Canadian Journal of Education
Revue canadienne de l'éducation

Using Robotics to Support the Acquisition of STEM and 21st-Century Competencies: Promising (and Practical) Directions

Allyson Stokes, Janice Aurini, Jessica Rizk, Robert Gorbet et John McLevey

Volume 45, numéro 4, hiver 2022

URI : https://id.erudit.org/iderudit/1096579ar
DOI : https://doi.org/10.53967/cje-rce.5455

Aller au sommaire du numéro

Éditeur(s)

Canadian Society for the Study of Education

ISSN

0380-2361 (imprimé)
1918-5979 (numérique)

Découvrir la revue

Citer cet article

Stokes, A., Aurini, J., Rizk, J., Gorbet, R. & McLevey, J. (2022). Using Robotics to Support the Acquisition of STEM and 21st-Century Competencies: Promising (and Practical) Directions. *Canadian Journal of Education / Revue canadienne de l'éducation*, *45*(4), 1141–1170. https://doi.org/10.53967/cje-rce.5455

Résumé de l'article

Dans le but d'améliorer la façon dont les éducateurs utilisent la robotique pour soutenir le développement des compétences du XXIe siècle et des STIM, nous rapportons ici les résultats de groupes de discussion et d'entretiens individuels avec 133 enseignants et 46 élèves du primaire, de 19 observations de vidéos enregistrées en classe et d'un sondage auprès des enseignants effectué en Ontario, au Canada. Nous constatons que les enseignants utilisent la robotique de diverses manières pour soutenir le développement des compétences cognitives, interpersonnelles et intrapersonnelles. Malgré les avantages potentiels, nos participants ont identifié plusieurs facteurs qui limitent l'adoption de l'enseignement et de l'apprentissage de la robotique à plus grande échelle. Notamment, l'intégration insuffisante dans les curriculums et les évaluations, une pénurie de ressources, et un manque de développement et de soutien professionnel. Nous suggérons des directives politiques pratiques pour soutenir l'intégration plus efficace de la robotique, et considérons la manière dont ces recommandations pourraient éclairer l'enseignement et l'apprentissage dans une salle de classe (post) Covid-19.

Using Robotics to Support the Acquisition of STEM and 21st-Century Competencies: Promising (and Practical) Directions

Allyson Stokes
Memorial University

Janice Aurini
University of Waterloo

Jessica Rizk
University of Waterloo

Robert Gorbet
University of Waterloo

John McLevey
University of Waterloo

Canadian Journal of Education / Revue canadienne de l'éducation

www.cje-rce.ca

Abstract

To enhance how educators use robotics to support the development of STEM and 21st century competencies, we report findings from focus groups and interviews with 133 elementary teachers and 46 elementary students, 19 video-recorded classroom observations, and a teacher survey from Ontario, Canada. We find that teachers use robotics in a variety of ways to support the development of cognitive, interpersonal, and intrapersonal skills. Despite the potential benefits, our participants identified several factors that limit the adoption of robotics teaching and learning on a wider scale, including insufficient curriculum and assessment integration, resources, and professional development and support. We provide practical policy guidelines to support the broader integration of robotics and reflect on how these recommendations may inform teaching and learning in a (post-) COVID-19 classroom.

Key words: robotics, STEM, teachers, teaching, 21st-century competencies, elementary education

Résumé

Dans le but d'améliorer la façon dont les éducateurs utilisent la robotique pour soutenir le développement des compétences du XXI^{e} siècle et des STIM, nous rapportons ici les résultats de groupes de discussion et d'entretiens individuels avec 133 enseignants et 46 élèves du primaire, de 19 observations de vidéos enregistrées en classe et d'un sondage auprès des enseignants effectué en Ontario, au Canada. Nous constatons que les enseignants utilisent la robotique de diverses manières pour soutenir le développement des compétences cognitives, interpersonnelles et intrapersonnelles. Malgré les avantages potentiels, nos participants ont identifié plusieurs facteurs qui limitent l'adoption de l'enseignement et de l'apprentissage de la robotique à plus grande échelle. Notamment, l'intégration insuffisante dans les curriculums et les évaluations, une pénurie de ressources, et un manque de développement et de soutien professionnel. Nous suggérons des directives politiques pratiques pour soutenir l'intégration plus efficace de la robotique, et considérons la manière dont ces recommandations pourraient éclairer l'enseignement et l'apprentissage dans une salle de classe (post) Covid-19.

Mots-clés : robotique, STIM, enseignants, enseignement, compétences du XXIe siècle,

Acknowledgements

We appreciate the willingness of school boards, staff, and students to complete surveys, participate in focus groups and interviews, invite us into their schools and classrooms, and share resources. This research was supported by the Council of Ontario Directors of Education.

Introduction

Researchers and policy makers stress the importance of developing students' STEM and 21st century competencies (Freeman et al., 2021; Kirschner & Stoyanov, 2018; Xie et al., 2015). Robotics has been touted as one way to support the development of these competencies, including mathematics and science learning, critical thinking, collaborative problem solving and creativity (e.g., Kim et al., 2015; Mills, et al., 2013; Yang et al., 2020; Zviel-Girshin et al., 2020). However, the promise of robotics falls short if it is under-utilized, improperly used, poorly understood by teachers and students, given to teachers with little to no training, or insufficiently tied to assessment and curriculum requirements (e.g., Affouneh et al., 2020; Becker & Park, 2011).

To enhance how students and teachers integrate robotics, we report findings from a study about the implementation, impact, and integration of robotics in nine school boards in Ontario, Canada. Drawing on focus groups and interviews with 133 elementary teachers and 46 elementary students, 19 classroom video-recorded observations, and a teacher survey, we summarize not only how robotics are perceived and used, but also the factors that limit the adoption of robotics on a wider scale (Aurini et al., 2017). We then provide practical guidelines to help education policy makers enhance the integration of robotics and reflect on how these recommendations may inform teaching and learning in a (post-) COVID-19 classroom.

