands-on project that helps children at a young age to see what engineers can do and see what new jobs are for the 21st century.*
>
> *Grade 7 Student*

Recent emphasis in education on 21st century competencies is inspired by the recognition that students need more than basic skills to navigate future education and economic challenges. While the term 'skill' refers to the "ability to perform tasks and solve problems" (Ontario Ministry of Education, 2016: 9), a 'competency' includes critical thinking, problem-solving, communication, collaboration and the ability to analyze information (Wagner, 2014). In other words, a competency "involves the ability to meet complex demands, by drawing on and mobilizing psychosocial resources (including skills and attitudes) in a particular context" (OECD, 2003: 4). Cultivating these competencies is seen to promote deeper learning, or in other words "learning for understanding" (Mehta and Fine, 2015: 3).

These skills are in high demand. According to a recent report prepared by the Canadian Council of Chief Executives (CCCE), an organization that represents 150 chief executives and leading entrepreneurs, the attributes that "matter most" when considering entry-level employers include people skills, communication skills, problem-solving skills, and creativity (2014: 7).

In interviews and focus groups, teachers describe robotics as a powerful tool to facilitate the development of these competencies. In nearly all cases, they did this without our prompting. In the survey, however, we explicitly asked teachers about how useful they considered robotics to be in helping cultivate specific 21st century competencies. Figure 13 is an overview of their responses.[7] For each competency, the 201 teachers we surveyed – all of whom have used robotics in their teaching – ranked the usefulness of robotics on a 5 point scale.

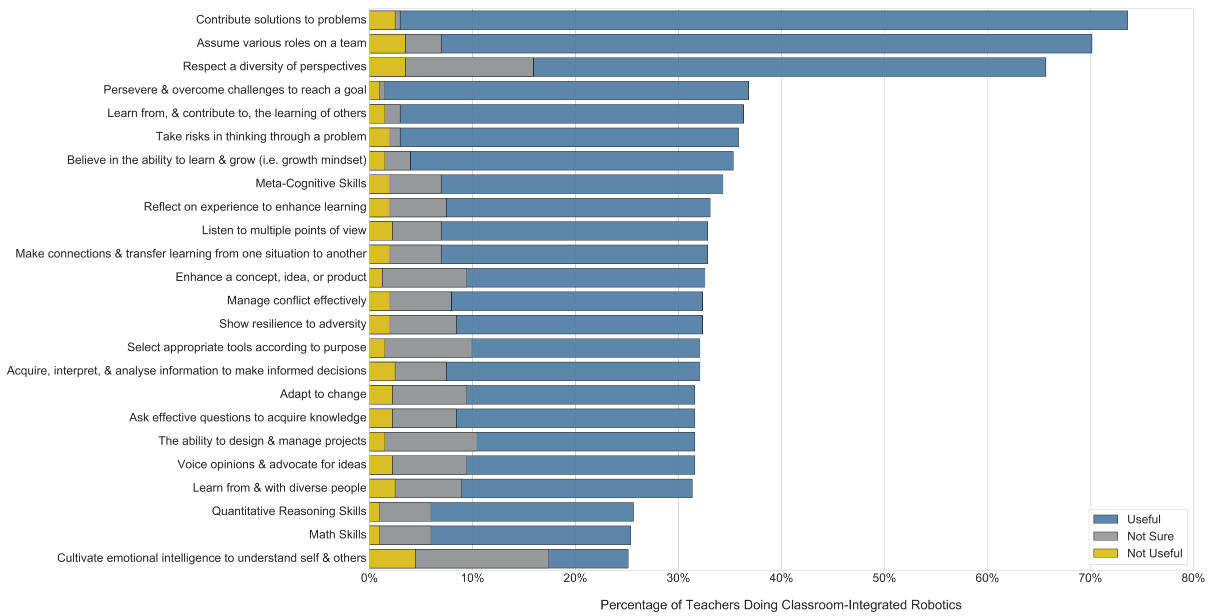

Figure 13: How useful are classroom-integrated robotics for cultivating 21st century competencies?

Similar to what we found in interviews and focus groups, teachers overwhelmingly found robotics to be helpful in cultivating 21st century competencies. In the rest of this section, we relate the research findings to the three pillars of 21st century competencies: Cognitive Skills, Interpersonal, and Intrapersonal Skills (Ontario Ministry of Education, 2016).

4.2.1.1 Cognitive Skills

> *It's a good experience. We're like engineers.*
>
> *Grade 7 Student*

'Cognitive skills' include the ability to understand, interpret and solve complex problems, evaluate evidence, and adapt and respond to changing conditions. They also include the ability to apply core academic subjects including, but not limited to, literacy, mathematics, science, and technology in a variety of contexts (Ontario Ministry of Education, 2016).

All of the robotics teachers make explicit connections between robotics and cognitive skills. They see robotics as "hands-on" and an "engaging way to do problem solving". As one teacher explained:

> Problem solving and resiliency is what coding and robotics really helps students develop. They get over that idea that it's not going to work the first time, and it might not work

[7] To simplify, we combined "Very useful" and "somewhat useful" into "useful," and "Not very useful" and "Not at all useful" into "Not useful."

> the 95th time. But eventually it will work if you keep fighting through it. Teaching kids about mindset and resiliency is going to lead to success in life, and robotics is one way to do that.

Similarly, students told us that robotics challenges them to "think outside the box" and that robotics makes math "fun" and relevant. As one student explained, before robotics he did not think math was useful. Teachers' experiences suggest this is a common belief among students, and described how robotics provides students with the "impetus to learn" math, science and language skills. As one instructional resource teacher who works with teachers and students in her school board explained:

> We've seen in lots of schools that coding robotics often triggers kids to realize that they need to learn math and science and language skills. 'So now I want to code this robot and I don't know enough about perimeter…,' so there's an impetus to learn more because it's in service of something else.

Our observations of hundreds of students support what teachers and students told us. We observed students working through a variety of problems and using mathematical, science and technological language and skills. They made mathematical conjectures, made predictions, explained their reasoning, and made arguments for taking a particular approach to their group members or their teacher. They used 'guess and check', documented and graphed their progress, journaled, and presented their work to their classmates.

Along the way, they encountered a variety of problems. Parts were sometimes missing or not working, they sometimes had to build their robot using other pieces, the coding had to be continually adjusted, and the assignments often proved to be very challenging. However, students remained highly engaged and perseverant, and were determined to come up with creative solutions. The following video-recorded excerpt is fairly representative of the conversations we had with students. In this example, a student is explaining to us the problems his group encountered during the 'parallel parking' challenge previously described.

> *Student*: In the programming, um, my group had a struggle with this. We put it at ninety degrees, but then it wouldn't go ninety degrees, so we had it go one-eighty degrees to make it turn ninety degrees. … What we did was we made a chart in our graphs and we wrote down how many rotations… how many centimeters was in one rotation. We figured out there [were] fifteen centimeters in one rotation.
>
> *Researcher*: How did you figure that out?
>
> *Student*: We put our robot on just one rotation and it went one rotation. When we looked at it, it was only fifteen centimeters. We measured it.

In another classroom, the teacher asks students to estimate how many grams their VEX robot can lift with its claw using objects in the classroom. Each group presented their estimates to the class, followed by a demonstration. Presenting their robot to the class, one group's robot tipped over. The entire class got involved trying to solve the problem, several students calling out "you need a counterweight!" After some experimentation (and lots of deliberation), the group decided to adjust their estimations and use a lighter object that would not flip over the robot.

