What is Technology (T) and What does it Hold for STEM Education? Definitions, Issues, and Tools

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The Conception of Technology

Scholars and politicians in the field of education acknowledge the potential and promise of technology for learning and teaching. It has recently become the most important and urgent agenda in most of the countries' educational policies and curriculum developments. In fact, it is often considered as a quick solution to our educational challenges. We, as educators, are clear that technology opens new horizons for students, teachers and educational settings. Nevertheless, decades of research and personal experiences have shown that technology integration into schools is a complex and multi–dimensional process. Effective and successful technology use in the educational settings requires us to know and work on several factors and make them to be consonant with each other. The first perhaps the most important one is to have a comprehensive conception of technology because it directly contributes to the development of teachers' belief systems. While some factors have been disappearing with the increased access to technology and improved teachers' relevant competencies, teachers' beliefs persist to be a key factor as they are robust and resistance to change (Ertmer, 2005).

Unless we have a clear understanding of what technology actually means, we will most probably miss the point of pedagogical value and transformative role of technology in education and thus fail to achieve a true and beneficial integration. The result would likely be a technically–oriented and superficial implementation and ultimately an unprofitable investment. Being an overly optimistic or pessimistic about technology will also lead to the adoption of it either as a magic wand to fix educational problems or a threat to disrupt educational activities. A recent study in Turkey shows that pre–service teachers have a restricted conception of technology mostly focusing on artifacts and technical characteristics, and calls for a teacher education culture and curriculum that emphasize a broader and balanced view of technology (Koc, 2013). It is well–known that teachers' pre–existing beliefs and views act as a filter for the acceptance of new knowledge and tools and significantly shape their usage in general teaching practices (Pajares, 1992; Richardson, 1996).

This is also true for teachers' specific technology integration practices (Ertmer & Ottenbreit–Leftwich, 2010). Therefore, providing teachers with a well–rounded conceptual base about the nature of technology is a first vital step because it influences how they adopt and apply technology in their pedagogical acts (Koc, 2013).

The word of "technology" is known to be derived from Greek words "techne" referring to manufacturing (e.g., techniques of tablets, 3D printers) and the arts (e.g., techniques of teaching, drawing) and "logic/logos" meaning word, thought, speech or principle. From this linguistic aspect, technology is defined as an endeavor or study on making a craft or mastery of an art. This is why it is prevalently known as the application of scientific knowledge and skills to our practical problems. It is not a distinct discipline itself but rather a practice of any discipline like constructive technology, educational technology, medical technology, and so on. This definition obviously involves both a tool/end and its process of production and consumption. However, our everyday understanding of technology is often bound to its instrumentalist perspectives. When talking about the use of technology in education, we usually refer to only technological tools and its features (e.g., tablets, robots, interactive boards). As we explain in the following sections, such a conception represents a restricted view of technology and its implementation. Strict subscription to this school of thought can hinder to think about and plan technology integration in detail and hence may lead to be unsuccessful or ineffective in this affair.

A closer look from the philosophical perspective reveals diverse approaches to understanding the meaning of technology and its consequences on human life. In his book, Critical Theory of Technology, Feenberg (1991) distinguishes various theories in terms of their prepositions about the nature of technology on two continuums. One indicates the extent of autonomy; technology is either autonomous or human–controllable. The other illustrates the degree of value–ladenness; technology is either neutral or value–laden. Based on the intersection of these continuums, he identifies four main types of theories of technology: instrumental, deterministic, substantive, and critical view.

The "instrumentalist perspective", often optimistic about technology, view technology as morally neutral and human–controllable. Technology is usually identified as anything mechanical or electrical tool that can be used for achieving a pre–determined end, either bad or good, and can be humanly controlled. According to Feenberg (1991), it is subservient to values established socio–cultural and political spheres. While technical aspects including appearance, utility, popularity, and aesthetic features are usually highlighted, factors such as the historical context and social shaping of a technology, human experiences and activities surrounding the technology are not considered. As we mentioned earlier, it is the most widely accepted view of technology not only in education sector but also in all other areas of the society. Technology is viewed as a rational and universally applicable entity so it is free of cultural, political, and ideological values. Due to this decontextualization, technology is expected to function in the same way and serve the same purposes anywhere it is used regardless of where it is originally produced. Moreover, technology itself and its consequences on human lives or society in general are considered to be independent of each other. Individuals are responsible for proper or improper usage of the technology, not the technology itself. The neutrality assumption has been criticized due to its ignorance of possible political, social, and human influences on the process of technology development and implementation. For example, Pacey (1992) gives an example of snowmobile use in Canada and North America. He points out that snowmobile is always regarded as the same machine whether it is used for earning a basic living, recreation, or environmentally destructive sport. He further argues that when a technology fails or has unintended or negative results, according to the instrumentalist view, the technology itself should not be blamed but rather "its misuse by politicians, the military, big business and other" is the causal factor (p. 2).

"Technological determinism" is another prevailing way of thinking about technology and its function in the society. It argues for a one–directional relationship between technology and society in which the former develops apart from the latter and autonomously causes social change and directly impacts people (MacKenzie, 1998). It is very popular and highly adopted among the politicians and development institutions. They usually advocate technology as the cause of success or failure (e.g., learning problems, low achievement, and high efficiency). According to Feenberg (1991), technological determinism is based on the following two arguments:

1. The pattern of technical progress is fixed, moving along one and the same track in all societies. Although political, cultural, and other factors may influence the pace of change, they cannot alter the general line of development, which reflects the autonomous logic of discovery.
2. Social organization must adapt to technical progress at each stage of development according to the "imperative" of technology. This adaptation executes an underlying technical necessity (pp. 122–123).