The Changing Context of Schooling and Labour Markets

The emergence of new technologies (e.g., artificial intelligence) and transformations in the organization of work (e.g., gig economy) are altering the landscape of schooling and labour markets (Advisory Council on Economic Growth, 2017; Kalleberg, 2011; Kirschner & Stoyanov, 2018; World Economic Forum, 2018). The COVID-19 pandemic is forecasted to accelerate these trends, fueling further digitization, automation, and technological shifts (Organisation for Economic Co-Operation and Development [OECD], 2020). Despite these realities, there is "insufficient student interest in science, technology, engineering, and mathematics (STEM)" (Kitchen et al., 2018, p. 529)—a problem that has been identified as a "pressing issue" by policy makers (Kitchen et al., 2018, p. 529). Research finds that not only are student attitudes a major factor in determining their desire to pursue STEM (Science, Technology, Engineering, and Mathematics) courses and careers, but that students can lose interest by their mid-elementary school years (e.g., Caspi et al., 2019; Maltese & Tai, 2011).

Teaching computational, digital, and technological literacy in an engaging way at an early age can help boost interest in STEM. The use of technology is also seen to enrich the classroom environment by fostering student engagement (see Rizk, 2018; Rizk & Davies, 2021) and providing students with opportunities to collaborate, use their imaginations, and problem solve (Mousa et al., 2017; Sullivan & Bers, 2016; Toh et al., 2016). Such hands-on STEM activities can nurture "positive STEM dispositions" that can encourage students' continued engagement throughout their school career and beyond (Christensen et al., 2015, p. 898).

Part of preparing students for a STEM labour market also includes fostering transferable 21stcentury competencies (e.g., Canadian Council of Chief Executives, 2014; Kirschner & Stoyanov, 2018; Ontario Ministry of Education, 2016; Premier's Highly Skilled Workforce Expert Panel, 2016; Stehle & Peters-Burton, 2019). These 21st century competencies can be broadly organized into three categories. *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 like literacy, mathematics, science, and technology in various contexts. *Interpersonal Skills* include getting along with others, the capacity to manage conflict, and learning how to manage team dynamics. They also include effective communication

and leadership. *Intrapersonal Skills,* sometimes referred to as "emotional intelligence," encompass skills that require individuals to take personal responsibility, such as perseverance and a growth mindset (Dweck, 2007; OECD, 2018; Ontario Ministry of Education, 2016; World Economic Forum, 2016).

Robotics in the Context of Elementary Education

Robotics—whereby students learn about the design, analysis, application, and operation of robots—has been promoted as an effective tool for developing positive STEM dispositions and 21st century skills (Zviel-Girshin et al., 2020). Robotics invites "guess and check" and "trial and error" approaches that encourage children to problem solve, take educated risks, and think creatively (Zviel-Girshin et al., 2020, p. 295). Since children can observe the consequences of their decisions in real time, robotics can also "help make abstract ideas more concrete" (Kazakoff et al., 2013, p. 246). Researchers have also documented enhanced performance in STEM (e.g., Karahoca et al., 2011; Larkins et al., 2013) and a wide variety of other subjects including social studies, literacy, music, and art (e.g., Eguchi & Uribe, 2017). When used effectively, children learn how to navigate a computer, code, or build a robot, and they also learn to use these tools to develop a wide variety of 21st century skills. Research demonstrates that children as young as four years old can build and program robots (e.g., Sullivan et al., 2013; see also Bers et al., 2014). Students see robotics education as "fun" and "exciting" (Zviel-Girshin et al., 2020, p. 294). Moreover, many children have a degree of comfort and know-how with using technology in various everyday settings, which likely creates greater ease and comfort when using robotics in educational settings (e.g., Kazakoff et al., 2013; Rizk & Hillier, 2021).

While some technology has been embraced by educators on a broader scale (e.g., iPads), the adoption of robotics has proven to be more challenging. Teachers often "do not recognize the benefits of educational robotics" (Kim et al., 2015, p. 16), and in some cases may perceive robotics as a "burden" (Zviel-Girshin et al., 2020, p. 295). Even when teachers recognize the promise of robotics, many lack the training or skills to integrate them meaningfully in the classroom (Kim et al., 2015; Nir et al., 2016). In fact, many teacher education programs do not require courses that would provide candidates with a foundation to teach robotics (e.g., Greenberg et al., 2013) and a sizeable proportion of seasoned teachers "lack confidence in their ability to teach digital and technology skills"

(Actua, 2020, p. 7). Not surprisingly, robotics is not widely integrated across K–12 classrooms in North America (e.g., Kim et al., 2015).

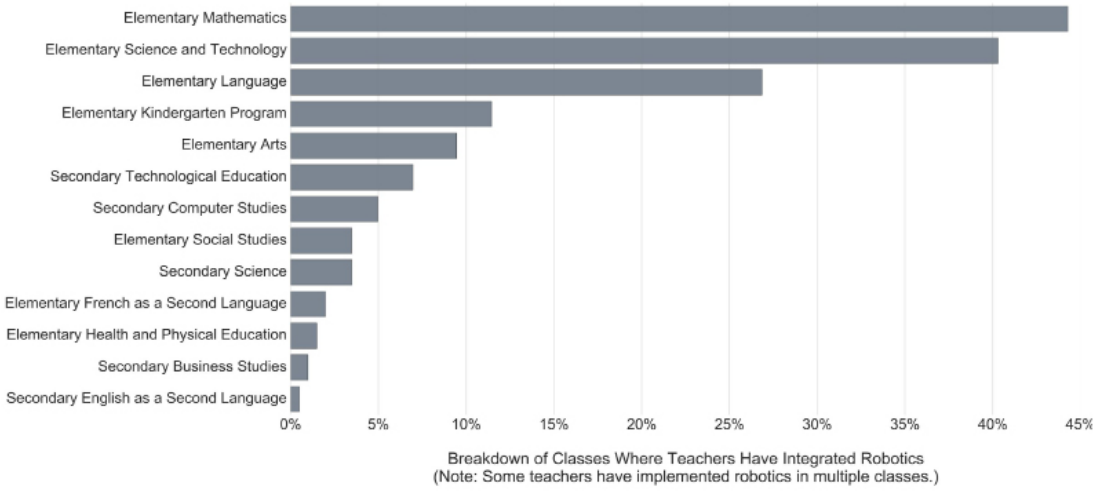
As a consequence, robotics use is often limited to after-school programs and clubs, competition teams, and summer camps. While these options can provide an enriching learning opportunity (e.g., Shah et al., 2018), participation is often limited to students who are already interested in STEM and robotics learning (e.g., Larkins et al., 2013). To expand its reach, robotics must shift from an "extracurricular" activity to a mainstream tool for developing STEM and 21st century competencies in the context of K–12 classrooms.