Teachers and students also recognize the importance of having a basic level of knowledge and com-

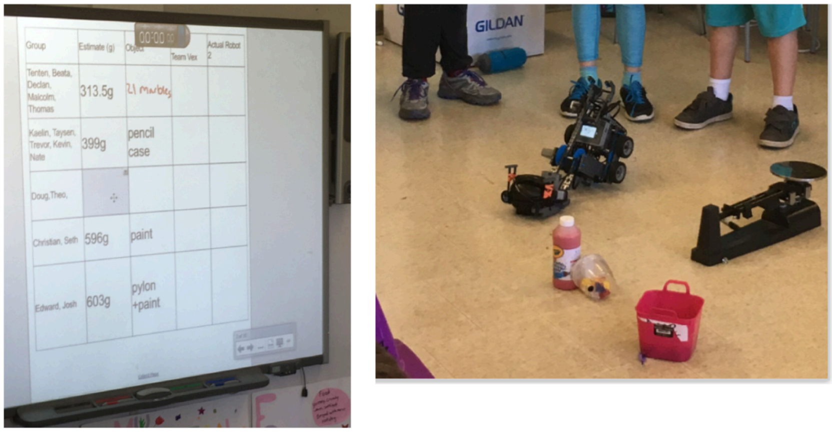

Figure 14: Grade 4 estimation challenge.

fort in the areas of robotics and coding; many argued that these are skills workers will need to be competitive in the future labour market. As one teacher put it:

> Last year 187,000 jobs were needed in computer science and we graduated 12,000 students. That's why [we need to teach students robotics and coding]…..it will be a multibillion dollar industry and we don't have nearly enough students graduating from computer science with the skills to fill those jobs. So, it's not that the jobs don't exist. We're not graduating students with the right skillset to do the jobs that are currently available.

These "industry specific" and "technological" skills were also cited in the CCCE report (2014:7). In short, the 'digital age' necessitates improving children's technological literacy for future education and employment opportunities (Elkin, Sullivan, and Bers, 2014: 155). Our data suggests that robotics helps teachers – and students – cultivate those cognitive skills.

4.2.1.2 Interpersonal and Intrapersonal Skills

> *I like it because it also helps us with collaboration because we have to work as a team in order to succeed with the challenges. Everyone has a role in my group. Yes, we work together really good and we end up getting the challenges completed. It is fairly easy because of our team work.*
>
> *Grade 5 Student*

Interpersonal and intrapersonal competencies go hand-in-hand. Interpersonal competencies include getting along with others, the capacity to manage conflict, and learning how to manage team dynamics. They also include effective communication and assuming leadership roles. Intrapersonal competencies, sometimes referred to as 'emotional intelligence', encompass a variety of skills that require individuals to take personal responsibility. This may include adapting to problems or challenges (in other words, 'perseverance') and embracing a growth mindset.

Robotics presents students with many opportunities to hone their interpersonal and intrapersonal skills. In fact, robotics is particularly well suited to develop these skills. Students typically work in groups of 2-4 on an assignment. The complexities of building a functional robot and completing the assignment demand students work together effectively. We observed students negotiating their roles (e.g., who will document progress, who will build the robot, who will create a presentation) and distributing the workload among their team members. We watched as students debated, listened to their group members, and tried to understand why a group member wanted to take a particular approach.

We also observed students working through various problems with a high degree of focus and determination. The robot and the coding rarely, if ever, works the first few times. In one classroom, for example, we watched as primary students tried to code a Dash to follow a square on the floor and answer the 'Challenge' question posed by the teacher. This proved to be a very difficult challenge, and we observed students moving their robots back to the starting line to 'try again' over and over again. However, the 'hum' of the classroom was positive. For the entire period, students worked together, shared their ideas, debated, and engaged in repeated trial and error. Groups discussed what they thought went wrong, why it went wrong, and how it might be resolved.

This example is fairly typical of what we observed and supported teachers' assessment of the benefits of robotics; in short, teachers told us that robotics has the potential to inspire more perseverance, teamwork and collaboration, and communication than many 'pen and paper' assignments. As one teacher explained, he has witnessed "incredible perseverance on a task" and opportunities for children to engage in meaningful collaborations and "deep, rich conversation… that kids don't always experience in regular classroom".

The relatively 'low stakes' of trying a new approach (e.g., changing the code) readily allows a variety of ideas to be tried out and incorporated. And, in many of the classrooms we observed, students have to take responsibility for most if not all aspects of the assignment. As one teacher described, there is a "huge amount of collaboration and trial and error". She also discussed how the "hands on" nature of robotics engages students who struggle to complete pen and paper assignments.

> I just gave them a bunch of blocks from the Kindergarten room and challenged them: 'What can you do?' They've come up with mazes, and with different things to maneuver the blocks. There's been a huge amount of collaboration and trial and error… They are engaged. They love it. The kids who may have a hard time focusing are not interested in traditional paper-and-pencil or reading; they are totally hands on with it. So that's been a huge bonus, I would say, for collaboration and team building and trial and error and not giving up on those types of growth mindset activities.

In addition to trial and error (or 'guess and check') approaches, we observed students working not only with their group members, but also turning to other groups to problem solve, conducting further research online, and referring to manuals. An added benefit of this approach to teaching and learning is that it requires students to work with other students outside their friendship network.

The nature of robotics also reduces opportunities for any one student to do all the work. There are simply too many moving parts (literally and figuratively) for any one student to 'hide' or avoid contributing in some manner. There are also opportunities for students to switch roles and learn from one another. We observed students moving from one role (e.g., coding) to another (e.g., graphing progress), and taking turns leading a particular part of the assignment. As one teacher summarized, "…I think that's what robotics allows us, is because it's not just the programming, it's the building, and the collaboration and the interactions".

4.2.2 Additional Benefits

> *I've had students that [at the beginning] couldn't even come in the classroom or would hide under tables. And where do they end up? The public speaking, the ideas, the brainstorming, the creativity. It's amazing. It doesn't just happen once. It happens every single time I see it. It happens when that child with autism comes in and has never been able to go to a summer camp program independently on his own, and, all of a sudden, can do it. Now, I just expect it.... They all shine. Every single one... That's always a beautiful moment when we see that.*
>
> *Teacher*

In addition to supporting the development of 21st century competencies, three other classroom and student benefits emerged clearly from our data collection: enhanced classroom management and ways of dealing with behavioural issues, the ability to reach different learners, and social benefits.

4.2.2.1 Behavioural Issues & Classroom Management

The hands-on and collaborative nature of robotics facilitates a high level of student engagement and a positive atmosphere in the classroom. Teachers told us that behavioural issues are greatly reduced or "disappear" when they use robotics. They observe how students who tend to be disinterested and disruptive in a traditional classroom become a "different person" in the context of a robotics activity. As one teacher explained, some of those students become his "superstars":

> We've put just over 300 students so far through the EV3 program that we run at the library, and I will say the students that may not be engaged in the classroom, when they come to the library or any space to design and build and code, they've been my superstars. … When they come there to build, they get totally engaged and they become a different person, so it was a nice transition for me because quite often you hear, 'so and so won't do this and that,' and then they come to you at your space and they're the exact opposite. It was very enlightening for me.

The success of using robotics encourages some teachers to greatly reduce or eliminate traditional pen and paper activities. One of our research sites was a grade 4 gifted classroom. Recognizing that her students need a totally different approach to teaching and learning, she decided to introduce robotics and other hands-on activities. According to her, this new approach "is working" and the kids are "excited about everything that we are doing".

Our observation in this classroom and in others also support her assessment. As another teacher explained, "once you've got that interest and that level of engagement, you see things like behaviours start to slide by and their anxiety is a lot less".

4.2.2.2 Reaching Different Learners

Robotics are also touted as an effective tool to reach different learners. Teachers told us that robotics "allow for differentiation across a grade quite easily" by varying the task according to different students' abilities. As one teacher explained:

> [Robotics] provides multiple levels for success at all ages, so you can really have a grade four class and differentiate so maybe this criteria of your learning goal was to make a

> square, whereas somebody else had to do an octagon and to code that and to have their robot actually do it. Now you've covered geometry and measurement and your robot is right there, so I find that the robots just really allow for differentiation across a grade quite easily.

Children with special needs are able to participate meaningfully in robotics and make connections with their classmates. We heard examples of how some children who are non-verbal or who are on the autism spectrum are doing robotics and coding to express themselves. A staff member who leads the robotics teams at one school, for example, explained how robotics allows students to play to their individual strengths and be included in a team challenge.

