Chapter 1
Bringing Robotics in Classrooms

Amy Eguchi

Abstract Learning with educational robotics provides students, who usually are the consumers of technology, with opportunities to stop, question, and think deeply about technology. When designing, constructing, programming, and documenting the development of autonomous robots or robotics projects, students not only learn how technology works, but they also apply the skills and content knowledge learned in school in a meaningful and exciting way. Educational robotics is rich with opportunities to integrate not only STEM but also many other disciplines, including literacy, social studies, dance, music, and art, while giving students the opportunity to find ways to work together to foster collaboration skills, express themselves using the technological tool, problem-solve, and think critically and innovatively. Educational robotics is a learning tool that enhances students' learning experience through *hands-on mind-on* learning. Most importantly, educational robotics provides a fun and exciting learning environment because of its hands-on nature and the integration of technology. The engaging learning environment motivates students to learn whatever skills and knowledge needed for them to accomplish their goals in order to complete the projects of their interest. For school-age children, most robotics activities have mainly been part of informal education, such as after school programs and summer camps (Benitti in Computers & Education, 58:978–988, 2012; Eguchi 2007b; Sklar and Eguchi in Proceedings of RoboCup-2004: Robot Soccer World Cup VIII, 2004), even though it has the potential to make learning more effective in formal education. It is very difficult for teachers to include robotics in regular curriculum because of the heavy focus on standardized testing and pressure to cover academic standards set by the government and/or their States. This chapter aims to promote robotics in classroom by connecting robotics learning with various STEM curriculum standards.

Keywords Educational robotics · Constructionism · Maker movement in education · Technological literacy · Innovation literacy

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1.1 Introduction—Need for Change in Education

The speed of change in our society has been accelerating since the birth of the Internet. New technological tools are being introduced into our daily life more rapidly than ever before. Roughly twenty years ago, the cellular phone entered our lives just as the Internet started to connect personal computers. Now, the introduction of new iProducts and/or new smartphone products, such as Galaxy, occurs almost every six months. Creative project crowd-funding platforms, connected through the Internet, such as Kickstarter (http://www.kickstarter.com), Indiegogo (https://www.indiegogo.com/), and Quirky (https://www.quirky.com), are also contributing to the accelerated birth of innovative and creative technological tools by providing essential funding directly from potential and/or interested consumers.

Among these various technological advancements, the speed of the changes that robotics technology has created has been drastically increasing in recent years. News headlines from major news sources, including the New York Times, CNN, Wall Street Journal, and BBC, frequently featuring various robotic innovations, are a strong indication of such phenomenon. On March 10, 2004, the US Defense Advanced Research Projects Agency (DARPA) funded the first DARPA Grand Challenge held in a California desert, which was introduced as “a first-of-its-kind race to foster the development of self-driving ground vehicles” (OUTREACH@DARPA.MIL 2014). Its goal was to develop cars autonomously navigated a 142-mile course. The first DARPA Grand Challenge was followed by the second Grand Challenge in 2005, and the Urban Challenge in 2007, where autonomous cars navigated a complex course in a staged city environment. About a decade later, in 2014, Tesla, an American automaker, has already rolled out their first semiautonomous driving system, AutoPilot, in the market. In 2016, Tesla introduced all of their cars to be built with the necessary hardware for full self-driving capability.

On June 5, 2014, Softbank Mobile, a Japanese company, in collaboration with Aldebaran Robotics, a French company, unveiled *Pepper*, the world’s first personal humanoid robot in Japan. Costing less than US$2000, Pepper is able to assist humans by reading and responding to human emotions (SoftBank Mobile Corp. and Aldebaran Robotics SAS 2014). Prior to Pepper, *NAO*, an autonomous and programmable humanoid robot developed by Aldebaran Robotics, has been used in various educational settings including RoboCup Soccer league for the development of algorithms for humanoid soccer since 2007, and for the research of children with Autism. Pepper has been developed to be “social companion for humans” (Middlehurst 2015, para. 5). The latest model is reported to have the ability to learn responses from a specific human using cloud technology-based AI (Tanabe 2015).

Governmental agencies from around the world have also invested in the development of robotics technologies. The DARPA funded the DARPA Robotics Challenge (DRC), which held between December 2013 to June 2015, ended with the DRC Finals. The DRC was “a competition of robot systems and software teams vying to develop robots capable of assisting humans in responding to natural and man-made disasters" (DARPA, n.a., para. 1). Its aim was to accelerate advanced research and development in robotics hardware and software that will enable future robots, in collaboration with humans, to perform the most hazardous activities in disaster zones, thus reducing casualties and saving lives. In February 2015, Japanese Ministry of Economy, Trade, and Industry has released its New Robot Strategy which outlines a plan to host the World Robot Summit in 2020, in the year when Tokyo Olympic is held (Ministry of Economy Trade and Industry, n.a.). This is part of the Japanese Economic Revitalization plan. In February 2016, the Executive Committee and the Advisory Board were formed to start the discussion and the planning for the World Robot Summit. The New Robot Strategy explains the goal of the World Robot Summit as a way to accelerate the research and development of robots and their introduction and diffusion into Japanese society. It aims to solve real issues in various areas, such as medical and health care, infrastructure inspection, agriculture, forestry and fisheries industry, manufacturing industry, service industry, and entertainment industry, use robotics technology as part of the competition, and demonstrate to society how robots can positively contribute to society. Furthermore, it aims to promote robots among people by introducing them through various games, and promoting various ways of living life with robots. The New Robot Strategy views the World Robot Summit as a driving force of the robot revolution, in which the infusion of robots will change the way people live every day.

The world and its economy are changing at such a rapid pace that it is impossible to predict what the economy will look like even at the end of next week (Robinson 2010). Despite all the drastic changes taking place in the world, public education has maintained almost the same system since its establishment in the middle of the nineteenth century (Robinson 2010). Although the requirements for an effective workforce have changed at the same speed as technological advancements, the majority of schools are continuing what was done in the past with little hope that they can adequately prepare students for the future (Robinson 2010). Some even state that if we could have teachers from the nineteenth-century time travel to our schools, they would have no problem teaching our students (Blikstien 2013). Because current public education places a heavy emphasis on memorization, our schools and curriculum are astonishingly similar to those in the nineteenth century (Blikstien 2013).