Technology impacts everyone's life because more aspects of life in technological/ networked society are becoming mediated by the use of digital technologies. According to the technological determinist position, people generally do not have any influence over the direction of technological evolution and thus technology is an autonomous and revolutionary force characterized by two oppositional perspectives: utopian or dystopian. The utopian position constructs technology as a positive and uplifting force that addresses and ultimately eradicates much of human misery while increasing opportunities for social progress. It is the common sense perspective and is associated with an enlightenment scientific–based social narrative of progress. This perspective, for instance, suggests that information and communication technologies liberate societies through facilitating an increase in social and economic capital and democratic participation (Katz & Rice, 2002). A dystopian perspective, on the contrary, believes that technology is an inherently dehumanizing force that will lead to social and physical destruction of society. For example, Postman (1992) and Slouka (1995) argue that the main problem of technology is its increasing isolation of people within virtualized simulations of reality that cuts them off from the real natural world. Based on the notion of social constructivism, some scholars propose “social construction of technology approach” to dispute technological determinism (MacKenzie & Wajcman, 1999). The relationship between technology and society is claimed as the opposite of what is claimed in technological determinism: the latter shapes the development of the former. The proponents of this approach assert that technology is not immutable but is a dependent variable characterized by human engineers, market forces, consumer needs and demands, and all other social factors.

Unlike the instrumental approach, the “substantive theory of technology” treats technology not a neutral tool, but rather embedded with values and ideologies in order to “constitute a new type of cultural system that restructures the entire social world as an object of control” (Feenberg, 1991, p. 7). It also holds that technology is autonomous and “tends to function independently of the system it serves…in the manner of a robot that no longer obeys its master” (Postman, 1992, p. 142). From this point of view, it resembles the theory of technological determinism. The substantive theory asserts an underlying essence or autonomous force to technology that overrides all traditional and competing values. Social changes are believed to be influenced if not determined by technological innovations since technology is fundamentally defined more than a machine and can very well embody or constitute social and cultural dimensions that may involve profound alterations for societies. Therefore, technical progress can overcome human willpower and have a substantive impact on individual ad community which, according to Ellul (1990), can be in three kinds: the desired, the foreseen, and the unforeseen.

The substantive view is best known through the work of Ellul and Heidegger. Ellul’s (1964) book, *The Technological Society*, describes the gradual process by which technology is subverting and absorbing the traditional values of human society. Ellul specifically defines technology as “la technique” which he defines as “the totality of methods rationally arrived at and having absolute efficiency (for a given stage of development) in every field of human activity” (1964, p. xxv). He argues that the technical erodes the bonds of traditional social groups, communities, and human relationships without building new social structures in their place. Technique itself becomes the central focus of society as the human being is progressively transformed into the object of technique (Ellul, 1964). Heidegger (1977) approaches the essence of technology from an ontological perspective and associates it with his concept of “Dasein”, the essence of “Being”. For Heidegger, the essence of technology relates to how technology as a phenomenon is “coming to presence” or evolving via human actions. He introduces the concept of “enframing” as the essence of technology, which is a way of understanding being, or as he phrases, a way of revealing. He argues that “techne” is a kind of knowing and its essence lies not in manufacturing goods or using tools, but in revealing. The danger of technology, for Heidegger, is that the machines begin to alter human existence and shape human destiny, and therefore, prevent individuals from understanding their own being and natural objective identity. Complementing this notion, Feenberg (1991) claims:

> The issue is not that machines have “taken over”, but that in choosing to use them we make many unwitting cultural choices. Technology is not simply a means but has become an environment and a way of life: this is its “substantive” impact. (p. 8)

Criticizing and synthesizing instrumental and substantive views of technology, Feenberg (1991) proposes a “critical view of technology”, a dialectical approach, in order to reveal the complex relationships between modern society and technology. He (1991) rejects the “autonomous” premise of substantive argument and the “neutrality” notion of instrumental view. However, he adopts the value–ladenness premise of the former and reflects the latter’s argument that technology is under human control. According to Feenberg (1991), critical theory uncovers the values and assumptions influencing the design and construction of a technological tool. Being a valuable alternative discourse, it challenges the idea of being trapped into the dilemma of either accepting whatever technology is available or assuming a useless anti–technological position. The critical perspective considers a given technology in terms of not only its design phase but also its diffusion and use contexts. Thus, technology and society are seen to be dialectically intertwined.

Having been influenced by the work of Marx and Marcuse, Feenberg (1991) refers to the concept of “technological ambivalence” by examining Marx’s three critiques of technology to uncover the connection between capitalism and technology: (a) “product critique” which focuses on the purposes for which technology is designed, (b) “process critique” regarding how technology is employed to accomplish those purposes, and (c) “design critique” related to the ways in which technical principles are applied in the design of technology (pp. 31–32).

According to his critical analysis:

> Technology is not a thing in the ordinary sense of the term, but an "ambivalent" process of development suspended between different possibilities. This "ambivalence" of technology is distinguished from neutrality by the role it attributes to social values in the design, and not merely the use, of technical systems. On this view, technology is not a destiny but a scene of struggle. (p. 14)

The term "technological ambivalence" emphasizes the various kinds of possibilities and choices available to society regarding technology adoption. Moreover, the decision process which reviews these potentialities is social, not technological, and involves complex social, cultural and hegemonic power relations. Feenberg, referring to work of Marcuse and Foucault, proposes that such decisions are mediated by a "technical code" that represents certain values and interests of the dominant social groups, and that ideas at the design phase of technology reflect "capitalist rationalization" of the modern society. For this reason, "technology is a dependent variable in the social system, shaped to a purpose by the dominant class, and subject to reshaping new purposes under a new hegemony" (p. 35). Different values and choices of designing certain technologies may frame different possible ways of life. This can be achieved, in Feenberg's sense, through democratic means including greater participation in the design and development of technology.