> For one of my teams, I picked someone who has Asperger's and so has social challenges with making friends. It was like the perfect group setting [for him]. … He's made a best friend through robotics. Now they hang out on the yard. It's been great for him….it reaches so many other people in a way that everyone can be included. Because there is so much you can do or not do to be on a team: you can be really good at building LEGO, but not at programming. Or, you may understand the basic concepts of computers so even if you're not good at programming, you can still contribute.

4.2.2.3 Social Benefits

Teachers also attribute social benefits to robotics inside and outside the classroom. The same staff quoted above echoed what we heard from a number of teachers when he explained that robotics "catches those kids that never get to represent their school". His robotics team provides an alternative avenue for students to gain status in their school outside of sports and academics. As he explained, "here they are wearing their school shirt, representing the school and they get to feel that school pride as they're part of something."

Similarly, another teacher observed that students who have not had a lot of success socially or academically in the past are "shining in my class" because they are now the 'go to' robotics expert. The gifted teacher cited above explained that students in her class have "struggled socially in the past" and that normally they are "passed aside" in her school because "they're weird maybe they don't have as much money as most of the kids in the neighborhood". According to many of the teachers we spoke to, robotics provides a way for such students to take a leadership position in the school and make connections and friendships with other students.

4.3 Challenges

Technology has been credited with improving children's learning including collaborative problem-solving and mathematics and science learning (Barreto and Benitti, 2012; Nugent et al., 2008; Sullivan, 2008; Mills, Chandra and Park 2014; Sullivan, 2011). However, other research suggests that the promise of technology can fall short, partly because it is under-utilized, improperly used, poorly understood by teachers and students, given to teachers with little to no training, or poorly integrated (e.g., Barreto and Benitti, 2012; Cuban, 2003; Vollstedt, Robinson and Wang, 2007). Current robotics initiatives face similar challenges. Here, we outline the main challenges articulated by educators in our study, including lack of integration into curriculum and assessment, lack of resources, lack of adequate professional development, time and space constraints, hardware and software issues, inequalities, and fragile programs.

4.3.1 Lack of Formal Integration: Curriculum and Assessment

> *...without having that specific language there, there will be teachers that will say, "This is not in my curriculum document, I don't have to do this, right?"*
>
> *Teacher*

One of the most ubiquitous challenges associated with doing robotics is the lack of formal integration: robotics and coding are not integrated in curriculum documents, and robotics and 21st century competencies are not connected to current methods of formal assessment. As a consequence, non-robotics teachers tend to see robotics as a separate subject. They also see it as a tool that only supports subjects like math and science, and do not see connections to other subjects such as literacy and social studies, even though there are successful examples to draw from. Overall, non-robotics teachers tend to see robotics as a "separate entity" that takes "away from curriculum time", particularly among teachers who are preparing their students for EQAO.

> Integrating it [is the biggest challenge]. I think that's where some of the reluctance in our schools [comes from]. While there are a couple of teachers that have really gone with it, there are others that don't want to have anything to do with the robots because, again, it's taking away from curriculum time. I think they don't know how they can use robotics as a tool to enhance the curriculum. I think they view it right now as a separate entity.

Non-robotics teachers who are open to trying robotics also struggle to find ways to integrate them. There is not enough information on how to use robotics as a teaching tool (or at least, they are not aware of such resources) and some teachers feel they lack the time to develop lesson plans with robotics. As one teacher explained, "when I look at those curriculum expectations, there is nothing in the documents that are very hands on… you really have to dig deep to make that connection." Connecting robotics to the curriculum is particularly problematic for teachers who do not already have a background in technology.

> … if you don't have any of that [technology] background and it doesn't work and you already feel like you're taking up curriculum time to do this, then you're not even going to start.

As one administrator explained, there are "lots of spaces" to integrate robotics, but the Ministry and school board need to "help find those connections and make them more explicit." Without guidance, the onus falls to individual teachers to spend time during evenings and weekends to learn how to use the robotics kits and code, research ways to connect robotics to curriculum and assessment requirements, and develop lesson plans.

Given that most teachers already feel time-poor, the lack of guidance on curriculum connections is a significant barrier to achieving teacher buy-in and to doing robotics in a sustainable way.

> It doesn't even have to be a separate curriculum because that's the last thing we need. Just

> something like an addendum showing us the STEAM education [connections] that exist. "These are the things you're covering in your class by doing these activities." That would be a huge benefit because I think more teachers would say, "Yeah, I'll do that. It's not an add on."

Without an explicit and progressive curriculum tie in, it is also unclear to teachers how robotics and coding, 21st century competencies (e.g., perseverance, collaboration, leadership), and cross-curricular activities (which robotics is particularly well suited to accomplish) relate to current approaches to assessment. Teachers also perceive that it is harder to measure many of the learning outcomes associated with robotics and 21st century competencies than a traditional math test or English assignment. Moreover, since they tend to view robotics as an extracurricular activity that falls outside of the formal curriculum, they also question how they can justify doing robotics or demonstrate learning outcomes to parents. The following excerpt from a focus group with teachers and administrators is representative of what we heard.

> *Teacher 1*: Teachers find the robotics and coding really valuable. It touches on most of the math and critical thinking and perseverance, but they don't get any specific report card comments from the robotics or the coding.
>
> *Teacher 2*: A lot of the teachers say, "That's great that you're doing it but what are we doing on our report card?" It is a constant theme.
>
> *Teacher 3*: You're right: it covers many, many things. So teachers often say, "Well, how can I put it on my report card?" It's always a bit of a stretch.

Logistical problems concerning how to to assess robotics also bring up larger questions regarding what should be assessed in the first place. As one senior administrator who is responsible for promoting technology in his board explained, "there's a gap between what we value and what we measure."

> There's a larger issue around assessment…Teachers and parents say they value certain things in their kids. They want them to be critical thinkers, problem solvers. They want them to have all those skills but then we … don't measure that. We measure something else and so there's a gap between what we value and what we measure, and I think that is where the frustration comes because you've got teachers who say "I value those things, but I need to measure math so I can put it on the report card."

Teachers and administrators mentioned that many education professionals, employers, and parents value 21st century competencies such as critical thinking, creativity, and teamwork, but current assessment practices do not evaluate these competencies.

4.3.2 Resources

> *That is my biggest stumbling block. I don't have enough [kits]. The grade one/two kids, they dive into it and eat it up and they want to code. But I have three LEGO WeDo kits for 22 kids. The feasibility of making that work well is almost impossible.*
>
> *Teacher*

In 2016, over 5,300 robotics kits were purchased from VEX Robotics (IQ and EDR kits), fischertechnik, LEGO (WeDo and Mindstorms EV3 kits) and Tetrix Robotics. Figures 15 and 16 summarize data on the number of kits that school boards in the province were able to purchase with support from CODE.

All boards, including wealthier and more urban boards, require more resources to effectively integrate robotics into their classes. As shown in Figures 15 and 16, most boards have more kits than schools, but still not enough to teach effectively. Doing robotics in the classroom always requires at least one kit for every three or four students. Consequently, all boards – even those able to purchase a relatively high number of kits – distribute the kits to a small number of schools, and many schools within boards have students who are not exposed to robotics.