Long before the disconnect between the societal needs and what schooling provides students became an issue, Paulo Freire introduced his new view of education, leading to the development of the critical pedagogy approach. In his book, "Pedagogy of Oppressed," Freire points out that educational practice expects teachers to be narrators of facts and required students "to memorize mechanically the narrated content" (Freire 1994). In his view, students are turned into containers to be filled by the teacher. When using this *banking* approach to education (Freire 1994), students are required to receive, memorize, and repeat knowledge and/or facts that are provided by their teachers. Freire argues, "[t]he teacher talks about reality as if it were motionless, static, compartmentalized, and predictable. Or else he expounds on a topic completely alien to the existential experience of the students" (Freire 1994, p. 52). Freire warns:

> …it is the people themselves who are filed away through the lack of creativity, transformation, and knowledge in this (at best) misguided system. For apart from inquiry apart from the praxis, individuals cannot be truly human. Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry, human beings pursue in the world, with the world, and with each other. (p. 53)

As society and economy changes, especially when changes in industries and workforce happen, "a new set of skills and intellectual activities become crucial for work, conviviality, and citizenship—often democratizing tasks and skills previously only accessible to experts" (Blikstien 2013, p. 1). Since, in previous era, the speed of the change was rather slower, the need for a new set of skills and intellectual activities did not happen as quick as it is now, maybe in every few centuries or so. This made it possible for public school system to successfully provide what society required. However, the recent acceleration of the change in society is forcefully requiring a new set of skills, intellectual activities, and ways of thinking to successful citizen while schooling has not made the transition to meet the needs.

In current society, more and more creativity and innovation are required. Yamakami (2012) emphasizes that recent technological advancement accelerated the speed of current innovation, drastically faster than in the past, and "as the speed of innovation has changed, the quantitative changes in speed have brought about qualitative changes in innovation" (p. 557). There is an urgent need for a radical and effective educational reform to keep up with societal changes. However, with the extensive focus on assessments through State mandate standardized testing, a concern is raised that more and more teachers are forced to teach to the test with more focus on memorization of facts. Even in the mid-1990s, similar concern as Freire was raised again (Grabinger and Dunlap 1995; Grabinger et al. 1997). Grabinger, Dunlap, and Duffield emphasized the importance of learning to think critically, to analyze and synthesize information in order to solve interdisciplinary problems, and to work collaboratively and productively with others in groups are important skills for participating effectively in society, and simply knowing some facts in a single domain and/or how to use tools are not enough for individuals to stay effective and competitive in increasingly complex society (Grabinger et al. 1997). Grabinger and Dunlap observed teachers in conventional classrooms and concluded that they used examples and problems that were simplified and decontextualized, leading to inadequate understanding of the acquired knowledge and an inability to effectively apply the knowledge to real situations. Students are often presented knowledge in conjunction with problems and examples that are not relevant to them and their needs and have no connection to their real life. The problems that students are asked to solve make them wonder, "Why do I need to know this?" (Grabinger and Dunlap 1995, p. 7). Because their learning is decontextualized and they cannot make connection between their learning and their life, student learning becomes an exercise of memorization of the facts transferred from their teachers. Moreover, they are not taught to acquire skills essential for effective thinking and reasoning (Grabinger and Dunlap 1995).

The US Government also highlights the need for fostering the contextualized knowledge and skills necessary to solve complex problems that we face every day among our youth (U.S. Department of Education 2015).

In a world that's becoming increasingly complex, where success is driven not only by *what* you know, but also by what you *can do* with what you know, it is more important than ever for our youth to be equipped with the knowledge and skills to solve tough problems, gather and evaluate evidence, and make sense of information. These are the types of skills that students learn by studying science, technology, engineering, and math—subjects collectively known as STEM (para. 2).

The government has raised the issue of the need for change in how we approach teaching as well, with a special focus recommended to be placed on STEM education. In 2011, President Obama stated:

> The first step in winning the future is encouraging American innovation. None of us can predict with certainty what the next big industry will be or where the new jobs will come from. Thirty years ago, we couldn't know that something called the Internet would lead to an economic revolution. What we can do – what America does better than anyone else – is spark the creativity and imagination of our people. (The White House 2011, para. 1)

The need for a STEM educated workforce is highlighted in the report titled "Strategy for American Innovation (SAI)—Securing Our Economic Growth and Prosperity" and "Federal Science, Technology, Engineering, and Mathematics (STEM) Education: 5 Year Strategic Plan." Moreover, it is recognized that the need for STEM knowledge and skills will continue to grow in the future (Tanenbaum 2016). The reports emphasize that it is essential that the country focuses on STEM education, with the aim to improve K-12 education, enhance US students' engagement in STEM disciplines, and graduate every student from high school ready for college and career, by inspiring and preparing more students, including girls and underrepresented groups, to excel in STEM field (National Economic Council, Council of Economic Advisers and Office of Science and Technology Policy 2011). The future economy and core employments will be driven primarily by innovation largely derived from advances in science and engineering (Committee on Highly Successful Schools for Programs for K-12 STEM Education Board on Science and Division of Behavioral and Social Sciences and Education 2011). However, the evidence shows that current education does not prepare a sufficiently large enough and well-equipped STEM workforce. For example, access to the full range of math and science courses that students need in order to pursue careers in STEM fields, such as Algebra I, geometry, Algebra II, calculus, biology, chemistry, and physics, is very limited in public schools. Although it is reported that more Asian-Americans and white students are likely to pursue STEM than other students of color, only 81% of Asian-American and 71% of white high school students attend high schools with a full range of math and science courses (U.S. Department of Education 2015). Furthermore, STEM literacy is necessary not only for those who pursue career in STEM fields but also for the general public.

Our current education system does not cultivate a culture of STEM, nor does it foster the development of a STEM literate public (U.S. Department of Education 2015). All students, no matter their race, zip code, or socioeconomic status, should be provided with the opportunity to be college-ready with STEM fluency. "STEM 2026" report also emphasizes the inequities in access, participation, and success in STEM subjects (U.S. Department of Education and Office of Innovation and Improvement 2016). They report the existence of persistent inequities between races, genders, socioeconomic groups, and among students with disabilities, thereby keeping the educational and poverty gaps wide and preventing us from fulfilling the needs of our technologically driven society. It is stated that effective STEM education accessible to and inclusive of all students is increasingly important so that our youth are equipped with "a new set of core knowledge and skills to solve difficult problems, gather and evaluate evidence, and make sense of information they receive from varied print and, increasingly, digital media" and prepared to become "a workforce where success results not just from what one knows, but what one is able to do with that knowledge" (U.S. Department of Education and Office of Innovation and Improvement 2016, p. i).

Similar issues exist in other countries. For example, the European Commission identified the STEM skill gap in participating countries (Communication from the Commission to the European Parliament, the Council and The European Economic and Social Committee and the Committee of the Regions 2011; Directorate-General for Research and Innovation 2015; Innovation Union 2015). It was pointed out that there are very few female students interested in science and pursue advanced level courses, even though innovation is required in both STEM and non-STEM related fields as well as in various aspects of our life (Communication from the Commission to the European Parliament, the Council, and the European Economic and Social Committee and the Committee of the Regions 2011). It was reported that one-third of the member countries had implemented awareness programs aiming to attract female students to STEM fields and research (Directorate-General for Research and Innovation 2015).