Context

This article is based on a study about the implementation of elementary classroom robotics in Ontario, Canada. The Ontario Ministry of Education (MOE) launched a technology and learning fund to enhance 21st century competencies and help students "become more technologically savvy" (Ontario Ministry of Education, 2014, p. 1). In addition to tablets, smartboards, and other devices, MOE purchased over 5,300 robotics kits 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 were made at the school board level about which kits to purchase depending on grade levels and subjects. 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. As shown in Figure 1, these kits are overwhelmingly being used in elementary math, science, and technology classes. However, teachers also used them in arts and language courses.

Figure 1

Breakdown of Classes Where Teachers Have Integrated Robotics



Methods

Research Design and Participants

To investigate how Ontario elementary classrooms used robotics, we adopted a mixed-methods research design. The Council of Ontario Directors (CODE)[1] identified nine school boards that were interested in participating in our study. Each school board contact person facilitated recruitment by identifying staff (and school sites) within their board who support or use robotics and emailed our letter of information to those people.

Focus groups. We held one initial expert panel focus group to advise on framing of the general focus group questions. The panel was comprised of teachers and administrators who have extensive experience with teaching using robotics in the classroom. We then conducted nine additional focus groups with teachers and administrators (one per school board), for a total of 95 participants. Board focus groups were approximately 2.5 hours long and included a mixture of eight to 14 staff (e.g., IT, teachers, principles), instructional resource teachers who support robotics, and teachers who use robotics. We

1 CODE is an advisory and consultative organization composed of the directors of each of the 72 district school boards in Ontario; Public, Catholic, and French Language.

asked participants to discuss current practices, what is working well, and the challenges associated with robotics.

Classroom observations and teacher interviews. We also conducted 19 one- to two-hour classroom observations, 11 of which were currently using robotics. We intentionally included a mix of teachers and students who were using robotics in their classrooms, and those who were not. Our comparative approach allowed us to systematically examine whether there are observable differences in student engagement between classrooms with and without robotics. Speaking with teachers who did not use robotics also provided us with valuable insights into the perceived barriers to utilizing robotics in classrooms.

Pre-and post-observation interviews were conducted with these classroom teachers to identify "look fors" during the observation (pre) and to reflect on what we observed (post). Our observations were video-recorded, allowing us to capture various dimensions of 21st century competencies such as collaboration (e.g., through negotiating ideas), flexibility (e.g., through openness to alternative perspectives), creativity (e.g., expressing a new idea), problem solving (e.g., developing a plan), and mathematics or science literacy (e.g., use of appropriate computation strategies). During the post-interview, we reviewed the video footage with the participating classroom teachers. They reflected on what we observed, pointed out interpersonal dynamics that we may not have been aware of, and discussed their perceptions of robotics and other technological tools. The teachers' professional expertise was critical and helped identify evidence of 21st century competencies and whether or how robotics enhanced classroom teaching and learning and student interactions.

Student focus groups. At each observation site, we also conducted six 30-minute focus groups with junior and intermediate students who were enrolled in classrooms using robotics at the time (one per school). In total, 46 students participated. We asked students to describe how robotics are used in their classrooms, what they liked about robotics, and the challenges they experienced using robotics.

Teacher survey. We also conducted a survey of 201 teachers and administrators at six of the participating boards that were involved in the robotics program (57% response rate). Through this survey we were able to quantify some of the issues that arose in the interviews and the 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, unrealized potential, and considerations for improvement. Data sources and participant numbers are identified in Table 1.

Table 1

Data Sources and Participants

Data Collected	Number Participants	Type of Participant
10 Focus Groups	95 Participants	Administrators and Teachers
6 Student Focus Groups	46 Participants	Junior and Intermediate Students
38 Interviews	38 Participants	Administrators and Teachers
19 Video-Recorded Observations	19 Classrooms	11 Classrooms Using Robotics, 8 Without
Teacher and Administrator Survey	201 Participants	57% Response Rate from 6 Boards

Overview of Procedures

We engaged in a multi-staged consent process. For the focus groups, our school board contacts identified potential focus group candidates. Once we had a list of potential candidates, the research team sent them a letter of information asking them to participate. Interested participants contacted the research team directly. All focus groups took place at the school board headquarters.

For school observations and interviews, a letter of information was sent to principals whom our board contacts had identified within their existing networks of schools that were currently engaged in robotics. Second, interested principals distributed the teacher letter of information to suitable teacher candidates within their school (one teacher who used robotics in the school and a same-grade teacher who did not). Third, interested teachers contacted researchers directly to participate in observations and interviews. Fourth, consenting classroom teachers then distributed a letter of information and consent to parents to recruit students for observations and focus groups. Participating classroom teachers collected consent forms. Fifth, once we had a list of students who received consent from a parent/guardian, we reviewed the protocol and asked students for their consent on the day of the observations and focus groups. Only students who received permission from a parent/guardian, and who gave their consent, participated in the video-recorded observations and/or focus group.