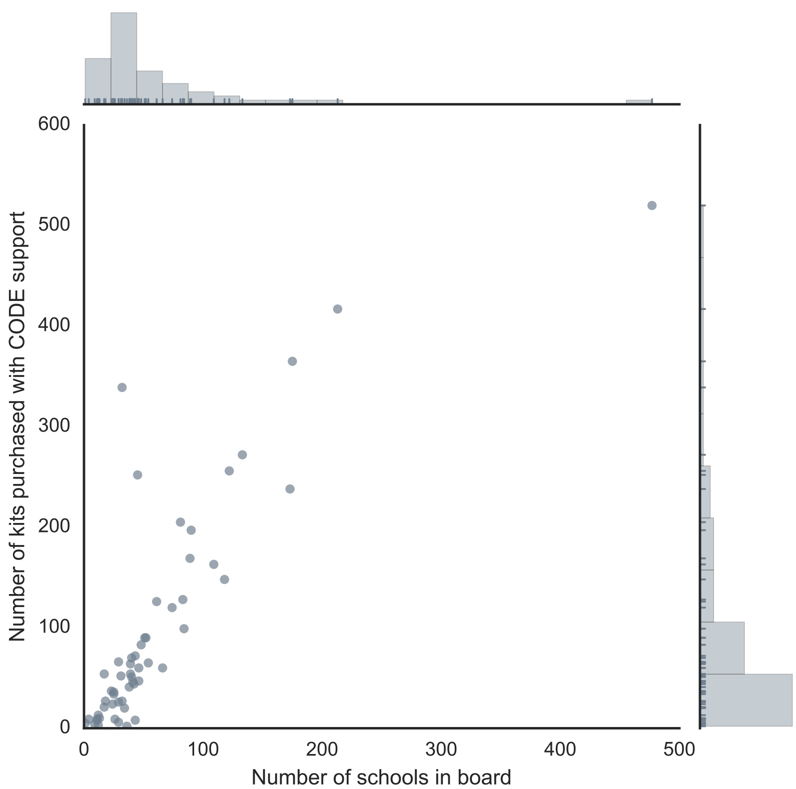

Figure 15: Scatterplots and marginal histograms of the number of schools within boards vs. number of kits purchased with CODE support.

Where possible, boards attempted to address this equity issue by having some kits go directly to schools where teachers are integrating robotics into their teaching, and then keeping the rest for general system circulation. The Toronto District School Board (TDSB), for example, currently keeps 284 kits (of their approximately 800) in general system circulation. However, even a board as large as TDSB does not currently have enough resources to enable all of their students to be exposed to robotics.

Resource issues came up repeatedly in our interviews and focus groups. Teachers and administrators rarely have enough robotics kits and supporting technologies to accommodate student demand. As we would expect based on the quantitative data presented above, teachers told us that the student to equipment ratios are too high. The length of time they can sign out the equipment and the length of a

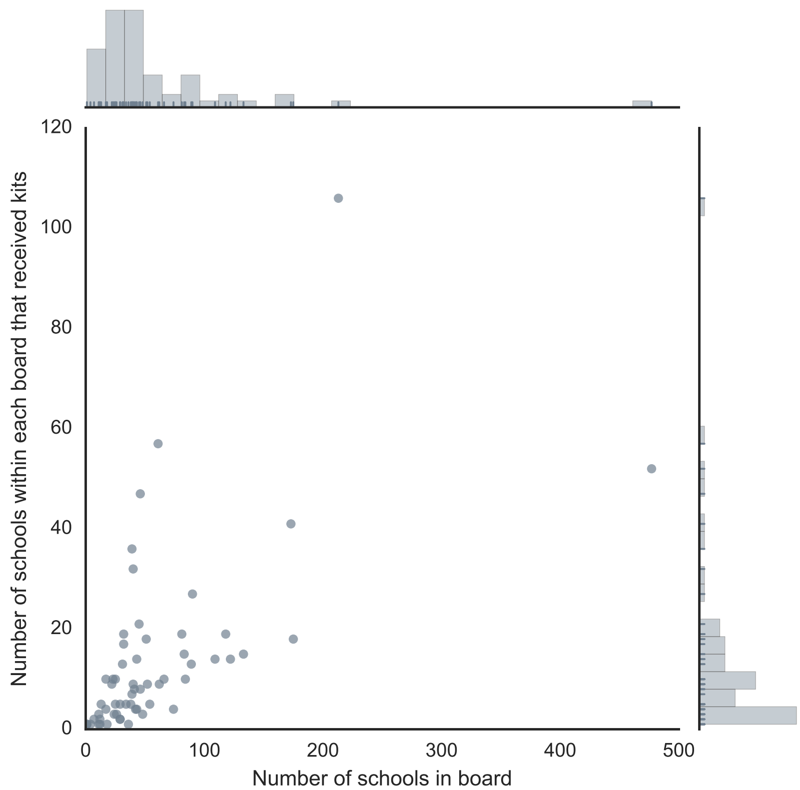

Figure 16: Scatterplots and marginal histograms of the number of schools within boards and number of schools that received robotics kits.

typical classroom period are also not long enough to meet learning goals. As one teacher explained:

> We have two robots [and] three Spheros for the school. I have 32 kids. And [as I explained] to our Vice-Principal, if I'm doing stations, that's great. But I need them in my room every morning, let's say for the first two periods. Well, when we have a sign out list and [own name] has taken them out [for two periods every day] when there's however many other classes, I think that's a challenge. So, the availability, the number of kits that we have, [is critical to] letting every student have an opportunity.

Since technologies change so rapidly, teachers and administrators also worry about spending a lot of money on hardware that may become outdated in a few years. Questions such as "what's going to happen when that technology breaks down?" and "what are the replacement costs?" were posed several times.

4.3.3 Professional Development and Support

To encourage the expansion of robotics and increase 'buy in', teachers also told us that they need more professional development and support. As we note above, most robotics teachers are the 'lone wolf' in their school. Throughout our discussions with robotics and non-robotics teachers, "being in the dark" and having "no idea where to start" were frequent themes. Robotics kits arrive or teachers find out that there are robotics resources at the board office or a neighbouring school. Yet, in the absence of a colleague or a dedicated person in the school board, most teachers are left to navigate the next steps on their own, even if they have a very supportive principal or instructional resource teacher. In most cases, the robotics teachers we spoke to had independently found out about the robotics kits and supporting technologies, learned how the kits work, taught themselves coding, made curriculum connections, found people at neighbouring schools who could help them, and developed lesson plans. This story played out again and again, in interviews, surveys, and focus groups. As one teacher explained:

> Even when I had the instructional program leader come from the board, she had no experience with VEX. I explained I'm getting robots and I'd like to weave it into my language and science… So, we kind of came up with it together. But it wasn't like there was somebody for me to go to.

In fact, our survey data suggest that most teachers are aware of very few colleagues they can turn to for advice on robotics-related issues.[8] We asked them to name the colleagues they feel they can turn to for advice, and 65% listed either nobody or only a single person (see Figure 17). Almost 15% listed only two colleagues. Similarly, the teachers we surveyed report that very few people turn to *them* for advice on integrating robotics into the classroom (see Figure 18), and that there are very few people that they have had a conversation with in the past year about classroom-integrated robotics (see Figure 19). Almost all of these teachers reported having nobody or only a single colleague within their board with whom they could share advice or have general conversations about robotics.

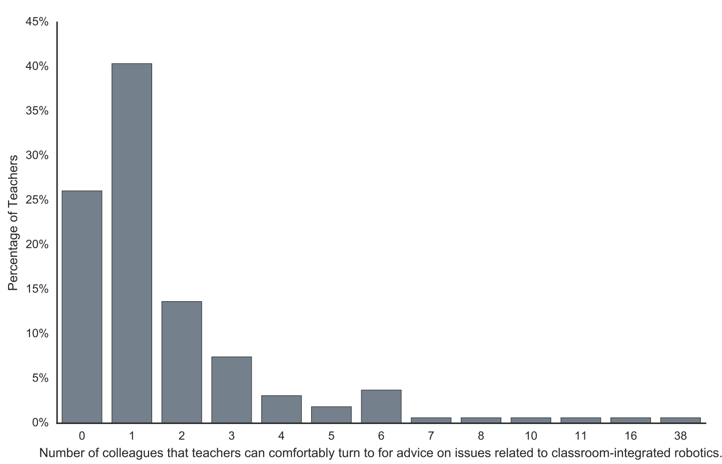

Figure 17: Number of colleagues that teachers can comfortably turn to for advice on issues related to classroom-integrated robotics.

Consequently, the process of integrating robotics is often fraught with uncertainty: What can I actually do with the robotics kit? What activities are even possible? How does the robotics kit and coding work? How do I meaningfully connect it to the curriculum? What kind of lessons can I design with robotics? What if something doesn't work during the lesson? What if a student has a question that I can't answer? Is there anyone at the board or another school who can help me or my students if we have questions? What kind of resources are available and where do I find them? Is there training available? I have the robotics kits, where do I find enough iPads or laptops? What kind of apps are available, and which apps are most effective for classroom teaching? Are there complementary web-

[8] These survey questions are informed by the literature on collecting ego network data using surveys. Our analysis here is limited to documenting in and out degree distributions for teachers' professional support networks.