The skills to innovate cannot be cultivated through current educational practice focusing heavily on the memorization of knowledge without providing opportunities for students to transfer them into practice. There are urgent calls for innovative educational approaches worldwide that can foster skills for innovators including critical thinking, problem-solving, creativity, inventiveness, collaboration and teamwork, and communication skills through transdisciplinary, learner-centered, collaborative, and project-based learning. This chapter explains how educational robotics as a learning tool can create an effective learning environment to foster the learning of STEM and skills for innovators. In addition, it aims to make learning with robotics more accessible to students in every classroom by providing resources and making connection between learning with robotics and different learning standards.

1.2 Robotics in Education

Educational robotics or robotics in education is the phrase widely used to describe the use of robotics as a learning tool in the classroom. Popular interest in robotics has increased at astonishing rate not only in general society but even more so in the educational community in last several years (Benitti 2012). At the same time, robotics technology, once accessible only to experts and robotics scientists, has been more and more accessible for teachers and students of any age (Cruz-Martin et al. 2012; Mataric 2004), accelerated by the development of robotics components and tools suitable for school-age children (Eguchi and Almeida 2013). Large offerings of robotics materials prompted their rapid dissemination across all K-12 grades, mainly in robotics extracurricular activities (Benitti 2012; Eguchi 2007b; Sklar and Eguchi 2004). Even much younger students than in previous years now participate in educational robotics activities. Pre-K to kindergarten students now use robotics tools, such as KIBO by KinderLab Robotics (http://kinderlabrobotics.com), Dash and Dot by Wonder Workshop (https://www.makewonder.com), and BeeBot by Terrapin Software (https://www.bee-bot.us).

One of the most accessible robotics kits suitable for elementary to middle school students, LEGO Mindstorms (http://www.mindstorms.lego.com/), has been in the market for almost two decades. LEGO Mindstorms EV3, which came out in the summer of 2012, has more sophisticated controller and sensors than its precedent, NXT, and costs about $400. Many third-party sensors students can add on to the Mindstorms controllers, making the kit more robust and attractive to users. A German-based company, Fischertechnik (http://www.fischertechnik.de/en/), manufactures the ROBO set with similar features to the LEGO Mindstorms kit. Robotis (http://www.en.robotis.com), a Korean-based robotic company that produces DARwIn-OP, a humanoid robot, also makes educational robotics kits for school-age children. Their OLLO is for younger students (elementary school), and BIOLOID is for older students (upper elementary, middle school to high school). Daisen (http://daisen-netstore.com), a Japanese electronics company, has several robotic kits including the e-Gadget series that can be expanded with more robust sensors and motors.

The cost of the robotics kits has been one of the factors in the past that prevented the implementation of robotics in classroom. However, the price of robotics components has become more affordable in recent years. Arduino (https://www.arduino.cc) and Raspberry Pi (https://www.raspberrypi.org) are easy to use controller boards/micro-computers for middle to high school students. Arduino UNO Rev 3, one of Arduino series, costs $25. Raspberry Pi Foundation introduced Raspberry Pi ZERO at the end of 2015 for $5. Its latest version, Raspberry Pi 3, is $35. The rapid development of affordable controller boards and microcomputers is making handmade robotics/robotics maker activities more accessible for school-aged children (Fig. 1.1). These are just a few examples out of a very long list of robotics kits and components that are available for educators and students.

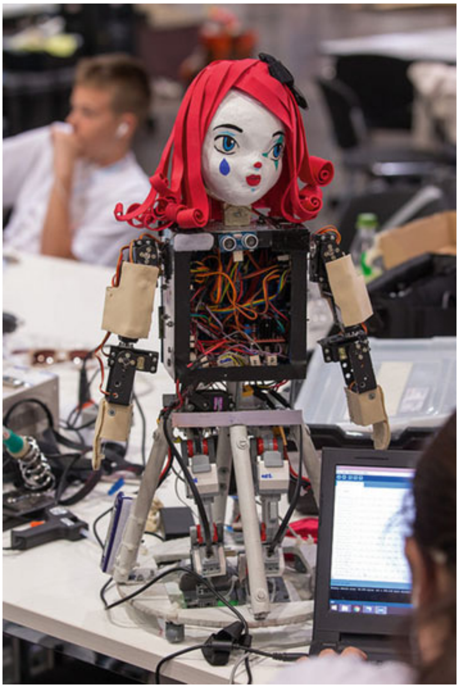

Fig. 1.1 Humanoid performance robot created with various controllers, motors, and sensors (© The RoboCup Federation. Used with permission)

1.2.1 Foundation of Robotics in Education

Educational robotics has its roots in constructionism theory. The theory of constructionism became reality through Logo, a computer programming language for children, which in turn became the foundation for the development of the *Programmable Brick* for the LEGO Mindstorms (Martin et al. 2000). Constructionism theory was developed by Saymour Papert, a student of Jean Piaget. Papert built on to Piaget's constructivist theory to develop his constructionist theory. Constructivism theory highlights that:

> Knowledge is not a commodity to be transmitted. Nor is it information to be delivered from one end, encoded, stored and reapplied at the other end. Instead, knowledge is experience, in the sense that it is actively constructed and reconstructed through direct interaction with the environment. (Ackermann 1996, p. 27)

Children continuously construct new knowledge through their active interaction with the world while they try to make sense of it. A simple or direct instruction of facts or knowledge does not *stick* with children since knowledge is not constructed by them. It is suggested that children's knowledge construction needs to be supported by the manipulation of artifacts—*object to think with.* Piaget explains that learning involves constructing new knowledge out of prior knowledge by manipulating artifacts and observing their behavior (Piaget 1929, 1954).

To enhance children's learning, it is crucial to provide them opportunities where they can "engage in hands-on explorations that fuel the constructive process" (Ackermann 2001, pp. 1–2). In addition, since children construct knowledge through their interactions with the world—their own experience contributes to their understanding of the world—they develop a good reason to hold onto their views and understanding. Piaget points out that children rarely let go of their view of the world even when adults tell them that their view is wrong. Instead of providing the right knowledge, we should encourage them to continue to explore, express, and exchange their views (Ackermann 2004). What educational robotics can provide is the electronic manipulative or tool to explore, think, and interact with for children.