Our intention for reviewing these views is to illustrate that there is not a unique philosophy of technology and its implications for a society. Besides, technology itself is constantly changing and developing from day to day. Therefore, understanding technology and its consequences on a society requires the engagement of various theories and practices in other disciplines as well. The aforementioned views suggest that the relationship of technology with any social institutions remains complicated. This also applies to education. They indicate how technology integration into education is a complex and uneasy issue from not only practical but also philosophical aspects. Each theory has both strengths and weaknesses. Educators need to know all philosophical approaches to technology and its implications for education so that they can develop a broader and balanced personal standpoint of technology integration. Combination of diverse perspectives might also contribute to the development of analytical frameworks for determining and implementing optimal educational policies.

The Role of Technology in STEM Education

From the above review of various thoughts of technology, we now realize that the term "technology" should refer to not only technical tools but also human activities including multifaceted organizations and value systems. This realization involves more comprehensive and precise conception of technology. To make such a general and systematic meaning of technology, Pacey (1992) proposes the concept of “technology–practice”, which is “the application of scientific and other knowledge to practical tasks by ordered systems that involve people and organizations, living things and machines” (p. 6). He categorize technology–practice into three general aspects: (a) organizational aspect that consists of activities of the designers, engineers, factories, users, and consumers, (b) technical aspect that refers to machines, techniques as well as the knowledge and skills to operate them, and (c) cultural aspect that means values, ethical codes, awareness, and creative activity, which influence the designers and inventors of technology. He considers the “technical aspect” as a restricted meaning of technology, and defines the general meaning by including all three aspects together which constitutes the concept of technology–practice. We believe that Pacey’s (1992) conceptualization is very appropriate to explain technology integration in educational settings. When we talk about the use of technology in teaching or learning, which is a special case of technology–practice, we need to consider all technical, organizational and cultural aspects.

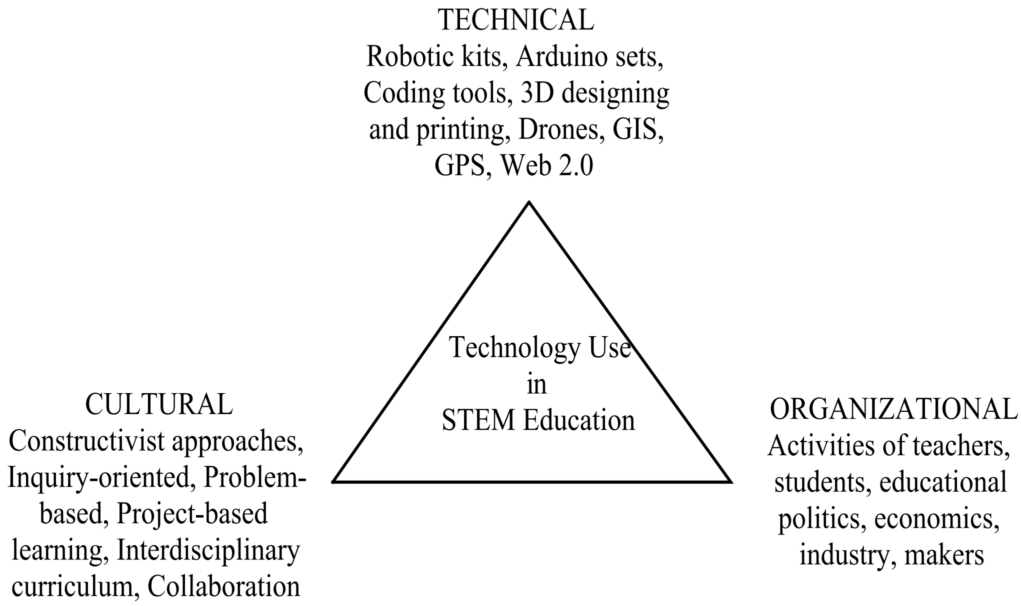

Figure 1. A Framework for Technology Use in STEM Education

Using Pacey’s (1992) general conceptualization of technology–practice as a theoretical base, we propose a three–legged framework for technology use in STEM education (Figure 1). Our framework highlights that effective technology integration to support STEM attitudes, knowledge and skills requires the consideration and coordination of technical, cultural and organizational factors. As suggested by the aforementioned philosophical perspectives of technology, it considers not only technological devices but also relevant human activities surrounding them and the values influencing their production and consumption. Hence, it acknowledges technology use in STEM education as not value–free and neutral.

All three factors need to work together to comprise technology implementation into STEM approach. Just like a tripod lost the stability when any of its legs is broken down, technology integration may also fail when any of these is neglected or has some deficiencies or impairments.

The first aspect “technical context” refers to hardware and software tools that support the development and implementation of STEM–based learning activities. Examples of currently available ones include but not limited to robotic kits, arduino sets, coding programs, 3D printers, cloud computing, geographic information systems (GIS), global positioning systems (GPS), Web 2.0 tools. In the proceeding section of this chapter, we introduce some of these tools in detail and discuss their educational potentials. Technological tools to be used for STEM activities are expected to include manipulative options through which students can design, develop and program interactive artifacts (Ortiz, Bos, & Smith, 2015). In this way, they are able to observe the consequences of the changes they make on some factors on the status of others (e.g., casual relationships between independent and dependent variables). Such tools also promote computational thinking, systematic reasoning, creativity and problem–solving, which are among the skills that we must teach our children in the 21st century. One another benefits of these technologies is to engage students in hands–on experimentation through which they can collect and analyze contextual data and translate abstract mathematics and science concepts into concrete real–world applications (Nugent, Barker, Grandgenett & Adamchuk, 2010).

Schools needs to plan a special budget for integrating STEM learning activities as accessing related technologies is relatively expensive. This may not be easily achieved by those public schools especially in the developing countries where such tools are usually imported. Technical infrastructure is an essential determinant of technology use in STEM education. Istanbul Aydın University organized the First STEM Education Workshop in 2015 in order to identify deficiencies and gaps in the Turkish K–12 and higher educational system germane to STEM and then suggest curricular and practical solutions to overcome these shortcomings. This was a comprehensive assessment of STEM implementation in Turkey with the participation of academicians, experts, administrators and teachers. The workshop report concluded that the most crucial shortcomings were related to such issues as interdisciplinary cooperation, teacher competency, technical infrastructure, student guidance, measurement and evaluation, curriculum integration and STEM courses (Akgündüz, Ertepınar, Ger, Sayı & Türk, 2015). Technical infrastructure here involves labs, ateliers and related technological equipments. It is the core element and thus any problem in its presence and function is automatically reflected in other issues, especially STEM practices in the schools.