Transcribed interviews and video recordings were imported into NVivo 11. To analyze the data, we developed a codebook and worked closely with a small group of research assistants. Codes were created based on pre-existing theories and themes such as robotics, 21st century competencies, and also as our understanding of the data grew. In this article, we draw from the descriptive codes that described the characteristics of the data (e.g.,

"21st century competencies"; "collaboration"; "professional development"). To examine how robotics potentially supports the teaching and learning of 21st century competencies, we used insights from nodes such as "Benefits of Robotics," "Reasons they Adopt Robotics," and "Student Engagement." Our analysis also captured evidence for the three 21st century pillars: cognitive skills (e.g., evidence of problem solving), interpersonal skills (e.g., examples of students giving constructive feedback to a partner), and interpersonal skills (e.g., perseverance, willingness to take risks). The challenges teachers and students noted are captured by several child nodes, including "No Support" to describe little to no resources, while "Lack of Coordination" describes the realities of having little to no coordination between the ministry, school board, and schools about implementing and assessing robotics. "Lone Wolf" captures teachers who described having little to no professional networks at their school or board to support robotics. We also include responses from group activities conducted during the focus groups (e.g., think, pair, share) and analyzed the survey data descriptively, with the goal of quantifying some of the themes that arose in the qualitative data with a broader sample of teachers and administrators.

The survey was administered after the majority of other empirical data were collected. This enabled us to develop questions to quantify many of the issues that we were identifying in the qualitative work, and to 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 also asked participants to answer some more qualitative, open-ended questions. We included their responses in our qualitative data analysis (Aurini et al., 2022).

Results

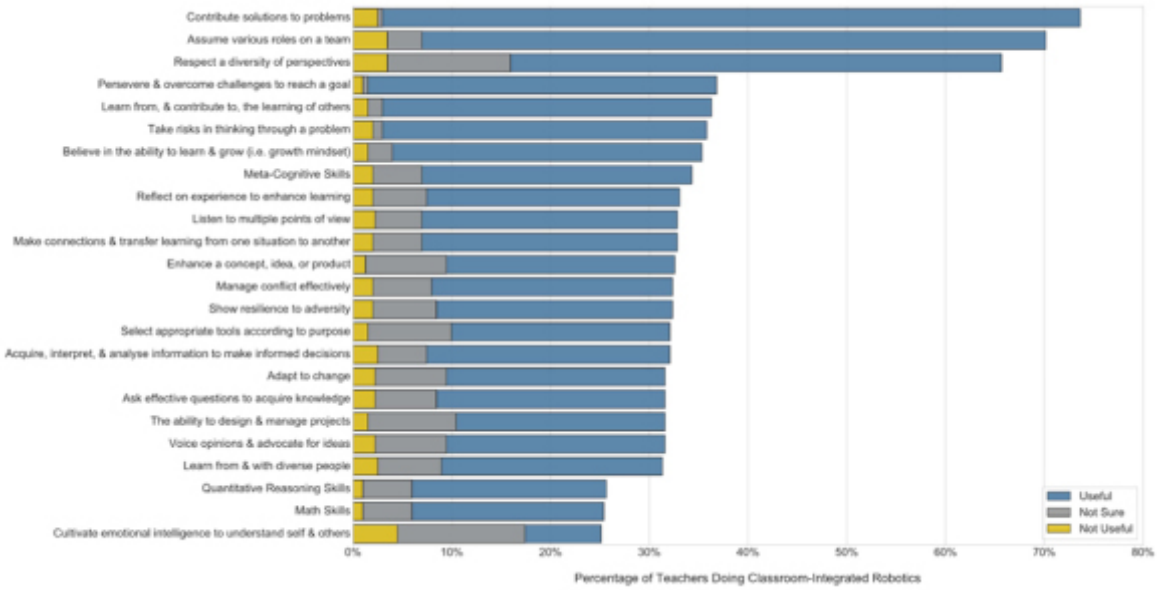
How Robotics Can Support the Development of STEM and 21st-Century Competencies

> ...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

Teachers describe robotics as a powerful tool to facilitate the development of STEM and 21st century 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 skills. Figure 2 provides an overview of their responses. For each competency, the 201 teachers we surveyed—all who have used robotics in their teaching—ranked the usefulness of robotics on a 5-point scale.

Figure 2

Teachers' Perceptions of How Useful Robotics Is in Helping Cultivate Skills



Cognitive Skills

> It's a good experience. We're like engineers. – Grade 7 student

The "digital age" necessitates improving children's technological literacy for future educational and employment opportunities (Elkin et al., 2014). Teachers made explicit connections between robotics and cognitive skills. They saw 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 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.

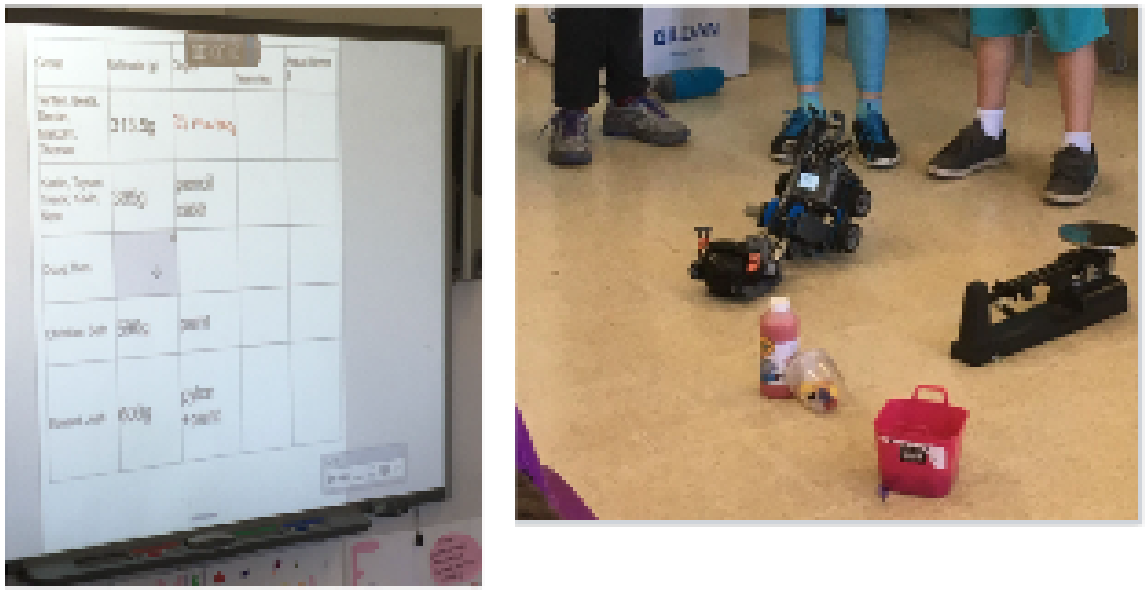
Similarly, students told us that robotics makes math "fun" and relevant, and challenges them to "think outside the box." As one student explained, before robotics he did not think math was useful. Teachers described how robotics provides students with the "impetus to learn" math, science, and language skills. As one instructional resource teacher 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."