While the focus of constructivism is epistemology—theory of knowledge—constructionism focuses on *learning*. Papert explains:

> Constructionism – the N word as opposed to the V word – shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the leaner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe. (Papert and Harel 1991)

The focus of constructivism is on the construction of knowledge in one's head. Whereas, constructionism focuses more on "the role of constructions in the world as a support for those in the head" (Bers 2008, p. 13), which is supported by physical or concrete construction *in the real world.* It is also highlighted that what differentiate constructionist learning from constructivism learning is its focus on "learning by constructing knowledge through the act of making something shareable" (Martinez and Stager 2013, p. 21). With constructionist learning, the *object to think with* is built or made, and what is physically constructed can be publicly shared—shown, discussed, examined, and admired by children. Children continuing this process of knowledge construction with physical artifacts will provide more learning experience that will be built upon, revising or reconstructing previously constructed knowledge (Papert 1993). Papert believes that the externalization of one's inner feelings and ideas contributes to the knowledge construction (Ackermann 2004). By expressing and sharing ideas in some tangible form, children shape and sharpen their ideas further. What educational robotics provides is a manipulative that a child can, not only think with, but also make her abstract idea and understanding of her world in her head *real*.

Educational robotics is a learning tool that allows or rather encourages children's exploration of their ideas using a technically and computationally enhanced tangible object. Papert emphasizes the importance of children's construction of knowledge through a tangible object by exploring their ideas. Eleanor Duckworth, another student of Piaget, echoes Papert's constructionist theory with her pedagogy of critical exploration. The critical exploration encourages children to actively and reflectively engage in a subject with their *wonderful ideas* which they developed through inquiry, and explore their ideas further through encountering complex materials and/or confusions, and trying out multiple possibilities, leading to the construction of new knowledge (Cavicchi et al. 2009). It denies direct teaching by adults or experts. Instead of providing answers or even implying that there is a *correct* answer, it emphasizes that teachers facilitate the personal process of learning. Duckworth states that the having of wonderful ideas is the essence of intellectual development (Duckworth 2006). Critical exploration considers learners as explores, like the ones in history, to face the areas of unknown, take risks, experience unexpected discoveries, through their journey of learning (Cavicchi et al. 2009). In addition, it considers a teacher as an explorer whose focus is on understanding of the individual child's experience of the exploration of his wonderful ideas and the process of the knowledge construction. Duckworth explains Piaget's basic idea of assimilation as a process:

> that a person takes any experience into her own previous understanding (schemes, structures); that we cannot assume that an experience whose meaning seems clear to us will have the same meaning to someone else. (Duckworth 2006, p. 158)

She emphasizes that a teacher must be determined to understand the meaning that any particular experience holds for her students (Duckworth 2005). Critical exploration suggests that children should be encouraged to think about, reflect on, and share their experience, while teachers should try to understand their thinking and understanding of the experience. Duckworth points out that critical exploration happens in two ways—"exploration of the subject matter by the child (the subject or the learner) and exploration of the child's thinking by adult (the researcher or the teacher)" (Duckworth 2005, p. 259).

Robots naturally spark children's interests and curiosity. As a learning tool, educational robotics excites children to explore their ideas through their inquiries and try out their hypotheses. It provides children with multiple ways to explore their wonderful ideas, find new discoveries, and build their knowledge through real-world experiences while using a technologically and computationally enhanced tool. The instantaneous feedback it provides, when children's ideas are tested on a robotic tool, can challenge and inspire them to explore their ideas further. In the following section, we will examine educational robotics and its role in the context of maker movement in education.

1.2.2 Educational Robotics in the Context of Maker Movement in Education

Making has been part of our culture since the beginning of human existence. Mark Hatch, the CEO of TechShop, explains:

> Making is fundamental to what it means to be human. We must make, create, and express ourselves to feel whole. There is something unique about making physical things. Things we make are like little pieces of us and seem to embody portions of our soul. (Hatch 2014, p. 11)

He argues that there is something about physical making that provides us with more personal fulfillment than virtual making. It is "its tangibility; you can touch it and sometimes smell and taste it" that give us satisfaction (p. 12).

The maker movement has gained increasing attention not only from the media and public, but also from the US Government. President Obama declared the first-ever White House Maker Faire to be hosted in June 2014, annually thereafter in June during the National Week of Making, and launched the Nation of Makers initiative (Kalil and Miller 2014). President Obama stated in 2015:

> Makers and builders and doers—of all ages and backgrounds—have pushed our country forward, developing creative solutions to important challenges and proving that ordinary Americans are capable of achieving the extraordinary when they have access to the resources they need. During National Week of Making, we celebrate the tinkerers and dreamers whose talent and drive have brought new ideas to life, and we recommit to cultivating the next generation of problem solvers. (Kalil and Miller 2014, para. 3)

Original Maker Faire was launched in Bay Area in 2005. Now, there are two flagship events—Maker Faire Bay Area and World Maker Faire New York—in addition to the National Maker Faire and mini Maker Faires organized nationally and worldwide. The maker movement has been created organically by makers, builders, and doers from around the world. The maker movement is becoming a driving force, in combination with creative makers and innovative technologies, including lower priced and accessible microcontrollers and personal 3D printers, to accelerate the innovation in manufacturing, engineering, industrial design, medicine, hardware and software technologies, and education (Maker Faire, n.a.). Although *making* refers to any form of physical making or building, the *making* in the maker movement refers to the ones enhanced with digital and technological tools, including robotics.

In Maker Movement Manifesto, Hatch explains that there are nine ideas that characterize the maker movement: make, share, give, learn, tool up (make tools of making including the digital and technological tools accessible), play, participate, support, and change (Hatch 2014). Maker movement is also considered to have its foundation in constructionism (Martinez and Stager 2013) since it provides opportunities for learning by making. Through making activities, people problem-solve and construct new knowledge.

Incorporating the maker movement into education has the potential to transform current teaching practices. Bringing maker movement discussions to education will provide us with a venue for rethinking the definition of learner, a learner and a learning environment (Halverson and Sheridan 2014), and how to help our students *learn*. Making activities can potentially provide a series of activities that can help improve children's construction and reconstruction of knowledge, and empower them to actively engage in their learning. Moreover, it has a potential to change our STEM learning through the process of technologically and digitally enhanced making. Making can be organized with a set of activities designed with a various set of learning goals, enabling teachers to provide a transdisciplinary approach of learning. Since it is rooted in constructionism, maker activities focusing on the learning process engage the intersection of STEM learning, involving computer science, design, art, and engineering (Halverson and Sheridan 2014). Moreover, digital making can provide students with opportunities to make *real* powerful and wonderful ideas and use expressive tools (Blikstien 2013). Similar to robotics technologies, digital fabrication technology has become more and more accessible in recent years, which made it possible for the maker movement to enter classrooms, which in turn has made “the intellectual activities enabled by the new technology become more valued and important in classroom” (Blikstien 2013, p. 2).