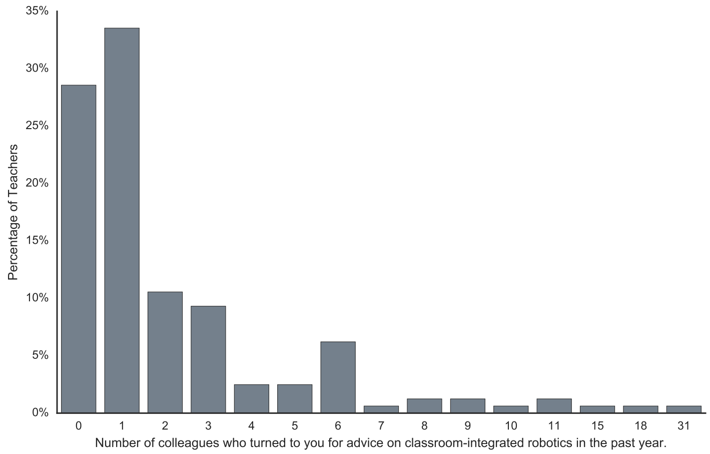

Figure 18: Number of colleagues that teachers provide advice and support to on issues related to classroom-integrated robotics.

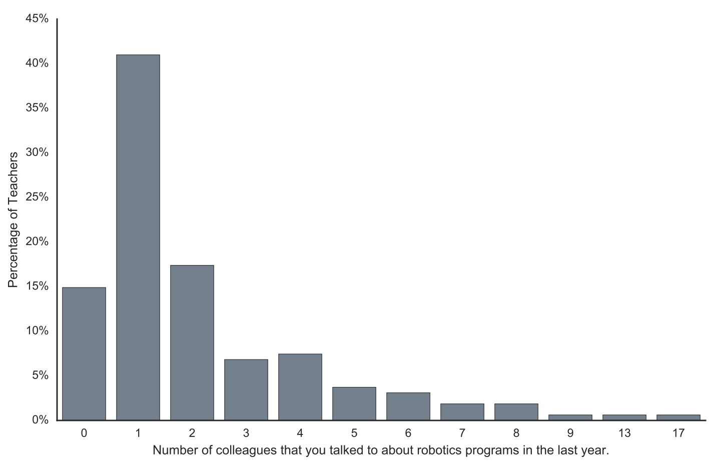

Figure 19: Number of colleagues that teachers talk to about robotics programs.

sites or apps? Some of the robotics kits I received have missing parts or have batteries that do not work, how do I get new parts?

As one teacher explained, integrating robotics in her classroom required a lot of "personal digging." This teacher highlights another aspect of current robotics initiatives: serendipity. When we asked teachers how they came to use robotics, phrases such as "I happened to" know someone, hear about robotics, or learn about some aspect of robotics and coding were used repeatedly.

> I happened to know the superintendent and asked her about the VEX [kits] and she put me in touch with the program leader from the board. But otherwise, I would have had no idea where to start. If I hadn't done it before, there was no information out there that I could see to put those connections together and to get it going. So, it was all my own personal digging that got us here. That was tough for sure.

Teachers also called for improved teacher collaboration and communication. While some school boards have resources (e.g., websites with resources) and dedicated people to help teachers with robotics, many do not. Instead, many teachers are seeking out support through blogs, Twitter or other online forums. While many teachers found these resources useful, most teachers felt that it was better to share information widely, rather than in closed groups (e.g., within a single school board). School boards also vary in terms of the quantity, quality and range of resources that are available.

Without sufficient and readily accessible training, support and resources, non-robotics teachers will continue to feel apprehensive about doing robotics. Understandably, without a curriculum and assessment connection, the potential challenges of integrating robotics are perceived as too risky for many teachers. Further, several teachers are worried about not being an "expert" and "failing" in front of students.

Unexpectedly, we found that senior teachers were more comfortable than their junior peers in two ways that facilitate the use of robotics in the classroom. First, they are more confident in their ability to match classroom robotics activities with specific curricular outcomes, perhaps because of years spent addressing these outcomes in a variety of different ways. Second, they are more willing to take risks in front of their students, perhaps because their greater experience gives them increased professional self-confidence.[9]

To overcome these challenges, teachers and administrators agreed that increasing the availability of high quality professional development opportunities (e.g., half- or full-day workshops that allow teachers to try out robotics and coding), providing teachers with time to visit the classrooms currently doing robotics, and available staff at the board (e.g., trained IT staff) are critical.

4.3.4 Time and Space Constraints

Many educators we spoke to identified time as a major challenge associated with robotics (e.g., the time it takes students to set up the iPads to program the robots, unboxing the robotics, setting up groups, building and coding the robot, and completing the assignment). Teachers also have to build in time to dismantle and pack up the robots due to lack of space or when another classroom signs out

[9] Interestingly, taking risks, learning from failure, and developing perseverance are facets of the 21st century competencies we're trying to teach.

the kits. Several teachers described this process as a "race against time." The length of time teachers are able to sign out the kits and the length of a typical subject period are often not enough. In some cases, students just get their robot and coding operational only to have to store it for the next class.

Many teachers also feel that there is not enough space in their classrooms or schools to build and store the robotics kits. In many cases the robots need to be built over a series of days or even weeks, making it difficult for teachers to find an appropriate space for them in the classroom. The following example is typical of what we heard and observed.

> …the challenge of space considerations. Just having the space for some kits that have a lot of different pieces. What happens when you get things set up and you need to leave it? You can't spend half the class putting it back in the box and putting it back together because you may need to continue to work on it.

To compensate for this challenge, some teachers described "carting them back and forth" to the principal's office, the library or another safe place in the school. We also observed classrooms that sacrificed a significant amount of floor space to house the robotics, leaving little to no room for other activities.

4.3.5 Hardware and Software Issues

Teachers also described a variety of hardware and software issues, including kit maintenance, technical and software issues, and a lack of technical support.

Maintenance of the kits is a big challenge, especially as they start to age, when they have missing pieces, or when pieces need to be replaced. Most robotics teachers do not have access to basic replacement parts or batteries. As one teacher explained, a "$400 kit is sitting there because the motor or brake is dead" and "we have no way to repair or replace" parts. Other kits have hundreds of very small pieces that go missing despite teachers' and students' best efforts. In some cases students are able to make do with other parts or share a battery. However, it is difficult to plan a lesson if the students do not have access to a functioning robotics kit with the appropriate pieces, a working motor or battery, or spare parts.

Many teachers do not have their own kits, and also have to rely on software being be installed from other locations. As a consequence, they are never sure whether they will be able to execute a lesson. Teachers described software that does not run properly, either because of maintenance issues, or updates that are needed. Sometimes teachers have trouble logging into a web site. Others plan to run a lesson, only to find out that the app or program they need has not been installed or that the iPads or other devices are not charged. As one teacher described:

> Some mornings I get there, turn on the light. The machine's on. It doesn't work. I can't open the LEGO software. Ours is installed virtually. I don't know what happens when those profiles are updated on Monday mornings … and the problem is that you've designed a full day around this and if it doesn't work … oh, boy…

Not all schools have adequate Wi-Fi coverage, and network security policies sometimes get in the way. As a consequence, students and teachers are sometimes unable to access the apps or websites they need to complete an assignment.

Currently, there is not enough technical support available for teachers. Several teachers told us that there is no "go to" person within the school or school board to contact for support. Teachers conceded that IT has other priorities (e.g., maintaining the computer network) and they are not always trained to support robotics. Instead, robotics teachers currently need to engage in extensive networking to find other colleagues or resources to support robotics activities in their classrooms. While the following example is about an embedded computing platform, it highlights the IT and network problems expressed by several teachers.

> [Robotics can be] like the Raspberry Pi, where you try to connect to the Wi-Fi and you've only got two hours in your lesson plan and [you spend all two hours just trying to connect]! … There's no support at the centre, the helpdesk doesn't understand what Linux is [or] what a Raspberry Pi is and it's very frustrating.