It is again important to acknowledge that, as our framework emphasizes, equipping schools with STEM–related technical tools is necessary but it alone is not adequate to ensure successful implementation. Organizational and cultural contexts should be considered as well. Unfortunately, technical aspects usually come to the forefront while others are less considered, if not completely ignored, in the process of technology integration. This gives the impression that capitalistic, populist and instrumentalist thoughts and movements seem to be more dominant than social, humanistic and pedagogical ones. Çepni (2017) argues that the presentation and perception of advertising and marketing readily–prepared/assembled tools (e.g., robotics, electronic circuits, coding) that are not associated with math and science learning objectives is one of the biggest mistake in STEM adoption in Turkey. He warns that such an approach may lead to the inflation of performing activities opposite to STEM philosophy (i.e., consumption–oriented rather than production–oriented) and eventually emergence of a STEM–tools garbage. Therefore, technical context need to be grounded on a well–established philosophical and scientific base.

The second aspect "cultural context" involves educational philosophies, policies, theoretical beliefs and values related to teaching and learning, and curriculum objectives. Such issues have direct influence on the determination of the role of technology in the schools. Technology integration has been defined by the activities and indicators of how teachers and students use technology. Prior studies reveal that in many cases, it has meant different things to different people, and the term appears to have evolved over the years. Therefore, how technology should be utilized in the schools has been an ongoing discussion among the educators. Generally speaking, three conditions stand out when thinking about the possible ways of using it for educational purposes: learning about technology, learning from technology, and learning with technology.

Learning about technology represents the awareness and literacy of technological tools. In this way of using technology, the aim of education is often the technology itself and to teach student how to operate it. This is usually observed when a specific technology is first introduced and diffused to a society and thus can be described as the beginning stage of technology integration. Learning from technology represents behaviorist perspectives for learning. Technology is usually programmed either to deliver education content or to offer drill–and–practice activities. The interaction between technology and a learner is one–directional from technology to the learner. It can be described as the intermediate stage of technology integration. Finally, learning with technology represents constructivist approaches to learning in which learners are decision makers and active participants of knowledge construction with the help of technological tools to support learning goals. It can be identified as the advanced stage of technology instruction. A critical review of literature on effective technology integration reveals that learning from technology is not the most effective way to improve learning in spite of helping learners to gain lower level sub–skills easily and perform them automatically whereas learning with technology is well–suited for meaningful learning by encouraging learners to actively process and organize information (Koc, 2005).

STEM education is mainly based on the constructivist epistemology because it advocates critical thinking, creativity, problem–solving, designing and productivity, entrepreneurship, authentic learning experiences and performance–based assessments (Çepni, 2017), which all are also premises of constructivist learning. Constructivists believe that humans have the ability to construct knowledge through an active process of discovery and problem solving. They regard technology as assistant for knowledge construction. In constructivist use of technology, fundamental tasks of learning such as planning, decision–making, and self–regulation are the responsibility of the learner, not the technology. Technical tools which support constructivist learning are often defined as cognitive tools, whose core attribute is not in the information that they carry, but the forms of learner activity and engagement that they support and encourage. In a similar vein, Jonassen (2000) developed the ideas of "mindtools": computer based tools that have been "adapted or developed to function as intellectual partners with the learner in order to engage and facilitate critical thinking and higher–order learning" (p. 11). According to him, the role of a mindtool is to extend the learner's cognitive functioning during the learning process, and to engage the learner in operations while constructing knowledge that they would not have been able to accomplish otherwise. "Mindtools enable learners to become critical thinkers. When using cognitive tools, learners engage in knowledge construction rather than knowledge reproduction" (p. 18). Therefore, it is reasonable to say that those technologies with cognitive tool characteristics are highly suitable for STEM education. Technology can be very functional to support meaningful learning when it is used to engage students in active, constructivist, intentional, authentic and cooperative learning (Jonassen, Peck & Wilson, 1999). Such engagements are also sought in STEM approach to prepare students as productive workers of future workplace. In fact, some constructivist strategies approaches including inquiry–oriented, problem–based, and project–based learning have been applied to improve STEM education (Kim et al., 2017).

The third aspect "organizational context" refers to appreciation of technology as human activity and part of life. It represents many facets of educational administration, policy makers, academics, teachers, students, and related professional organizations. It makes explicit the role of such actors in technology integration. Any attempts for STEM–related technology practices in the schools should be primarily driven by educational stakeholders and organizations, not the external political and economic environments and imperatives, as we frequently encounter. Çepni (2017) indicates how STEM is increasingly represented in exhibitions, fairs, clubs rather than educational institutions and their programs as one of the mistakes being made in STEM practices in Turkey. Teachers ought to embrace STEM and diffuse its innovations within their educational environments. Moreover, the success of technology integration depends on its actors' adaptation to technical and pedagogical changes. Teachers are the key role for making any changes in education. As Hargreaves (1994) points out, "the involvement of teachers in educational change is vital to its success, especially if the change is complex and is to affect many settings over long periods of time" (p. 11). The organizational context emphasizes an alignment and compatibility between the design and development of STEM technologies and the implementation of them in the schools. Educators should take active role in both phases to prevent from the potentials gaps and mismatches.