Robotics in education is a pioneer of the maker movement in education since it has been in practice long before the maker movement emerged. Educational robotics has enhanced existing learning activities with a powerful technologically empowered medium (Blikstien 2013). The programmable brick or controller, connected with motors and various sensors, adds “computational behaviors to familiar materials—craft, LEGOs, wheels” (pp. 6–7). It provides children a new way of expressing their wonderful and powerful ideas with physical artifacts with technologically fueled everyday materials. Through the process and experience children have working with technologically enhanced artifacts, children construct and reconstruct their knowledge. The emergency of digital fabrication tools accessible to non-experts including children has powered up the capacity and quality of work that children can engage in. The digital fabrication has added another form of expression and realization of children’s wonderful and powerful ideas to educational robotics (Figs. 1.2 and 1.3).

Advocates of the maker movement in education strongly suggest that it is important to make the maker learning opportunities accessible to all students, including females and underprivileged (Blikstien 2013; Halverson and Sheridan 2014; Martinez and Stager 2013) because it has a potential to attract students who are traditionally disengaged from technologically enhanced making activities. Lessons in educational robotics tend to start with building a robotics car. This is a great way of learning programming with motors and sensors. However, not everyone is attracted and/or interested in building a car (Rusk et al. 2008). This approach tends to attract tech-savvy boys. But girls may feel intimidated or shy

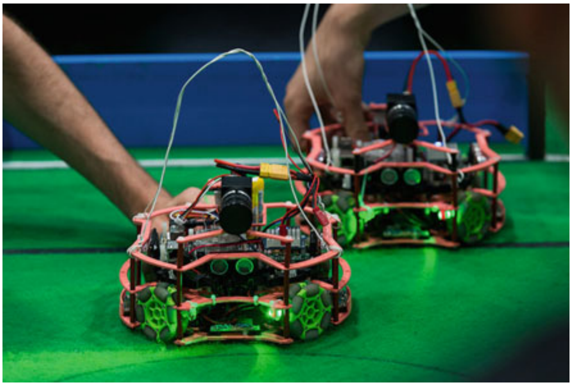

Fig. 1.2 Robotics creation (© The RoboCup Federation. Used with permission)

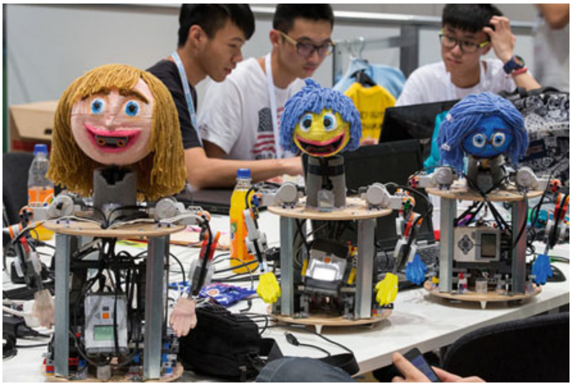

Fig. 1.3 Soccer robots and performance robots (© The RoboCup Federation. Used with permission)

away from robotics activities just because it is a car-based robotics. Technologically enhanced maker activities that use everyday materials such as craft materials, fabrics, and various construction materials can lower the bar for those who think robotics is only for tech-savvy boys to jump in.

To make technologically enhanced maker education accessible to *all* learners, it is important to make sure that the materials and tools are accessible to *all* children. Recent development of cutting-edge technological tools, both software and hardware, has provided opportunities for children to engage in various technologically enhanced making activities such as "advanced scientific exploration, create interactive textiles, build simulations and games, program videogames, design virtual robotics system, create sophisticated 3D worlds and games though programming, build new types of cybernetics creatures, explore environmental science and geographical information systems," (Blikstien 2013, p. 5) and build robotics inventions. Although such developments have contributed to the popularity of maker movement and digital fabrication, there still is a divide in the population of potential users between the *haves* and *have-nots*. It is crucial to bring maker education into all classrooms so that everyone has a chance to learn from maker activities. Halverson and Sheridan point out that the maker movement reaches out to both formal and informal education and can potentially bring equity in education (Halverson and Sheridan 2014). We need to democratize the making in education for *all*. Halverson and Sheridan (Halverson and Sheridan 2014) emphasize:

> the great promise of the maker movement in education is to democratize access to the discourses of power that accompany becoming a producer of artifacts, especially when those artifacts use twenty-first-century technologies. (p. 500)

Technologically enhanced making in education can provide students with powerful tool for empowerment by enabling them with skills and knowledge important for their future as well as for making changes in society. To successfully bring maker education, especially educational robotics, into formal educational settings, teachers and educators interested need to be informed what students are learning through maker activities and what works. Because of this reason, it is important to identify the student learning outcomes through robotics making activities and how to make it work in formal classrooms. In the following section, various skills and learning outcomes that making with robotics can bring to classroom will be discussed.

1.3 Learning with Educational Robotics—Skills and Student Learning

Educational robotics is an effective tool for facilitating students' STEM learning. Studies show that learning with robots provides opportunities for students to obtain both content knowledge in physics, biology, geography, mathematics, science, electronics, and mechanical engineering, and acquiring critical academic skills, such as writing, reading, research, creativity, collaboration, critical thinking, decision-making, problem-solving, and communication skills, and design and computational thinking skills (Dimitris et al. 2009; Atmatzidou and Demetriadis 2012; Benitti 2012; Carbonaro et al. 2004; Eguchi 2014, 2016; Elkind 2008; Kolberg and Orlev 2001; Miller et al. 2008; Nourbakhsh et al. 2004; Oppliger 2002; Sklar and Eguchi 2004; Sklar et al. 2002, 2003).

Making with robotics is effective because it creates a fun and engaging hands-on learning environment for students. Unlike a traditional classroom setting where students listen to teacher's instruction in a more disciplined and structured way, making with robotics necessitates that students engage in manipulating, assembling, and reassembling materials while going through the design learning process and problem-solving program errors through trial and error. The learning approaches that enhance learning through making with robotics are project-based, problem-based, learning by design, student-centered, and constructionist learning approaches where the focus is on the process of learning, rather than the final product.

When working on making with robotics activities, it is highly recommended that students work in small groups (Eguchi 2012, 2015; Eguchi and Uribe 2012). By working in groups, students obtain skills needed for effective collaboration. The students are excited and motivated to share their ideas, engage in collaborative decision-making, provide constructive criticism, and acquire communication skills (Eguchi 2007a, c; Miller et al. 2008). Group work provides students the opportunity to explore and solve real-world problems with their peers. Working on a team-based and project-based robotics project helps students with low esteem to improve their technology capacity, teamwork skills, and communication skills (Miller et al. 2008).

Moreover, students working in groups on robotics making projects learn subject knowledge and the skills necessary for them to successfully complete a project while exploring real-world problems and challenges. As students tackle real-world problems, develop solutions, and demonstrate their learning by physically testing their solutions with their robotics creation, they are actively engaged in a kind of learning that results in deeper subject knowledge acquisition (Edutopia, n.a.). Making with robotics makes possible a transdisciplinary learning environment where students can come across various concepts in STEM and other disciplines in a contextualizing fashion. With contextualized learning while making robotics, abstract concepts, such as friction and momentum, become visible and concrete for students to grasp as they try out their ideas with their robotics invention (Blikstien 2013) (Fig. 1.4).