As teachers explained, "we need someone in ITS with robotics and coding experience that can answer those calls." "I get why it has to roll out [without trained ITS staff] but I think now we're probably two years past the time where we should have had [trained support]." Without technical support, non-robotics teachers are often very reluctant to try robotics.

4.3.6 Inequalities

Money and access (e.g., to resources, technologies, supports) are not evenly distributed, in part because of the discretionary funds that schools in wealthier communities can easily raise through their parent councils. As one teacher stated, the "have schools" have parent councils that can raise over $1,000 per student without much difficulty, whereas schools with limited funding have to make hard decisions about financial priorities. As another teacher explained:

> Schools [themselves] don't have any money. But [at our school] our Parent Council [raised] $6,000 for robots. … So, certainly [inequity] is an issue. I know that some of the schools have only one or two robots.

Similarly, teachers from schools with more money and resources acknowledged their privileged positions and recognized that access is not equal across schools and school boards.

> If parts break or something, it's nice for us because we do have extra kits that we've been able to pull things from. But I know of other schools that only have a couple of things. So, if a battery stops working [then] they're sharing a battery, those kinds of things….

In lower-socioeconomic communities, robotics (and technology generally) is often viewed as secondary to dealing with more pressing issues such as student safety, absences, nutrition, and so forth. Some teachers in these schools are enthusiastic about the potential robotics has for cultivating important skill-sets, but more basic student needs have to be prioritized. Thus, students coming from middle and upper-middle class families and wealthier schools appear to have advantages in terms of exposure to robotics, coding and other forms of technology education.

Teachers also acknowledged inequities that arise when children do not have equal access to resources, technologies, and learning opportunities inside and outside of the classroom. Unequal access means that some students will exit elementary and secondary school with vastly different levels of exposure to robotics, coding and other technology. When students do not develop a strong self-concept as competent in STEM, lose interest in STEM, or anticipate barriers in STEM, they are less likely to continue taking science and mathematics courses in high school once they satisfy minimum course requirements (see Charles and Grusky, 2004).

Regarding gender inequality, many teachers claimed to see no differences between boys and girls interest or abilities in learning robotics. It was mentioned, however, that there is less gender inequality in relation to technology at the elementary level than in high school.

4.3.7 Fragile Programs

The challenges cited above – including lack of curriculum and assessment integration, lack of resources and professional development, and inequalities within and across boards – result in robotics initiatives that are not firmly embedded within schools and school boards. One important problem with the resulting "lone wolf" or "champion" model is that robotics programs fizzle out if that particular teacher leaves the school. One principal explained that their school "lost [a teacher] because of rules about seniority" and now "has nobody on staff that even expresses an interest." "Passing the torch" to someone else (i.e., finding a new champion if an existing champion leaves) can be quite difficult.

> My struggle all year has been trying to find people to jump on board to help build this skillset within the staff that I know will be there longer than I will, to be able to promote and support this work in our school. We have what we call our Innovation Lab. … We have our robotics [and all kinds of other technology] in there. … It's like pulling teeth to get [teachers] there… Every time someone comes, [the kids] love it [and beg to come back]. Kids who are begging you to be a part of that – if that's not enough, what's going to change it for you? … Bottom line is, as long as it remains an option and an extra like your knitting club, skipping club, dancing club, there is no way for an administrator to say, "I need you to do this. This must be done."

The impact of this precarity is magnified when resources are re-allocated at the Board level. As senior administrators and Directors change, entire programs which flourished under previous administration with strong board-wide resource support for robotics may be compromised.

Robotics initiatives within schools will remain fragile without a more systematic and collaborative approach to building programs and integrating robotics into curriculum.

5 Considerations

As emphasized in the report, one of the biggest challenges that boards, schools, administrators, and teachers face is knowing how to integrate robotics into the curriculum effectively. Having access to resources (e.g., more kits) is a pervasive challenge, but the first problem to address is related to teacher training. In order for resources to be put to good use, boards need teachers who can confidently and capably integrate robotics into their classrooms. Teachers' professional development, then, is an important early investment. High-quality professional development includes, but is not limited to, hands-on learning opportunities that allow teachers to work with robotics kits and coding in a collaborative setting, opportunities to network and collaborate with other robotics teachers, and opportunities to visit other classrooms to see new and innovative ways to incorporate robotics and coding. To that end, before providing specific considerations in areas related to robotics integration, we offer the following high-level consideration:

> **Consideration 1:** Prioritize professional development and support teachers in their efforts to learn more about robotics and coding.

Below, we provide seven further considerations related to curriculum documents, assessment, resources and equality within and across schools, and cultivating formal collaborations.

5.1 Curriculum Documents

Currently, robotics and coding are not reflected in curriculum documents. There are two ways that this could be changed: (a) add new curricular expectations for robotics and coding, or (b) develop materials to help teachers meet existing curricular expectations with robotics and coding. We heard from teachers in focus groups, interviews, and surveys that they *did not* think it would be good to have new curricular expectations for robotics. Instead, there was strong support for clarity in how to address existing curricular expectations using robotics.

Updating curriculum documents and coordinating the development of lesson plans and their connection to existing assessment expectations would help encourage the expansion and cross-curricular integration of robotics. These changes would highlight its relevance beyond science, mathematics, and technology; support teacher and student engagement in robotics and coding by providing explicit examples and problems; and legitimate robotics and coding as promising ways to meet important learning objectives. They would also help overcome the perception that some teachers and administrators have that robotics and coding are simply "add ons" or distractions. Indeed, current robotics teachers readily find ways to get students more engaged in the subject matter, and to incorporate literacy, mathematics, science, and the development of 21^{st} century competencies. Finally, the updating of curriculum documents may help reduce other challenges – such as the fragility of robotics programs and the relative lack of resources in small schools and rural areas – by fostering more official channels for collaboration and sharing.

Teachers, especially those new to robotics or hesitant to tackle integration in their classrooms, said repeatedly that a key barrier to integrating robotics is knowing how robotics can be done in a way that contributes directly to the MOE's curriculum expectations. Many teachers who have adopted robotics in their classrooms are developing lesson plans from which their peers could benefit. Sharing those lesson plans and creating professional support groups would greatly benefit all teachers, but it would be especially valuable to teachers in rural and remote boards where there may be less direct support at the board level or in their own professional social networks.

> **Consideration 2:** Integrate robotics, coding, and computational thinking into curriculum documents and make these documents equally available to all schools across the province.

2.1: Include the development of shared materials – such as lesson plans, guiding questions, sample problems, design challenges, and practical advice on how to manage and troubleshoot kits – that can be accessed by all teachers province-wide.

2.2: Develop new materials that help teachers connect robotics to other subjects, in addition to maths and sciences.

2.3: Ensure these materials are equally accessible to all schools by making them available on a dedicated website, and by providing an online forum for teachers to connect with a community of colleagues to share other resources and collectively solve problems.

2.4: Create centralized "curriculum expectations grids" as part of lesson plans, so that teachers can easily map between lesson plans and curricular expectations.[10]

5.2 Assessment

A frequent theme that emerged is the lack of connection between robotics and assessment requirements. This contributes to robotics being seen as ancillary and "in the way" of the "real work" that needs to be completed and assessed. It is clear from our focus groups that more teachers would be willing to prioritize robotics in the classroom if there were a clearer connection to outcomes on report cards. Part of the solution is to provide good curricular examples of cross-curricular integration activities involving robotics and coding (see considerations on curriculum documents).

More generally, teachers are understandably uncomfortable with the formal assessment of 21st century competencies, which is seen as more subjective than other types of assessment in STEM subjects. Paradoxically, this may be especially true for the math and science teachers who most readily want to adopt robotics in their classrooms. Teachers who are interested in doing robotics in English or Humanities and Social Sciences are already more comfortable with this seemingly less objective form of assessment. This issue is not limited to Ontario: many jurisdictions internationally are working on the assessment of these competencies and Ontario can benefit from that work.[11]

Focus group participants spoke of a misalignment between what parents and educators value and what is assessed and reported, especially when it comes to 21st century competencies. This may be evidence of a lag in policy and curriculum documents relative to social values.