Effective teacher preparation is the most crucial enabler for using STEM technologies. Teachers should be taught about how to operate related devices and implement them as learning and teaching tools as well as given the best examples of technology use accordant with STEM concepts and principles. This is required for not only computer teachers but also all branch teachers because STEM emphasizes an interdisciplinary approach. However, we observe that pre–service teacher education programs in Turkey do not have adequate technology courses. Just like a number of pedagogical formation courses to gain general competencies of teaching profession, there should also be technological formation courses to gain STEM–related technological knowledge and skill sets. Professional development activities (e.g., in–service training programs, congress/symposiums, publications) and incentives can also be offered to school communities in order to be adapted to STEM technology implementations and related new roles.

Current Technological Tools for STEM Education

STEM in education plays a critical role in preparing students for careers as adults. Nearly 80% of future careers will require some STEM skills. Therefore, a stimulating STEM education is essential for developing the basic analytical, problem–solving and critical thinking skills central to academic achievement and workforce readiness in the 21st century (Moeller, 2012). Technology in STEM subjects refers to tools that make abstract ideas more concrete and accessible through experiential learning and provide dynamic representations of STEM systems to enhance student learning of complex concepts. As psychologists and philosophers have long argued (Clark & Chalmers, 1998) that technology in STEM education has the potential to promote sensory motor experiences which has a vital role on cognitive development. These technological tools provide opportunities for learners to explore and examine abstract concepts in concrete ways. Technological tools both digital and hardware may provide concrete, hands on, graphical symbolic experiences in STEM teaching and learning environments. They make students accessible to design, explore and test the knowledge they acquired at varying levels. A wide range of digital technologies may provide opportunities for students to develop a formal model of a real world situation to carry out safe and efficient simulated virtual experiments in both formal and informal learning environments and to realize their project ideas in project based learning conditions.

Technology offers many opportunities, as a contributory subject, for the teaching of STEM content through enabling tools and practical application of skills (Sidawi, 2009). It plays a vital role in instruction as well as STEM teaching and learning but it requires careful integration. Even the latest state of art technological tool may not replace human social interaction or good teaching. Therefore, students may need scaffolding, guidance and caring during the learning process. For a successful STEM education, we need to use the technology to solve complex problems that work across the disciplines. To achieve this goal, we, as educators, need to blend technology in methods that help to scaffold and develop independent learning in our students (Davies et al., 2013). According to Pasnik and Hupert (2016) technology STEM learning and teaching can be enhanced if technology is used to provide models, promote social interactions, collaborations and opportunities to develop science skills, practices. As we argued earlier, technology use in STEM should focus on learning with technology rather than learning from technology. The following are a short introduction of the most popular STEM technology tools, hardware and software that teacher can facilitate in their STEM teaching both in formal and informal learning environments.

3D Printing

Three dimensional (3D) printing, also known as "additive manufacturing" or "rapid prototyping", is a manufacturing process that builds layers to create a 3D solid object from a digital model created with computer–aided design (CAD). Objects are constructed based on their digital graphical model using a layering process and printed using various materials such as: rubber, metal, plastics, and even sugar or hot cacao powder (Figure 2). It is a rapid prototyping technology that has gained increasing recognition in many different fields. 3D printing technologies for creating tactile experiences offer revolutionary ways of conveying spatial information and multimodal learning. They offer economical alternative to creating 3D models that increases opportunities for customization and experimentation in educational and medical implications. 3D printed models can offer innovative ways of understanding spatial concepts for objects that would otherwise be too large, small, valuable, or dangerous to hand to a student in teaching and learning process.

3D printers are gaining popularity internationally across STEM education. In order to prepare today's students to take on STEM jobs in their futures, they need to experience STEM subjects in an engaging, exciting, and hands–on way. 3D printing as a multisensory experience is a great way to make this possible. Therefore, 3D printing technology is critical to raise students up for a competitive world particularly in STEM contexts (Easley, Buehler, Salib & Hurst, 2017). It has a radically transformative effect and can support vital skills development in many subject domains. It has implications most obviously for creative thinking and design. Therefore, there is a considerable potential of 3D printers. For instance, it enables links to be made between mathematics, design and physics. Furthermore, in science education, 3D printers can be utilized to present atomic structure in Grade 10 Chemistry classes, with a positive correlation found between its integration into instruction and learning (Chery, Mburu, Ward & Fontecchio, 2015). Additionally, 3D printers can be utilized in a context to discuss the properties of plastics, to build models for teaching science such as molecules, eye–balls, cells and sine waves, and to build components for working equipment such as rockets in integrating science teaching into STEM. In Mathematics, for instance, 3D printer can be utilized to demonstrate a 3D graph for various algebraic equations as well as producing examples of regular shapes.

3D printing technology is proving to be one of the most adaptable and innovative technologies of the 21st century, with diverse applications spanning medicine, engineering, art, design and even the domestic realm. Therefore, they offer an opportunity for schools to explore innovative ways of teaching STEM subjects, stimulating students' interest and enriching the curriculum. This evolving technology is also being used in the education sector, transforming the STEM curriculum and creating powerful learning tools. 3D printing experiences enrich the learning environment providing students with hands–on experiences using an actual manufacturing tool and generate numerous creative and useful products.

Utilizing 3D printers requires hands–on skills technique and being able to follow step–by–step instructions which are relevant to STEM related career. Even though the use of 3D printing technologies is relatively new in educational settings, the disciplines of architecture and engineering were early adopters of additive manufacturing technologies (Celani, 2012). Students in engineering, especially mechatronics, mechanical engineering and also architecture are expected to master CAD programs. Therefore utilizing 3D printers in STEM education is crucial to prepare them to the future STEM careers. 3D printer can be utilized in two ways in STEM education. First, STEM learners can use 3D printers for the process of making the 3D print file and print the tactile object using a 3D printer as a design and production phase. The second, using 3D printers as a way to experience a tactile object that would not be possible without touching or handling the 3D print itself (Kolitsky, 2014). 3D printers can be used to create 3D replication of famous artists' art works in order to examine them by touching which would not be possible in real world. 3D printing can also enable students who are blind to experience visual art.