There are new literacies, including mathematics, engineering, science (Blikstien 2013) as well as technological and innovation literacies, considered to be crucial for students to gain fluency in the twenty-first-century skills necessary for becoming effective citizens of the future. Learning these new literacies is supported by making with robotics. Technological and innovation literacies will be further introduced below, followed by various student learning outcomes supported by making with educational robotics activities.

1.3.1 Technological Literacy

As various technological tools have become more and more advanced and accessible to non-experts including children, the intellectual activities and learning through these activities have become more valued by society and becoming increasingly acknowledged by the education community (Blikstien 2013). At the same time, technological skills, such as typing, have become less valued and technological fluency has become more valued. For example, desired computer skills have become *computational fluency* or *literacy* (diSessa cited in Blikstien 2013), and a broader understanding of technological fluency has been expanded to include engineering knowledge and the process of engineering design (National Research Council cited in Blikstien 2013). Computational thinking is also an important part of technological literacy. Blikstien explains that technological

Fig. 1.4 Students collaborating on programming a soccer robot (© The RoboCup Federation. Used with permission)

literacy is a "general set of skills and intellectual dispositions for all citizens," while technological competence means "in-depth knowledge that professional engineers and scientists need to know to perform their work" (p. 3). Being fluent in technology is now desirable for everyone in society. Technologically enhanced making with robotics contributes to the development of technological fluency among students.

1.3.2 Innovation Literacy

Innovation literacy, another set of crucial skills that our children need to acquire, has been introduced and supported in several publications from various fields (i.e., Erdogan et al. 2013; Gelb and Caldicott 2007; Yamakami 2012). Erdogan et al. (2013) urge educators to consider innovation to be a necessary focus of student learning of twenty-first-century skills (Partnership for 21st Century Skills 2008), requiring the development of new learning environments that foster innovation. It is suggested that students learn innovation through contextualized transdisciplinary approaches since innovation requires a range of skills and knowledge for bringing innovative ideas into reality (Govindarajan cited in Gelb and Caldicott 2007).

Erdogan et al. (2013) describe innovation literacy as an interdisciplinary literacy involving reading, math, and science literacies, and social skills such as collaboration and originality. Innovation literacy is a set of skills that enables people to understand and use information, such as texts and graphs, and to make logically and scientifically supported decisions on how to develop innovative outcomes and/or solutions (Erdogan et al. 2013). OECD (2015) supports this view of innovation literacy. Innovation literacy includes both domain-specific skills and knowledge and broader competencies such as creativity, critical thinking, collaboration/teamwork, and communication skills. The Conference Board of Canada addresses the skills for innovation including creativity, problem-solving, continuous improvement (persistence) skills, risk assessment and risk-taking skills, and relationship—building and communication skills (The Conference Board of Canada, n.a.).

Making with robotics fosters various innovation literacy skills including subject-related literacy and academic skills such as engineering design including continuous improvement skills, computational thinking, creativity, problem-solving, communication and collaboration skills, and creativity, as explained in the previous sections.

1.3.3 Student Learning with Educational Robotics

Educational robotics is a learning tool that fosters various skills and knowledge essential for *every* student to take part in creating the future innovations that society needs. This skill set and knowledge will also enable students to turn their imagination and innovation into reality as well as find a new way of self-expression (Alimisis 2013). However, for school-age children, most making with robotics activities has been part of informal education (Alimisis 2013; Benitti 2012; Blikstien 2013; Eguchi 2007b; Sklar and Eguchi 2004). There are several factors preventing teachers from bringing robotics into their classroom. Robotics or engineering is not a core curriculum strand in most schools. There have been enthusiastic and creative teachers who have developed ideas for ways to connect learning through robotics making with traditional subject matter learning outcomes and standards. It is difficult to fit making with robotics into existing school curriculum which defines learning by subject areas, disconnected from each other. Although it is clear that contextualized transdisciplinary approaches create optimal learning opportunities for technological and innovative literacies as well as meaningful knowledge acquisition, current curriculum and classroom practice do not embrace the potential making with robotics can bring into classroom. When trying to bring making with robotics into formal education, it becomes crucial to address the student learning outcomes that align with curriculum standards.

There are several pioneer teachers who aligned and addressed making with robotics activities with student learning outcomes (i.e., Bratzel 2007, 2009, 2014; Kee 2011, 2013, 2015, 2016). Their efforts have helped some of the early adaptors to bring making with robotics into classroom. More efforts to connect making with robotics activities with various learning standards set by governmental agencies have been made by various robotics competitions. They have responded to educators' needs to align activities with student learning outcomes so that more teachers will be able to adopt robotics making in their curriculum. For example, VEX and VEX robotics Autodesk's one-semester robotics curriculum for 9–12 grades, which is aligned with four curriculum standards—ITEEA standards for Technological Literacy, Common Core State Standards for Mathematics and English, Next Generation Science Standards (VEX EDR, n.a.). FIRST Robotics Competition also provides its FIRST Robotics Competition Standard Alignment Map aligning their activities with four curriculum standards—Common Core State Standards, Next Generation Science Standards, Next Generation Science Standards, and 21st Century Learning Skills (FIRST Robotics Competition 2016). RoboCupJunior Australia, an Australian division of RoboCup Junior, prepared curriculum map to address Australian Curriculum—Technologies set by ACARA (Australian Curriculum, Assessment and Reporting Authority) (Moreton et al. 2014).

In the following section, we will focus on some of the US Government mandated standards and describe how making with robotics activities can support students as they work to achieve their learning goals.

1.3.3.1 Mathematics with Educational Robotics

Since educational robotics is a tool used to promote STEM learning through hands-on activities, mathematics is one of the subject areas addressed through the making with robotics activities. Common Core State Standards for Mathematics presents eight Mathematics Practical Standards that teachers of all levels should aim to develop in their students:

- MP1: Make sense of problems and persevere in solving them
- MP2: Reason abstractly and quantitatively
- MP3: Construct viable arguments and critique the reasoning of others
- MP4: Model with mathematics
- MP5: Use appropriate tools strategically
- MP6: Attend to precision
- MP7: Look for and make sense of structure
- MP8: Look for and express regularity in repeated reasoning

Common Core State Standards Initiative (2010).