Our observations support what teachers and students told us. We observed students making mathematical conjectures, forming predictions, explaining their reasoning, and constructing arguments for taking a particular approach. They used "guess and check," documented and graphed their progress, journaled, and presented their work to classmates (see Figure 3).

Figure 3

Grade 4 Estimation Challenge



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, perseverant, and determined to come up with creative solutions. The following video-recorded excerpt is representative of the conversations we had with students. In this example, a student is explaining the problems his group encountered during the "parallel parking" challenge using a robot.

> **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 [were] in one rotation. We figured out there [were] 15 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 15 centimeters. We measured it.

In another classroom, the teacher asked students to estimate how many grams their VEX robot could lift with its claw using objects in the classroom. Each group presented their estimates to the class, followed by a demonstration. One group's robot tipped over. The entire class got involved in trying to solve the problem, with several students calling out "you need a counter-weight!" After some experimentation (and lots of deliberation), the group adjusted their estimation and found a lighter object that would not flip over the robot.

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 [well] and we end up getting the challenges completed. It is fairly easy because of our teamwork. – Grade 5 student

Robotics presents students with opportunities to hone interpersonal and intrapersonal skills. The complexities of building a functional robot and completing the assignment demand that 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 team members. Students debated, listened to group members, and tried to understand why a member wanted to take a particular approach. 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 a regular classroom."

We also observed students working through various problems with a high degree of focus and determination. The robot and the coding rarely, if ever, work the first few times. In one classroom, we watched primary students try to code a Dash to follow a square on the floor. We observed students moving their robots back to the starting line to "try again" over and over. However, the "hum" of the classroom was positive. Throughout the period, students worked together, shared ideas, debated, and engaged in repea-

ted trial and error. Groups discussed what they thought went wrong, why, and how it might be resolved.

The relatively "low stakes" of trying a new approach (e.g., changing the code) readily allowed a variety of ideas to be tried out. 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 [and] 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.

The nature of robotics also reduced opportunities for any one student to do all the work. There are simply too many moving parts (literally and figuratively) for any individual to avoid contributing. We observed students moving from one role (e.g., coding) to another (e.g., graphing progress). 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."

In sum, our data suggest that when robotics are used effectively, they can support the development of STEM and 21st century competencies. Three other benefits also emerged from our data. 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. 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. Finally, teachers also attribute social benefits to robotics inside and outside the classroom. According to many of the teachers we spoke to, robotics encouraged students to engage with other children outside of their regular friendship networks.

Challenges of Supporting Robotics Classroom Teaching and Learning

Technology has been credited with improving children's learning, including in collaborative problem solving, mathematics, and science (Barreto & Benitti, 2012; Mills et al., 2013). While our qualitative and quantitative data support this assessment, we also learned the ways in which the promise of robotics can fall short.

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?" – Junior/intermediate teacher

A lack of formal integration into curriculum and assessment invites a variety of implementation challenges. In this context, teachers may perceive robotics as a "separate entity" that takes "away from curriculum time." They also tend not to see connections to subjects like literacy and social studies. As one teacher said,

> 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.

Even teachers who are open to trying robotics struggle to find adequate information or find 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 without a prior background in technology.

As one administrator explained, there are "lots of spaces" to integrate robotics, but the school board needs 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 learning how to use robotics kits and code, researching ways to connect robotics to curriculum and assessment requirements, and developing 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, as one teacher explained.

> 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 explicit curriculum links, they tend to view robotics as an extracurricular activity and question how to justify doing robotics or demonstrate learning outcomes to parents. The following conversation from a focus group with teachers and administrators is representative of what participants communicated to the research team.

> **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 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."

Without formal integration, the development of robotics initiatives often rests on a handful of "trail blazers"—individuals who champion robotics to their colleagues, seek out resources, and devote time to mentoring other teachers.

Resources and Time

> That is my biggest stumbling block. I don't have enough [kits]. The Grade 1/2 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

The meaningful integration of robotics requires at least one robot and supporting technology (e.g., iPad) for every three or four students. Even when teachers have access to a sufficient number of robots, they often run into other challenges: difficulty accessing enough tablets or netbooks to use the kits, kits that are not appropriate for the grade level, delays while software is installed centrally on school machines, and insufficient Wi-Fi to download supplementary materials and documentation.

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

Teachers also feel that there is not enough space in their classrooms or schools to build and store the 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 is exemplary of what we typically 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 significant floor space to house the robotics, leaving little to no room for other activities.

Professional Development and Support

To encourage the expansion of robotics and increase "buy in," teachers often need more professional development and support. Most teachers who used robotics in our sample are the "lone wolf" in their school. Throughout our discussions with robotics and non-robotics users, "being in the dark" and having "no idea where to start" were frequent themes. 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, robotics teachers 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 repeatedly 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 have very few colleagues they can turn to for advice on robotics-related issues. When asked to name colleagues they feel they can turn to for advice, 65% listed either nobody or only a single person. A further 15% listed only two colleagues. Similarly, teachers reported that very few people turn to them for advice, and that there are very few people with whom they have had a conversation within the past year about classroom-integrated robotics.

Overall Fragility

The challenges cited above (e.g., lack of curriculum and assessment integration, lack of time and learning support for teachers) can result in robotics initiatives that are not firmly embedded within schools and school boards. One important problem with the "lone wolf" or "champion" model is that robotics programs fizzle out if that teacher leaves the school. One principal explained that their school "lost [a teacher] because of rules about seniority" and now "has nobody on staff who even expresses an interest." Passing the torch to someone else 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…. We have our robotics [and all kinds of other technology in the school lab]…. It's like pulling teeth to get teachers there…. Every time someone comes, [the kids] love it…kids who are begging you to be a part of that…. 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 support for robotics may be compromised. Thus, the potential for robotics to support the development of 21st century competencies will be vulnerable without a more systematic and collaborative approach to building resilient programs and integrating robotics into curriculum.