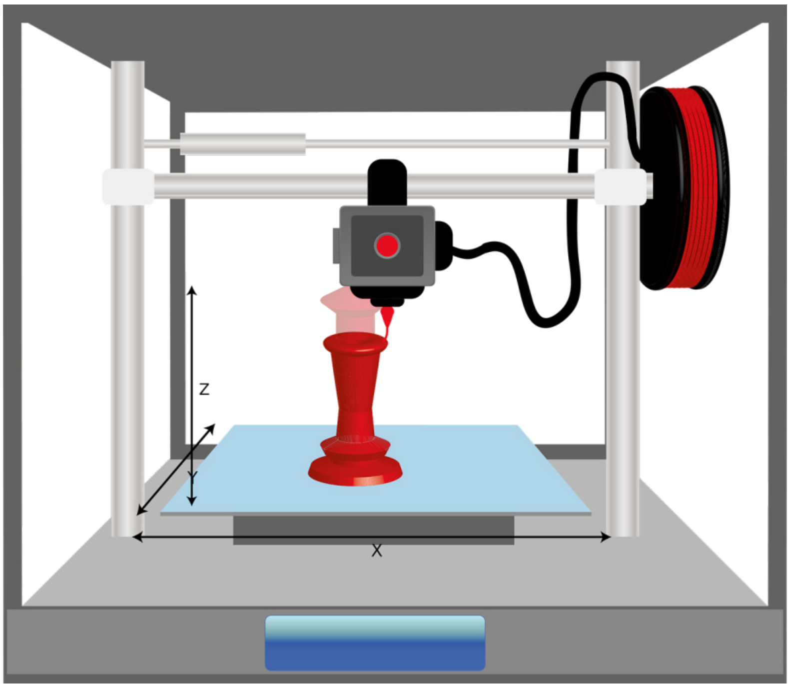

Figure 2. Graphical Representation of 3D Printing

In order to integrate 3D printing and design into STEM classroom, teachers and students need to utilize 3D design software to modify and create parts. CAD and computer–aided manufacture (CAM) contributes to developing students' practical skills to "achieve a professional quality" (Ofsted, 2011 as cited in Jones, Tyrer & Zanker, 2013). The most common 3D design and CAD programs that work well for teachers are SketchUp and ThinkerCAD. Other programs such as Solidworks and Autodesk 360 can be too complex to start with for beginners.

SketchUp

SketchUp is a design program that was supported by Google. It is a very crisp program that clearly shows how objects are forming. In other words, it shades the sides so that students easily know which side of a cube is the top.

It has reference features in the viewport so that students can easy know which direction is up or right or left regardless of what angle they are looking at an object from. SketchUp uses the same methodologies as more advanced design programs to create shapes. They have you draw a sketch on a 2D plane and then that sketch can be "extruded" to create a 3D shape.

The disadvantage of SketchUp is that it is not very 3D printer friendly. The Beta Cloud version does not generate .STL or .OBJ files which are necessary to 3D print an object.

The desktop version of the software can export those files, but it is not as simple as other programs. Overall, SketchUp is a good program for introducing CAD in general to beginners.

ThinkerCAD

ThinkerCAD is a program created by Autodesk. It allows beginners to drag and drop basic shapes into a workspace and then reshape them. Student may place a cube into the workspace and then grab the edges and corners to turn it into a board or some other rectangular prisms. When it comes time to create a file for 3D printing, TinkerCAD allows saving and exporting in 3D printing formats (.stl, .obj.). It is entirely cloud–based, so schools that have moved away from desktop labs can use it easily. The downside of TinkerCAD is that it is highly dependent on dimensioning. However, overall it is an excellent program to start students out with.

Robotic in STEM

Robotics in K–12 STEM education is a growing field and getting popular at all levels each year. Studies show that robotics can be utilized in STEM education for a variety of purposes such as motivating students to seek STEM careers (Ruiz–del–Solar & Aviles, 2004), improving critical thinking and problem solving skills (Eguchi, 2014; Ricca, Lulis & Bade, 2006), enhancing students' ability to solve logical and mathematical problems (Lindh & Holgersson, 2007) and encouraging collaboration and team work (Eguchi, 2016; Weinberg, White, Karacal, Engel & Hu, 2005).

The notion of using robotics in education goes back to earlier research on Seymour Papert's LOGO programming work in the 1970s. He created LEGO programming language that children can program computer and robots to gain sense of control over technology. Papert believes that students learn better when they are experiencing and discovering things by themselves (Papert, 1980). According to Slangen, Keulen and Gravemeijer (2011), robots can be utilized to do math and science rather than study them by contextual learning with the premise that an engaged student learns better. With the help of STEM educational robots students can take the knowledge from math and physics and apply them to real world situations. For instance, in order to assign a task to a robot, students needs to apply their coding, math and physics knowledge in to practice (Eguchi, 2014).

There is an increasing reliance and dependence on technology and computer programming in today's society. Educational STEM robots can bridge this gap by bringing basic programming languages allowing students not only have fun but also learn coding to prepare themselves in the future competitive market. STEM robot kits allow students to learn concepts through trial and error, application, and hands–on experiences, ensuring that they understand what they are dealing with. Many educational robotic kits are used in all educational levels such as Lego Mindstorms and mBot.

mBot

mBot is an entrance level educational robot, suitable for beginners in STEM learning. mBot is easy to assemble and works together with mBlock, a graphical program inspired by Scratch 2.0 to provide hands–on experience with programming, electronics, and robotics. Drag–and–drop graphical programming software, mBlock, enables hardware connectivity to provide a quick and easy way to learn programming through robot control and interactions.