Consideration 3: Continue the work begun in the Phase 1 Discussion Paper on assessment of 21st century competencies (MOE 2016), support teachers in the transitions related to assessment, and revise report cards to ensure that these skills are seen to be valued and worth committing time and energy to in the classroom.

[10] For example, see those provided by LEGO and VEX that map to various US education standards: http://bit.ly/lego_standards and http://bit.ly/vex_standards.

[11] For example, (1) State of Washington, "21st Century Skills", available at: http://www.k12.wa.us/CareerTechEd/TwentyFirstCenturySkills.aspx. (2) Partnership for 21st Century Learning, "21st CENTURY ASSESSMENT: RUBRICS FOR THE 4CS-A REVIEW", available at http://www.p21.org/news-events/p21blog/1556-21%5Est%5E-century-assessment-rubrics-for-the-4cs-a-review. (3) People For Education (Ontario), "Measuring What Matters", available at http://peopleforeducation.ca/measuring-what-matters/

5.3 Resources and Equality Within and Across Boards

Schools vary in their ability to access and support robotics, coding and other technologies. There are two main issues: staffing and socioeconomic inequality. In terms of staffing, not all schools have staff members who are currently doing robotics. Within schools doing robotics, typically only one or two classes have an opportunity to engage in robotics and coding, even within the same grade level. Currently, robotics teachers are often feel like the 'lone wolf' within their schools. There are teachers who are interested in trying robotics, but they do not know where to start or where to find resources. These circumstances discourage the adoption and expansion of robotics and coding. As a consequence, students within and across schools have varying exposure to robotics, coding or other technological learning. In terms of socioeconomic factors, some schools have tremendous resources and fundraising capabilities. These schools are able to purchase robotics kits and supporting technology. Moreover, such schools often have a pool of parental 'know how'; parents who can support robotics by providing demonstrations, advice and trouble-shooting tips. Such schools are also more likely to have students who have their own cell phones, tablets, and other devices to support robotics initiatives. Other schools have greatly reduced access to additional resources and struggle to obtain the necessary robotics kits, tablets, netbooks, as well as smart boards and other educational technologies.

These differences in resources have tremendous impact on students' classroom experiences. In one school, for example, a Grade 8 teacher only has 4 robotics kits for 30 students. Consequently, most students are not able to fully participate and the benefits of robotics are seriously limited (e.g., ability for all students to easily engage in trial and error). An effective setup requires 1 kit per 3 or 4 students, plus the relevant software installed on tablets or netbooks, typically iPads and Chromebooks. Even when teachers have access to a sufficient number of robots, they sometimes have difficulty accessing enough tablets or netbooks to use the kits, or the kits are not appropriate for the grade level. When they do have the tablets and netbooks, the relevant software is not always installed and the teacher needs to wait for someone at the school board office to install the software remotely. Finally, some schools do not have sufficient Wi-Fi to download supplementary materials and documentation for the kits, making it difficult for students and teachers to use relevant online resources.

High school teachers emphasize that students who lack exposure in earlier grades are less likely to enroll in computer, science and technology courses in secondary school. They suspect this is particularly the case for young women. Research supports these assumptions. As one OECD reports finds, "the decision to continue with S&T at a higher level of education (and to choose this as a career) is strongly influenced by experience at earlier levels of schooling, and indeed in most cases depends on achieving a certain level in mathematics and science in primary and especially secondary school" (2008: 80). For girls, their interest, engagement, and self-concept as capable in STEM affects their continued enrollment in math and science courses in high school and the pipeline of women entering STEM fields (OECD, 2008; Standing Committee on the Status of Women, 2015).

Providing funding and support could help increase the equitable distribution of robotics, coding and other technological learning within and across school boards. However, it would be good to ensure that the early distribution of resources begins with investments in relevant professional development for teachers, and strategically matches current resources with teachers who can grow robotics and coding education within their local boards and schools. This will ensure that resources are well-utilized, that teachers feel supported in meeting MOE expectations, while adequate capacity is built in schools that are currently not ready to start integrating robotics and coding into their classrooms.

> **Consideration 4:** Provide funding and support to increase the equitable distribution of robotics, coding and other technological learning within and across school boards. To maximize student success and engagement, provide funding to ensure that classrooms are equipped with a sufficient number of robotics kits and supporting technology that are grade level appropriate.
>
> **Consideration 5:** Ensure that all students in the province of Ontario have an opportunity to be exposed to robotics, coding and technological learning at some point during their elementary school career. To do this:
>
> **5.1**: Identify schools that have limited staff and resource capacity to support robotics.
>
> **5.2**: Identify robotics, coding and technology 'gaps' across and within schools and classrooms.
>
> **5.3**: Map out strategic schools and classrooms/grade levels to close gaps.

We believe it would be beneficial to limit the kinds of kits which will be supported and provide centralized recommendations and purchasing. First, providing a limited number of kits with grade- and subject-specific considerations reduces the number of decisions (and hence the barrier to entry) for teachers who are new to robotics. Second, it provides a measure of province-wide standardization, improving the support available by limiting the platforms to be supported, both by formal Board IT support personnel and via informal social networks. Third, it will increase the relevance of shared lesson plans since a greater percentage will be appropriate for any one platform. Finally, from a purchasing perspective it allows the Ministry/Boards to negotiate better deals, and possibly more complex partnerships, with specific suppliers.

As suggested in Section 3.2 on page 11, inclusion of kits on the approved list should be guided by consideration of what MOE considers "robotics." We suggest that the primary criterion should be that there be a physical device (constructed by the students or not) which can be programmed to accomplish a variety of tasks. A secondary consideration should be the degree of flexibility that the students have in creating the physical design of their robots. This will range from none (e.g., BlueBot or Sphero), which may be quite appropriate for young students, to complete flexibility (e.g., LEGO EV3 or VEX).

> **Consideration 6:** Centralize and facilitate the tender process by offering a list of pre-approved kits. This greatly simplifies what would otherwise be a very complicated process of researching and ordering kits appropriate for various grade levels and subject areas. It also helps ensure that standardized curriculum objectives are appropriate for the kits that boards eventually purchase. Finally, it allows for bulk purchasing discounts and alleviates some of the administrative overhead for the boards/schools.

In short subject periods and small classrooms, much of the time can be spent in taking out and putting away the kits. Space is also a common concern. Long-term organized storage of the kits can also be an issue within the school. Having a common space like an "Innovation Lab" or a library or makerspace where materials can be left out from period to period, allows for more time on task and longer, more engaged assignments.

> **Consideration 7:** To maximize student success and engagement, provide teachers with adequate space and time to meaningfully engage robotics teaching and learning.

5.4 Cultivating Formal Collaborations

Several school boards and schools included in this study benefit from the development of strategic partnerships. Several elementary schools, for example, connect with their local high school robotics teachers or clubs. Working with elementary robotics teachers, high school teachers and students provide technical support and demonstrations. High school students also volunteer at the elementary schools and support robotics classroom teaching and learning. Nearby postsecondary institutions are another possible option. As noted above, one teacher has a connection with a professor at a nearby college program. Her students visit the college to observe robotics 'in action'. She is also able to borrow robotics kits from the college. Other school boards have developed partnerships with local technology and related businesses. These businesses provide technical support, training opportunities for teachers and resources.

> **Consideration 8:** To support the implementation, integration, and expansion of robotics and coding, encourage and facilitate the development of strategic collaborations and partnerships. Some possible examples include collaborations with other schools, school boards, postsecondary institutions, private partnership, and non-profit organizations whose mandate is to promote robotics in education.

6 Conclusion

This report details the findings from an Action Research Study on robotics and the development of 21st Century Competencies. We found that teachers are using robotics in a variety of creative ways to support meaningful classroom teaching and learning. Despite the potential benefits of robotics, teachers cited several barriers that limit the potential of robotics. However, what we also heard from teachers is that the benefits of robotics are worth the investment.