Conclusions and Policy Recommendations

We propose seven policy recommendations. Each recommendation targets specific challenges identified in our research.

Recommendation 1 – Curriculum

Integrate robotics, coding, and computational thinking into curriculum documents. The current lack of integration in curriculum documents leads to a perception among teachers

that these are simply "add ons" or only useful in the context of STEM. To legitimate robotics and coding as promising ways to meet a variety of learning objectives, materials should be developed to help teachers meet existing curricular expectations in all subjects.

Recommendation 2 – Assessment

Revise assessment tools and report cards to recognize robotics as one of the many ways of achieving curricular objectives. As one administrator emphasized, "We measure what we value, and we value what we measure." Our data demonstrate that more teachers would be willing to integrate robotics and other forms of technology in the classroom if there were explicit connections between robotics, a wide range of subjects, and assessment tools.

Recommendation 3 - Professional Development

Prioritize professional development and support teachers in their efforts to learn more about robotics and coding. Providing more funding, hardware, and curriculum support is not helpful if teachers lack knowledge about effective classroom use. High-quality professional development includes 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 teachers, and opportunities to visit other classrooms to see new and innovative ways to incorporate robotics and coding.

Recommendation 4 - Equalize Access

Develop official channels for collaboration and sharing. Sharing lesson plans and creating professional support groups would greatly benefit all teachers, but most particularly those in rural and remote boards. These efforts could include the creation of central repositories of shared materials (e.g., lesson plans, design challenges) and curriculum expectation grids that show teachers how to map robotics and coding onto existing curricular expectations across a wide range of subjects.

Recommendation 5 - Equity and Access

Provide funding and support to increase the equitable distribution of robotics, coding, and other technological learning within and across school districts. Ensure that all students have an opportunity to be exposed to robotics, coding, and technological learning at some point during their elementary school career. To maximize student success and engagement, identify those schools that have limited staff and resource capacity to support robotics. Provide those schools with additional resources (e.g., technology and learning consultants, staff training) and funding to ensure that classrooms are equipped with a sufficient number of grade-appropriate robotics kits. Classroom robotics requires at least one kit for every three to four students.

Recommendation 6 - Realizing Space and Resource Efficiencies

To maximize student success and engagement, provide teachers with adequate space and time to engage meaningfully with robotics teaching and learning. Having a common space like an "Innovation Lab," a library, or makerspace where materials can be left out allows for more time on task and longer, more involved, assignments.

Recommendation 7 - Nurture Strategic Partnerships

Encourage and facilitate the development of strategic collaborations that can offer professional development and training. Some possible examples include collaborations with other schools, school boards, post-secondary institutions, private partnership, and non-profit organizations whose mandate is to promote robotics in education. In our study, for example, elementary schools connected with their local high school robotics clubs. High school teachers and students provided technical support and demonstrations. Another teacher in our study partnered with a nearby post-secondary institution and was given robotics kits on loan. Her students also visited the college to observe robotics "in action."

Discussion

Stakeholders across all sectors (i.e., education, government, policy, industry) in Canada are grappling with how to increase student "exposure and access to the science, engi-

neering and technology fields," prepare students for "multiple career pathways," and to expand teachers' "knowledge of current and future labour market needs" (Premier's Highly Skilled Workforce Expert Panel, 2016, p. 62). Indeed, there is a general agreement that a broad range of skills is needed to "achieve *future-proof learning*" (e.g., Kirschner & Stoyanov, 2018, p. 3, emphasis in original). Despite these concerns (and considering labour market opportunities), "STEM interest during adolescence continues to decline" (Shaby et al., 2021, p. 628).

Researchers stress that it is critical to understand "implementation barriers" that might affect students' engagement in programs that support STEM learning (Kezar & Holcombe, 2018, p. 864). When it is integrated meaningfully into the classroom, robotics can be a powerful tool to spark students' interest in STEM, along with developing a broad range of 21st century skills (Kazakoff et al., 2013; Ioannou & Makridou, 2018; Rizk, 2020). However, the promise of robotics falls short without proper curriculum and assessment integration and support for emerging and existing robotics users (teachers and students). Participants also noted several barriers to integrating robotics on a wider scale, such as time, space, and funding, that could limit their potential. We also outlined practical policy solutions to overcome these challenges so that more educators are able to add robotics to their teaching toolkit. An important recommendation that surfaced through this research was the need to incorporate robotics and coding into existing curriculum and assessment guidelines, and to provide teachers with access to high quality professional development and technical support. Such changes would support a more equitable distribution of resources to ensure that all children could have the opportunity to engage in robotics at some point during their elementary school career.

This study was conducted prior to the COVID-19 pandemic. The OECD predicts that the COVID-19 pandemic will likely intensify digitization, automation, and technological shifts in the labour market (OECD, 2020). According to an assessment of eight countries (e.g., China, United Kingdom, United States), 20 to 25 percent of their workforces could work remotely three to five days per week, an increase of four to five times prior to the pandemic (McKinsey Global Institute, 2021). Business leaders estimate a reduction of office space and reduced business travel as companies realize the benefits of remote and flexible workspaces and video-conferencing (McKinsey Global Institute, 2021).

Are schools ready for the accelerated pace of changes to the nature and organization of work? There is good reason to feel optimistic. On one hand, the scramble to shift

to a remote learning environment exposed existing gaps in the areas of digital and technological literacy among staff and students. On the other hand, the pandemic also created an opportunity to revaluate how we approach the curriculum, student engagement, assessment, and the development of 21st century competencies (Onyema et al., 2020). It has also raised important questions about whether intensifying the use of technology, like robotics, would allow us to pivot more quickly and meet the needs of future labour markets.