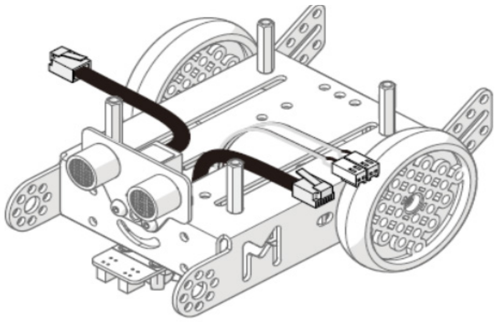

Figure 3. mBot Educational Robot

LEGO Mindstorms

LEGO Mindstorm kit is developed to allow learners to build customizable, programmable robots while teaching the principal concepts of physics, mathematics and engineering. It is a programmable teaching tool which was designed through inspiration by Piaget's theories of cognitive development (Piaget & Inhelder, 1966).

Programming Mindstorms robot is done via a flowchart language called Robolab, based on a language called LabVIEW. The programming structure simulates a flowchart design icon by icon and allows the robot to perform different operations autonomously. The graphical approach allows students to build programs by dragging and dropping virtual representations of various operations such as moving, braking, or rotating an arm attached to a motor. The iconic blocks are then connected via a virtual "wire". The program created via the graphical sequence of operations is then uploaded to the brick and the robot performs the commands as programmed (Chetty, 2015).

There are two generations of Mindstorms currently in use: NXT (second generation) and EV3 (third generation) (Figure 4). Major NXT parts are orange and EV3 parts are red. EV3 software is compatible with the NXT parts with a few exceptions (Valk, 2014).

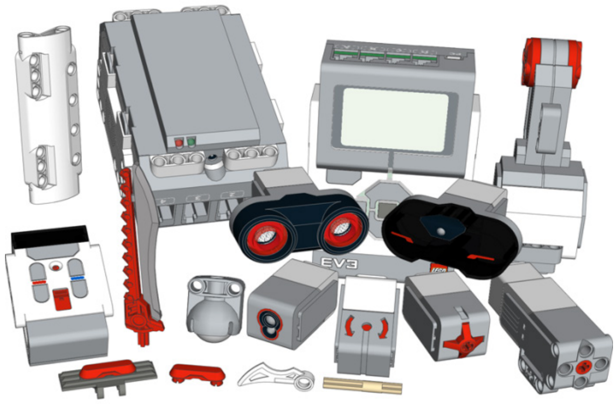

Figure 4. LEGO Mindstorms EV3 Kit

Laser Cutting

Laser cutting is a technology that uses a laser to cut materials for industrial manufacturing applications. A laser cutter uses a coherent beam of light to cut material, most often sheet metal, but also wood, diamond, glass, plastics and silicon (Figure 5). The beam is directed through a lens via mirrors or fiber optics. The lens focus on the beam at the work zone to burn, melt or vaporize the material. Exactly which process the material undergoes depends on the type of laser cutting involved.

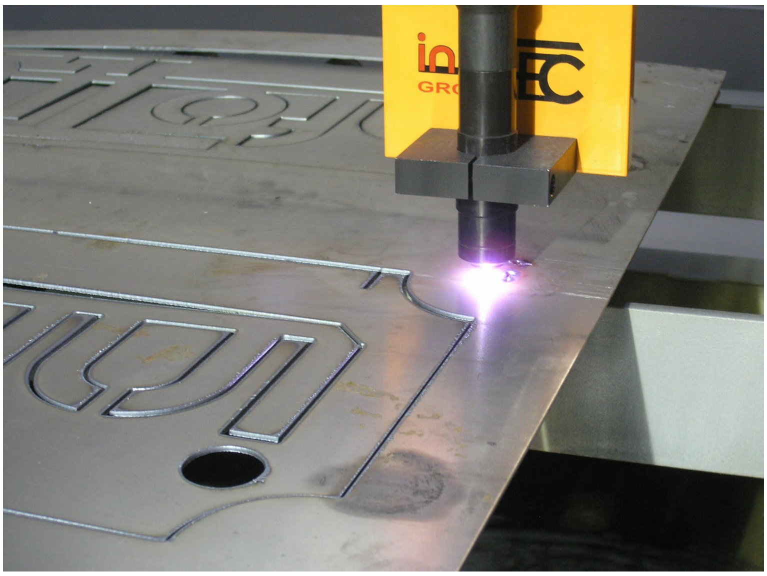

Figure 5. Laser Cutting Machine

Laser cutting can be divided into two types: laser fusion cutting and ablative laser cutting. The former involves melting material in a column and using a high–pressure stream of gas to shear the molten material away, leaving an open cut kerf. In contrast, the latter removes material layer by layer using a pulsed laser, which is like chiseling, only with light and on a microscopic scale. This generally means evaporating the material, rather than melting it (Wright, 2018).

Laser cutting allows schools to bring hands–on interactive technology to a lab or makerspace. The laser cutting brings engagement to all students, regardless of age, gender and interests.

Arduino

The origin of Arduino comes from Ivrea, Italy in 2005. The aim is to support students in their projects in order to create a cheap and efficient prototyping. The Arduino developer group led by Massimo Banzi and David Cuartielles decided to name the project prototype after a historical character named "Arduin of Ivrea". "Arduino" is the Italian version of the name, meaning "strong friend" (Wheat, 2011).

Arduino is an open–source electronics platform based on easy–to–use hardware and software. It is intended for anyone making interactive projects. It provides a simple way to learn how to program microcontrollers to sense and react to events in the real world. Its software is written in C or C++ programming language. The Arduino development board is an implementation of wiring, a similar physical computing platform, which is based on the processing multimedia programming environment (Arduino, 2011). Basic model of Arduino is shown in Figure 6.