As we detail in this report, teachers outlined practical ways to overcome these challenges so that more educators are able to include robotics in their teaching toolkit. These include incorporating robotics and coding into existing curriculum and assessment guidelines and providing teachers with access to high quality professional development and technical support. These changes would support the more equitable distribution of resources and ensure all children have the opportunity to engage robotics at some point during their elementary school career.

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A Appendices

A.1 Elaborated Data Collection Rationale

A multi-method approach was adopted to examine the implementation, impact, and integration of robotics and its connection to 21st century competencies.

1. **Focus Groups**: Focus groups allowed us to gather information about current board practices and how participants perceive the benefits and challenges of using robotics.
2. **Interviews and Video-recorded Observations**: We interviewed primary-junior and intermediate robotics and non-robotics teachers and conducted video-recorded observations of their classrooms.
3. **Teacher and Administrator Survey**: We conducted a survey of teachers and administrators involved in the robotics program. This survey quantified some of the issues that arose in the interviews and focus groups. The survey included questions about teacher and administrator experiences, professional development and support, challenges, assessments of the value or limitations of robotics in cultivating 21st century competencies, challenges, unrealized potential, and considerations for improvement.
4. **Administrative Reports**: We coded and analyzed the content of reports submitted to CODE by all school boards who purchased robotics kits with CODE support. These administrative reports included quantitative data on the numbers, types, and distribution of kits purchased, and qualitative data on teachers' professional development and other implementation issues.

First, we conducted focus groups with teachers and administrators. We connected with a wide range of participants, including instructional resource teachers, principals, classroom teachers, consultants, and IT staff. We asked participants to discuss current practices, what is working well, and the challenges associated with robotics. We also asked participants to provide concrete practical or policy considerations at Ministry, school board and school levels. We also spoke to junior and intermediate students who are currently enrolled in classrooms using robotics. We asked students to describe how robotics are used in their classrooms, what they liked about robotics, and the challenges they have experienced using robotics.

Second, we conducted pre-observation interviews to find out about teachers' perceptions of and experiences with robotics, and to identify 'look-fors' during the observation. Third, we video-recorded a lesson in each of the participating teachers' classrooms. Video recording allowed us to document various dimensions of 21st-century competencies, including evidence of collaboration (e.g., negotiating ideas), flexibility (e.g., openness to alternative perspectives), creativity (e.g., expressing a new idea), problemsolving (e.g., developing a plan) and mathematics or science literacy (e.g., use of appropriate computation strategies). We were able to review footage multiple times and pick up on evidence that is not always obvious the first time (e.g., body language). As noted in a recent MOE report, video recording has the benefit of "seeing nuances and gestures that don't get recorded on paper," "ah-ha" moments, and capturing evidence that moves "away from EQAO as the only indicator of student achievement" (Randall, Ryerson, McGuire and Kokis. 2014). Finally, we reviewed the video footage with the participating classroom teachers. Teachers' professional expertise was critical, and helped identify evidence of 21st-century competencies and whether or how robotics enhanced classroom teaching and learning. A comparative approach allowed us to consider whether there are observable differences between classrooms with and without robotics. Non-robotics teachers also provided valuable insights into the perceived barriers or objections to introducing robotics. Many of the considerations detailed in this report are informed by their opinions.

We used active consent throughout the data collection process. Only children who had permission from a parent and who signed a child assent letter participated in the video-recorded observation and student focus group.

The survey was administered after the majority of other empirical data was collected. This enabled us to develop questions to quantify many of the issues that we were identifying in the qualitative work, and to rigorously test, refine, and improve the design and implementation of the survey. We worked closely with nine boards to collect sampling frames for two groups: (1) teachers and administrators who were somehow involved with classroom-integrated robotics, and (2) teachers and administrators who were not. Ultimately, three of the nine boards were not able to provide a sampling frame or a suitable alternative, and so were not included in the survey data collection.

For the remaining six boards, we sent invitations to participate in the survey to all teachers and administrators who our board contacts identified as being involved in classroom-integrated robotics within their board. Of the 350 people identified, 201 completed the survey, resulting in a 57% response rate. In addition we sent invitations to participate in a shorter version of the survey to a stratified random sample of teachers and administrators who were not involved in classroom-integrated robotics. Unfortunately the response rate for this set of teachers was too small to use.

Although one of the key objectives of the survey was to quantify issues that were coming up in interviews, focus groups, and observations, we did ask participants to answer some more qualitative open-ended questions. We included their responses in our qualitative data analysis.

Finally, we would like to thank CODE for providing the administrative reports from boards across the province. Once coded, these documents enabled us to better understand the distribution of resources within and across boards. Additionally, the more open-ended parts of the reports allowed us to compare our own qualitative data with reports from many more school boards.

A.2 Examples of Incorporating a Sample Robotics Problem into the Ontario Curriculum

A.2.1 Primary

Example for: Grade 3, "Mathematics: Geometry & Spatial Sense"

Ontario Curriculum Document & Sample Problem: Identify and compare various polygons (i.e., triangles, quadrilaterals, pentagons, hexagons, heptagons, octagons) and sort them by their geometric properties (i.e., number of sides; side lengths; number of interior angles; number of right angles) (page 59).

Compare various angles, using concrete materials and pictorial representations, and describe angles as bigger than, smaller than, or about the same as other angles (e.g., "Two of the angles on the red pattern block are bigger than all the angles on the green pattern block.") (page 59)

Sample Robotics Problem: Using masking tape, create various polygons on the floor and make the robot go around the shape. Students can estimate the length of the sides and angles before measuring to have the robot complete its task. (e.g. "I think the robot needs to turn 90 degrees to complete the triangle.")

Suggested Robotic Kit for Division: Dot and Dash, Sphero, Lego WeDo 2.0

A.2.2 Junior

Example for: Grade 4, "Science & Technology: Understanding Structures and Mechanism – Pulleys and Gears"

Ontario Curriculum Document & Sample Problem: 2.3 Use technological problem-solving skills (see page 16) to design, build, and test a pulley or gear system that performs a specific task.

Design, build, and test a mechanism that will raise and lower a flag. Design, build, and test a changing billboard. Design, build, and test a model elevator that could be used in a barn. Design, build, and test a model drawbridge for a castle. (page 88)

Sample Robotics Problem: Build a robot with different size gears to test which size gears, or combination of gears, make your robot deliver an object quickly and undamaged. (e.g. "I think the smaller gear will move the robot faster.")

Suggested Robotic Kit for Division: Lego WeDo 2.0, Lego Mindstorms EV3, Vex (for more advanced students)

A.2.3 Intermediate

Example for: Grade 7, "Science & Technology: Understanding Structures and Mechanisms – Form and Function"

Ontario Curriculum Document & Sample Problem: 1.1 Evaluate the importance for individuals, society, the economy, and the environment of factors that should be considered in designing and building structures and devices to meet specific needs (e.g., function; efficiency; ease of use; user preferences; aesthetics; cost; intended lifespan; effect on the environment; safety, health, legal requirements).

2.3 Investigate the factors that determine the ability of a structure to support a load (e.g., the weight of the structure itself; the magnitude of the external loads it will need to support; the strength of the materials used to build it).

2.4 Use technological problem-solving skills (see page 16) to determine the most efficient way for a structure (e.g., a chair, a shelf, a bridge) to support a given load.

2.5 Investigate methods used by engineers to ensure structural safety (e.g., incorporating sensors in structures to detect unusual stresses and give early warning of failure; designing structures to carry much heavier loads than they will actually have to bear.

2.7 Use a variety of forms (e.g., oral, written, graphic, multimedia) to communicate with different audiences and for a variety of purposes (e.g., use a graphic organizer to show the steps taken in designing and making a product).

3.5 Describe the role of symmetry in structures (e.g., aesthetic appeal, structural stability).

3.6 Identify and describe factors that can cause a structure to fail (e.g., bad design, faulty construction, foundation failure, extraordinary loads (pages 130-131).

Sample Robotics Problem: Design a robot that solves an everyday problem in society (e.g., robot that cleans dog waste; robot that can carry groceries).

Suggested Robotic Kit for Division: Lego Mindstorms EV3, Vex