Perhaps a growing demand for more STEM skills prompted the Ontario Ministry of Education to revise the elementary science and technology curriculum (see Ontario News Room, 2022). Among other expectations like food literacy, the curriculum will now include a new focus on coding (e.g., teaching students to program a robot using robotic kits) and connecting STEM learning to real-world applications. Since the release of the previous curriculum in 2007, there have been many significant scientific and technological innovations—everything from smart technologies to the rise of artificial intelligence (AI)—all of which have altered the nature of the job skills that are needed in today's global economy. This curriculum change comes at an opportune moment for Ontario students to not only teach them critical skills, but to re-engage them post-COVID-19 (e.g., Aurini & Davies, 2021). We hope other provinces follow suit. While several ministries across the country have made significant investments in robotics (e.g., British Columbia), developing widespread and sustainable teaching and learning opportunities for staff and students requires aligning robotics, coding, and other technologies with curriculum, assessment, and training requirements.

References

Advisory Council on Economic Growth. (2017). *Learning nation: Equipping Canada's workforce with the skills for the future.* https://www.budget.gc.ca/aceg-ccce/pdf/learning-nation-eng.pdf

Actua. (2020). *Canadian teachers' readiness for STEM education: Results from Actua's national survey of teachers.* https://www.actua.ca/wp-content/uploads/2020/09/For-Publication_Actua-National-Teacher-Survey-Report_2020-2.pdf

Affouneh, S., Salha, S., Burgos, D., Khlaif, Z. N., Saifi, A. G., Mater, N., & Odeh, A. (2020). Factors that foster and deter STEM professional development. *Science Education*, *10*(5), 857–872. https://doi.org/10.1002/sce.21591

Aurini, J., & Davies, S. (2021). Covid-19 school closures and educational achievement gaps: Lessons from summer setback research. *Canadian Sociological Review, 58*(2), 165–185.

Aurini, J., Heath, M., & Howells, S. (2022). *The how to of qualitative research* (2nd ed.). SAGE.

Aurini, J., McLevey, J., Stokes, A., & Gorbet, R. (2017). *Robotics and 21st century learning*. Ontario Ministry of Education, Council of Directors of Education.

Becker, K. H., & Park, K. (2011). Integrative approaches among Science, Technology, Engineering, and Mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM Education: Innovations and Research, 12*(5-6), 23–37.

Bers, M., Flannery, L., Kazakoff, E., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145–157. https://doi.org/10.1016/j.compedu.2013.10.020

Barreto, F., & Benitti, V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58*(3), 978–988. https://doi.org/10.1016/j.compedu.2011.10.006

Canadian Council of Chief Executives. (2014). *Preliminary survey report: The skill needs of major Canadian employers.* http://www.ceocouncil.ca/wp-content/uploads/2014/01/Preliminary-report-on-skills-survey-Jan-20-2014-2.pdf

Caspi, A., Gorsky, P., Nitzani-Hendal, R., Zacharia, Z., Rosenfeld, S., Berman, S., & Shidhouse, B. (2019). Ninth-grade students' perception of the factors that led them to major in high school science, technology, engineering and mathematics disciplines. *Science Education*, *103*(5), 1176–1205. https://doi.org/10.1002/sce.21524

Christensen, R., Knezek, G., & Tyler-Wood, T. (2015). Alignment of hands-on STEM engagement activities with positive STEM dispositions in secondary school students. *Journal of Science Education and Technology, 24*, 898–909. https://doi.org/10.1007/s10956-015-9572-6

Dweck, C. S. (2007). *Mindset: The new psychology of success.* Random House.

Eguchi, A., & Uribe, L. (2017) Robotics to promote STEM learning: Educational robotics unit for 4th grade science. *IEEE Integrated STEM Education Conference.* https://doi.org/10.1109/ISECon.2017.7910240

Elkin, M., Sullivan, A., & Bers, M. U. (2014). Implementing a robotics curriculum in an early childhood Montessori classroom. *Journal of Information Technology Education: Innovations in Practice, 13,* 153–169. https://doi.org/10.28945/2094

Freeman, J. A., Gottfried, M. A., & Stratte Plasman, J. (2021). STEM-focused career courses and college pipeline for students with learning disabilities. *Educational Policy.* Advance online publication. https://doi.org/10.1177/08959048211019988

Greenberg, J., McKee, A., & Walsh, K. (2013). *Teacher prep review 2013 report.* National Council on Teacher Quality. http://www.nctq.org/dmsView/Teacher_Prep_Review_2013_Report

Ioannou, A., & Makridou, E. (2018). Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work. *Education and Information Technologies*, *23*, 2541–2544. https://doi.org/10.1007/s10639-018-9729-z

Kalleberg, A. (2011). *Good jobs, bad jobs: The rise of polarized and precarious employment systems in the United States, 1970s-2000s.* Russell Sage Foundation.

Karahoca, D., Karahoca, A., & Uzunboylub, H. (2011). Robotics teaching in primary school education by project-based learning for supporting science and technology courses. *Procedia Computer Science, 3*(1), 1425–1431. https://doi.org/10.1016/j.procs.2011.01.025

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal*, *41*, 245–255. https://doi.org/10.1007/s10643-012-0554-5

Kezar, A. J., & Holcombe, E. M. (2018). Challenges of implementing integrated programs for underrepresented students in STEM: A study of the CSU collaboratives. *Educational Policy, 34,* 864–893. https://doi.org/10.1177/0895904818802091

Kim, C., Kim, D., Yan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education*, *91*, 14–31. https://doi.org/10.1016/j.compedu.2015.08.005

Kirschner, P. A., & Stoyanov, S. (2018). Education youth for nonexistent/not yet existing professions. *Educational Policy, 34*(3), 477–517. https://doi.org/10.1177/0895904818802086

Kitchen, J. A., Sonnert, G., & Sadler, P. M. (2018). The impact of college-and university-run high school summer programs on students' end of high school STEM career aspirations. *Science Education, 102*(3), 529–547. https://doi.org/10.1002/sce.21332

Larkins, D. B., Moore, J. C., Rubbo, L. J., & Covington, L. R. (2013) Application of the cognitive apprenticeship framework to a middle school robotics camp. In *SIGCSE '13: Proceeding of the 44th ACM Technical Symposium on Computer Science Education* (pp. 89–94). Association for Computing Machinery. https://dl.acm.org/doi/abs/10.1145/2445196.2445226