Making with robotics activities addresses all eight Mathematics Practice Standards. While engaged in making with robotics activities, students develop skills to dissect, understand, and analyze problems that they encounter, then develop, test, and improve solutions using data collected and mathematical formulas (MP1). By solving a variety of problems that they encounter while working on robotics making —designing, building, and programming their robotics creations, students develop the skill to think, understand, and solve problems abstractly and quantitatively (MP2). Since making with robotics uses the project-based approach whereby a small group of students work together on their robotics creation, students will develop communication and collaboration skills including constructing viable arguments and critiquing the reasoning of others in constructive ways (MP3). In the process of making, students create different solutions for their construction models and codes using various mathematical tools (i.e., graphs, charts, and tables) for decision-making to improve their robotics creation (MP4). Students engaged in making with robotics activities learn to select the appropriate tool needed to solve problems that they encounter. For example, students examine the problem that they have to solve, evaluate possible solutions, and select the correct sensor for the best solution that they choose (MP5). Since students work on their robotics creation as a group, good communication is a key to success. Students develop skills to communicate precisely to each other. Through their robotics work, students learn to use academic language to precisely communicate their ideas with details (MP6). While building and programming their robotics creations, students learn to recognize and use structures and patterns (MP7). Students engaged on robotics making activities go through a reiterated process as they solve the problems and challenges that they face. Throughout the process, they learn to look for and express regularity in repeated reasoning (MP8). Through the robotics making activities, students encounter a variety of occasions when they apply mathematical concepts, such as the concepts of number and operations, measurement and data, geometry, ratios and proportional relationships, expressions, and equations. Making with robotics not only provides students opportunities to learn mathematical concepts but also applies their learning to a real-world situation.

1.3.3.2 English Language Arts with Educational Robotics

Common Core State Standards for English Language Arts (ELA) emphasize the importance of the College and Career Readiness Anchor (CCRA) Standards as they form the backbone of the ELA/literacy standards. Student learning through making with robotics activities addresses some of the CCRA standards, which are listed below:

- CCRA/R1: Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text
- CCRA/R4: Interpret words and phrases as they are used in a text, including determining technical, connotative, and figurative meanings, and analyze how specific word choices shape meaning or tone
- CCRA/R7: Integrate and evaluate content presented in diverse formats and media, including visually and quantitatively, as well as in words
- CCRA/W1: Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence
- CCRA/W2: Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content
- CCRA/W4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience
- CCRA/W5: Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach
- CCRA/W6: Using technology, including the Internet, to produce and publish writing and to interact and collaborate with others
- CCRA/W7: Conduct short as well as more sustained research projects based on focused questions, demonstrating understanding of the subject under investigation
- CCRA/W8: Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism
- CCRA/W9: Draw evidence from literary or informational texts to support analysis, reflection, and research
- CCRA/W10: Write routinely over extended time frames (time for research, reflection, and revision) and shorter time frames (a single sitting or a day or two) for a range of tasks, purposes, and audiences

- CCRA/SL1: Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively
- CCRA/SL2: Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally
- CCRA/SL3: Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric
- CCRA/SL4: Present information, findings, and supporting evidence such that listeners can follow the line of reasoning, and the organization, development, and style are appropriate to task, purpose, and audience
- CCRA/SL5: Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations
- CCRA/SL6: Adapt speech to a variety of contexts and communicative tasks, demonstrating command of formal English when indicated or appropriate
- CCRA/L1: Demonstrate command of the conventions of Standard English grammar and usage when writing or speaking
- CCRA/L2: Demonstrate command of the conventions of Standard English capitalization, punctuation, and spelling when writing
- CCRA/L4: Determine or clarify the meaning of unknown and multiple-meaning words and phrases by using context clues, analyzing meaningful word parts, and consulting general and specialized reference materials, as appropriate
- CCRA/L5: Demonstrate understanding of figurative language, word relationships, and nuances in word meanings
- CCRA/L6: Acquire and use accurately a range of general academic and domain-specific words and phrases sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when encountering an unknown term important to comprehension or expression

Making with robotics activities addresses the Common Core Standards for ELA—Science and Technical Subjects for grade level. Although educational robotics is a tool to promote STEM learning, the project-based approach requires students to engage in various reading and writing tasks. When students work on a project of their choice, students conduct research on the topic of their project, read and analyze materials, come up with a solution, and write it up. They use various media including digital media from the Internet for their research. Since it is a collaborative group work, students learn to communicate effectively to each other. They learn to evaluate, analyze, and understand each other's point of view, reasoning, and use of evidence. Throughout the process of making, students are required to keep reflective journals or log books, in which they record their learning journey including their problem-solving strategies, data that they collected and their analysis of the data, summary of their group discussion, problems that they faced and how they plan to solve it, mistakes they made and how to avoid it next time, and their feelings. In addition, students work on presenting their robotics creation to the public—classmates, teachers, families, and school and beyond. To prepare for the presentations, students work on evaluating and summarizing their making process using various writings that they have done through the process, synthesizing their own writing, various sources, and data used during the making process, into the final form of presentation. Students use any tools to create their presentation including digital media tools, visual display, and/or craft materials.

1.3.3.3 Engineering Design (Engineering Literacy) with Educational Robotics

The Next Generation Science Standards (NGSS) emphasizes engineering design practices as a skill set that is an integral part of science education, which all citizens should learn (Next Generation Science Standard 2013). NGSS places engineering design as the same level as scientific inquiry when teaching science disciplines in K-12 education. It considers engineering and science as instrumental in creating solutions to the major challenges we face. The key to the engineering design is the iterative cycle of the design process when used to solve problems. There are three core components in engineering design set by NGSS:

(a) *Defining and delimiting engineering problems* involves stating the problem to be solved as clearly as possible in terms of criteria for success, and constrains or limits.
(b) *Designing solutions to engineering problems* begins with generating a number of different possible solutions, then evaluating potential solutions to see which ones best meet the criteria and constraints of the problem.
(c) *Optimizing the design solution* involves a process in which solutions are systematically tested and refined and the final design is improved by trading off less important features for those that are more important (p. 2).

The three components do not always follow in order. Since the engineering design process is an iterative cycle, a problem can be redefined or new solutions can be generated to replace an idea that does not work at any stage of the cycle.

Engineering design process is one of the important skills that students obtain through the learning by design with robotics making. Students use trial and error strategy during the engineering design process to refine and recreate their solutions to the problems that they face. Students could redesign, reconstruct, and reprogram their robotics creations as many times as needed to come up with a satisfied final design and solution.

1.3.3.4 Computational Thinking with Educational Robotics

Computational thinking has gained great attention in the field of education in recent years, especially after the *Hour of Code* was launched in December 2013 in the USA and England implemented its computing education in 2014. In a seminal article on computational thinking by Jeannette Wing in 2006, Wing predicted that computational thinking would be a fundamental skill used by everyone in the world by the middle of twenty-first century (Wing 2006). Computational thinking has its focuses on the process of abstraction. Wing's view of computational thinking is as follows:

> [i]nformally, computational thinking describes the mental activity in formulating a problem to admit a computational solution. The solution can be carried out by a human or machine, or more generally, by combinations of humans and machines. (Wing 2010, para. 1)

Wing's term of computational thinking is broadly described as the design and analysis of problems and their solutions.