Maltese, A. V., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. *Science Education, 95*(5), 877–907. https://doi.org/10.1002/sce.20441

McKinsey Global Institute. (2021). *The future of work after Covid-19.* https://www.mckinsey.com/featured-insights/future-of-work/the-future-of-work-after-covid-19

Mills, K., Chandra, V., & Park, J. (2013). The architecture of children's use of language and tools when problem solving collaboratively with robotics. *Australian Educational Research*, *40*(3), 315–337. https://doi.org/10.1007/s13384-013-0094-z

Mousa, A., Ismail, T., & Salam, M. (2017). A robotic cube to preschool children for acquiring the mathematical and colours concepts. *Computer Science, 11*(7),1809–1812. https://doi.org/10.3389/fpsyg.2020.02011

Nir, A., Ben-David, A., Bogler, R., Inbar, D., & Zohar, A. (2016). School autonomy and 21st century skills in the Israeli educational system: Discrepancies between the declarative and operational levels. *International Journal of Educational Management, 30*(7), 1231–1246. https://doi.org/10.1108/IJEM-11-2015-0149

Organisation for Economic Co-Operation and Development. (2018). *The future of education and skills: Education 2030.* https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf

Organisation for Economic Co-Operation and Development. (2020). *Job creation and local economic development 2020: Building better.* https://www.oecd-ilibrary.org/sites/a0361fec-en/index.html?itemId=/content/component/a0361fec-en#snotes-d7e13498

Ontario Ministry of Education. (2014). A*chieving excellence: A renewed vision for education in Ontario.* https://www.oise.utoronto.ca/atkinson/UserFiles/File/Policy_Monitor/ON_01_04_14_-_renewedVision.pdf

Ontario Ministry of Education. (2016). *Towards defining 21st century competencies for Ontario. Foundation Document for Discussion.* http://www.edugains.ca/resources21CL/About21stCentury/21CL_21stCenturyCompetencies.pdf.

Ontario News Room. (2022). *Ontario modernizing school science curriculum*. https://news.ontario.ca/en/release/1001722/ontario-modernizing-school-science-curriculum

Onyema, E. M., Eucheria, N. C., Obafemi, F. A., Sen, S., Atonye, F. G., Sharma, A., & Olsayed, A. O. (2020). Impact of Coronavirus pandemic on education. *Journal of Education and Practice, 11*(13), 108–121. https://doi.org/10.7176/JEP/11-13-12

Premier's Highly Skilled Workforce Expert Panel. (2016). *Building the workforce of tomorrow: A shared responsibility.* https://files.ontario.ca/hsw_rev_engaoda_web-final_july6.pdf

Rizk, J. (2018). *The 21st century classroom: Technology as a transformative tool in educational routines, rules, and rituals* [Doctoral dissertation, McMaster University]. MacSphere. http://hdl.handle.net/11375/23639

Rizk, J. (2020). Considerations for implementing emerging technologies and innovative pedagogies in twenty-first-century classrooms. In S. Yu, M. Ally, & A. Tsinakos (Eds.), *Emerging technologies and pedagogies in the curriculum* (pp. 447–460). Springer. https://doi.org/10.1007/978-981-15-0618-5_26

Rizk, J., & Davies, S. (2021). Can digital technology bridge the classroom engagement gap? Findings from a qualitative study of K-8 classrooms in 10 Ontario school boards. *Social Sciences, 10*(1), 12. https://doi.org/10.3390/socsci10010012

Rizk, J., & C. Hillier (2021). "Everything's technology now": The role of technology in home- and school-based summer learning activities. *Journal of Children and Media, 15*(2), 272–290. doi.org/10.1080/17482798.2020.1778498

Shaby, N., Staus, N., Dieking, L. D., & Falk, J. H. (2021). Pathways of interest and participation: How STEM-interested youth navigate a learning ecosystem. *Science Education*, *105*(4), 628–652. https://doi.org/10.1002/sce.21621

Shah, A. M., Wylie, C., Gitomer, D., & Noam, G. (2018). Improving STEM program quality in out-of-school time: Tool development and validation. *Science Education*, *102*(2), 238–259. https://doi.org/10.1002/sce.21327

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, *6,* 39. https://doi.org/10.1186/s40594-019-0192-1

Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International Journal of Technology and Design Education*, *26*, 3–20. https://doi.org/10.1007/S10798-015-9304-5

Sullivan, A., Kazakoff, E. R., & Bers, M. U. (2013). The wheels on the bot go round and round: Robotics curriculum in pre-kindergarten. *Journal of Information Technology, 12,* 203–219. https://doi.org/10.28945/1887

Taylor, R., Fadel, C., Helyn, K., & Care, E. (2020). *Competencies for the 21st century: Jurisdictional progress*. Brookings Institute. https://www.brookings.edu/wp-content/uploads/2020/10/Competencies-for-the-21st-century-jurisdictional-progress-FINAL-1.pdf

Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I.-M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Educational Technology & Society*, *19*(2), 148–163.

Yang, Y., Long, Y., Sun, D., Van Aalst, J., & Cheng, S. (2020). Fostering students' creativity via educational robotics: An investigation of teachers' pedagogical practices based on teacher interviews. *British Journal of Educational Technology, 51*(5), 1826–1842. https://doi.org/10.1111/bjet.12985

World Economic Forum. (2016). *What are the 21st century skills every student needs?* https://www.weforum.org/agenda/2016/03/21st-century-skills-future-jobs-students/

World Economic Forum. (2018). *The global competitiveness report 2018.* http://www3.weforum.org/docs/GCR2018/05FullReport/TheGlobalCompetitivenessReport2018.pdf

Xie, Y., Fang, M., & Shauman, K. (2015). STEM education. *Annual Review of Sociology, 41,* 331–357. https://doi.org/10.1146/annurev-soc-071312-145659

Zviel-Girshin, R., Adi, L., & Chait, S. (2020). Robotics as a tool to enhance technological thinking in early childhood. *Journal of Science Education and Technology*, *29*(2), 294–302. https://doi.org/10.1007/s10956-020-09815-x