The International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) share the common understanding that computational thinking should be integral part of education for school-age children. SITE and CSTA highlight that "computational thinkers are the creators, designers, and developers of the technology tools and systems that are now contributing to major advances in almost every field of human understanding and endeavor" (Computer Science Teachers Association and International Society for Technology in Education 2011, p. 7). There is a greater pressure in society to educate more computational thinkers than ever before. Although computational thinking is not one of the standards required by government except for a couple of countries, like England, it is important to consider including it as part of student learning through making with robotics. ISTE and CSTA collaborated to develop the following operational definition of computational thinking for primary and secondary education:

Computational thinking (CT) is a problem-solving process that includes (but is not limited to) the following characteristics:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them
- Logically organizing and analyzing data
- Representing data through abstractions such as models and simulations
- Automating solutions through algorithmic thinking (a series of ordered steps)
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem-solving process to a wide variety of problems

These skills are supported and enhanced by a number of dispositions or attitudes that are essential dimensions of CT. These dispositions or attitudes include the following:

- Confidence in dealing with complexity
- Persistence in working with difficult problems
- Tolerance for ambiguity
- The ability to deal with open-ended problems

- The ability to communicate and work with others to achieve a common goal or solution (Computer Science Teachers Association and International Society for Technology in Education 2011, p. 13)

Since computing is part of making with robotics, it provides the right environment in which students obtain computational thinking skills. For example, students demonstrate their abstraction and algorithmic thinking through the algorithm they create since an algorithm is an abstraction of a process, broken down in ordered steps. Such steps are created with sensor inputs, carry out the series of ordered steps, and produce outputs to accomplish the targeted goal. Students who can create effective algorithms for their problems develop the skill to formulate the steps in a way to effectively use the robotic tool. This requires the skills to identify, analyze, and implement the solution with the most effective and efficient steps. Experienced programmers can create effective but simple solutions. Those abilities need to be supported by the right dispositions, including persistence, tolerance, an ability to communicate and work effectively with others, and an ability to deal with open-ended problems. Such dispositions can be obtained from their participation in making with robotics activities and the learning process. Through maker activities with robotics, students gain the confidence needed to deal with complexity. Quite often, students encounter complex problems while making with robotics, which help students to develop the confidence to persist.

1.4 Conclusion

The speed change introduced into society, especially with technological domains, has been accelerating since the birth of the Internet. This means that a different set of skills, such as creativity and innovation, are required for the workforce to effectively continue to invent and innovate. The problem that we are facing is that our public education has not kept pace with the work force needs of our rapidly changing society. A new wave of innovation in education, such as educational robotics, maker movement, and digital fabrication, has the potential to bring about the necessary changes in formal education. Although educational robotics, maker movement, and digital fabrication are not new in its use by informal education in recent years, it is important to bring these approaches and tools into formal educational classroom settings so that such learning experiences are accessible to *all* students, not only those who are privileged or boys.

One way of lowering the barrier for teachers and educators is connecting such learning activities with existing learning standards. However, simply bringing making with robotics activities into classrooms does not automatically bring desirable learning outcomes. Since making with robotics has its base in constructionist learning, teachers have to create a constructionist learning environment where the focus is on learners' exploration of their ideas using technological tools. In other words, students become the agent to *program* the computer and robots rather than just a consumer of technology (Blikstien 2013). By doing so, students acquire “a sense of mastery over a piece of the most modern and powerful technology” (Papert 1993, p. 5). The technology provides a powerful tool for students to build “their own intellectual structures” (Papert 1993, p. 7). With learner-centered approaches, teachers have to refrain from traditional ways of *teaching* and become facilitators of students’ learning. It is also necessary for students to change from *passive* learners to *active* learners. Since the core activities are *making*, the students’ learning should naturally shift from learning by *listening* to learning by *doing*.

Teacher as a facilitator of students’ learning requires various skills in teachers. One of the skills is the ability to scaffold students’ learning by asking the right questions to bring students’ own inquiries out. With making with robotics, there is generally no one right way to solve a challenge. Not having one *right* answer but multiple ways of tackling a problem is an experience with which many teachers are not familiar. Not having one correct answer tends to make both teachers and students uncomfortable. However, many times, students learn the most from discussions and teacher’s penetrating questions (Rogers and Portsmore 2004). It is crucial for teachers to provide learning opportunities that are open for students’ ideas and let students create and design technological making projects. However, young students may get stuck or lost in their own ideas (Bers 2008). It is important that teachers scaffold the process of making with guiding and provoking questions. Hmelo-Silver, Duncan, and Chinn suggest that scaffolding can provide students opportunities to “engage in complex tasks that would otherwise be beyond their current abilities” (Han and Bhattacharya 2001; Hmelo-Silver et al. 2007, p. 100). Scaffolding, includes providing coaching, modeling, guiding, task structuring, pushes students to think deeply, and supports them to become effective information seekers and problem-solvers, as well as expert at finding help and necessary resources for themselves (Bers 2008; Hmelo-Silver et al. 2007).

Making with robotics activities needs to have broader perspectives in order to be inclusive and responds to various student interests. If teachers use conventional educational robotics approaches such as using robotics car, they can reach only the children talented in science, math, and technology, and fewer girls than boys. Studies have shown that the way educational robotics is introduced into the educational settings is often unnecessarily narrow in its focus (Rusk et al. 2008). Rusk, Resnick, Berg, and Pezalla-Granlund suggest robotics making activities be designed to use a theme-based approach rather than challenge-focused approach, a transdisciplinary approach in order to connect various subject areas, especially art and engineering—STREAM (STEM with Robotics and Arts), or a storytelling/narrative approach as a new way of self-expression. An end of unit exhibition provides an opportunity for students to share their robotic creations (Rusk et al. 2008). By widening unit outcomes, teachers can engage and encourage a wider diversity of student participation. Creating inclusive learning environments using making with robotics activities will attract students who may not self-identify as strong in mathematics and/or science, as well as girls who think robotics is only for boys.

By bringing learning through making with robotics into every classroom, educators have the potential to provide *all* students with the opportunity to learn the skills and knowledge that they need to become effective members of the workforce and future innovators and creators. Making with robotics provides transdisciplinary learning environments in which students can encounter a range of STEM concepts as well as concepts from other subject areas including English, arts, and history in contextualized fashion. It also fosters the learning of various new literacies including technological and innovation literacies. Making with robotics can provide non-traditional learning environment that sparks students' interests and imagination. It can inspire *all* students' curiosity, enthusiasm for learning, and build self-confidence (Rogers and Portsmore 2004). Making with robotics has the possibility to become a game-changer in education, turning traditional education into a new form of *innovative* learning experience for all students.

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