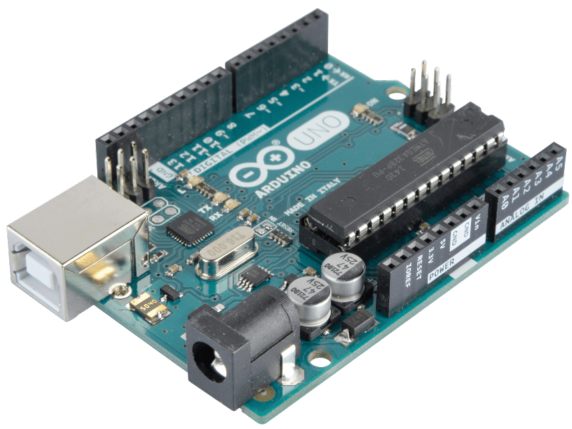

Figure 6. Basic Arduino Set

Arduino consists of many sensors in order to receive inputs from its environment and allows the user to control lights, motors and other actuators. It is an easy tool to be used by students without a background in electronics and programming. Arduino IDE is programming environment that allows the user to draft different kind of programs and load them into the Arduino microcontroller (Banzi, 2011).

Makey Makey

The Makey Makey is a microcontroller that has been pre–programmed. It connects to your computer via USB and has a range of standard keyboard inputs (space, arrows, click, etc). The Makey Makey interprets basic electronic connections as inputs and sends these signals to your computer as keyboard inputs. It is a circuit board that allows users to connect everyday objects to computer programs using alligator clips and a USB cable (Figure 7). The board uses closed loop electrical signals to send the computer either a keyboard stroke or mouse click signal.

Makey Makey is part of a creative and technological downshift in which very smart electronics are simplified to make the world manipulable by ordinary people in ways previously available only to developers. It is an invention kit that encourages people to find creative ways to interact with their computers, by using everyday objects as a replacement for keyboards and mice. Makey Makey is a useful, hands–on learning technology tool for learners of all ages, regardless of their academic strengths or weaknesses. Students can create anything from works of art to game controllers and more. Scratch is a drag and drop interactive programming interface that allows students to create interactive stories, animations, and games and interfaces with Makey Makey.

Figure 7. Make Makey Kit

Raspberry Pi

The Raspberry Pi is a low cost, credit–card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. It is a capable little device that enables people of all ages to explore computing, and to learn how to program in languages like Scratch and Python. It was originally designed for education, inspired by the 1981 BBC Micro. Its creator Eben Upton's goal was to create a low–cost device that would improve programming skills and hardware understanding at the pre–university level. But, thanks to its small size and accessible price, it was quickly adopted by tinkerers, makers, and electronics enthusiasts for projects that require more than a basic microcontroller (such as Arduino devices) (Figure 8). Raspberry Pi can be utilized as a STEM tool for students to learn programming and coding because everything around them is more or less computerized in some or the other way. Therefore, Raspberry Pi can help students make interesting STEM projects by making a replication of computing machine that they see around them or do it yourself projects. STEM education aims at teaching students the concept behind things they see in their day–to–day life. One of the most common things students observe is the weather. Sunlight, rain, snow – all of these become a thing of curiosity. Raspberry Pi box can be converted into a small weather station using Python programming that enables interacting with the USB connected weather stations. Thus, teachers can enrich the world of STEM education by encouraging students to make rather than only observe.

Figure 8. Raspberry Pi Microcontroller

Drones

Unstaffed flying objects, unmanned aerial vehicles, remotely piloted aircraft. These are all alternative names for drones. Drones or Unmanned Aerial Vehicles (UAVs) have been used in the military since at least 1849. However, the development of lightweight materials improved communications technologies and decreasing costs have made drones more accessible and affordable to the educational use. These factors have also allowed drones to be used for a variety of purposes outside the military, including aerial surveillance, monitoring, deliveries and STEM education.

How do drones can be utilized in STEM education? Students may learn programming drones for a specific purpose. They can work on about how fast the drone would go with the coded instructions with factors such as calculating if there was wind on the day, what the potential wind resistance would be. They test the manual flight of the drones, so they can get an idea of how the flight dynamics and pattern of flying work for them.

One of the best ways to use drones in the classroom is to have students design and build their own drone as a class project. Making drones in the classroom may teach students to learn about robotics, math, electronics, chemistry, programming, and hands–on experience. Furthermore, students acquire the analytical thinking skills needed to understand how many different disciplines function together. Thermographic cameras are helping students studying courses related to photography, media and entertainment in nighttime scenarios.

The incorporation of thermal imaging in drones may improve learning in dark. Student may use drones to collect samples from the locations where they may not reach or go due to health risks, geological barriers. They may track wild or sea animals to identify them in the wild and track their movements from above.

Figure 9. An Educational Drone

Scratch

Scratch is a computer–coding tool designed to increase digital literacies promoting technological careers for students. It is a free visual programming language developed by the Lifelong Kindergarten group at the MIT Media Lab (Resnick et al., 2009). Scratch was developed for young people develop their visual programming language made up of block code which they drag to the workspace to animate sprites. Students can complete a range of projects including programming and sharing interactive stories, games, and animations.

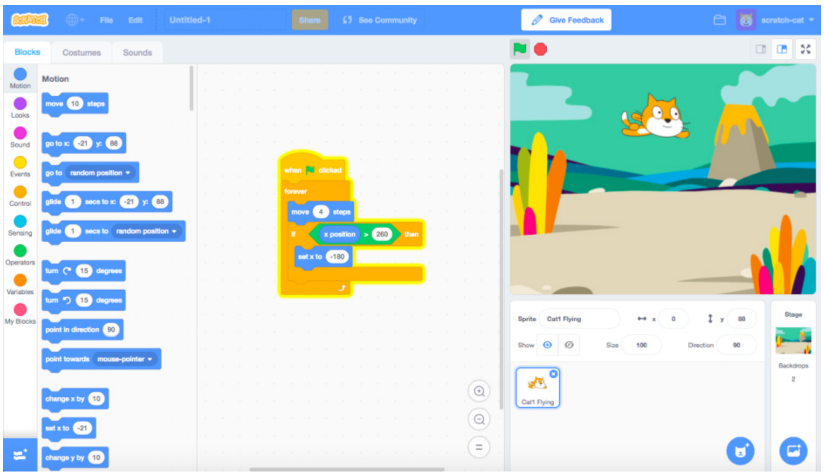

Figure 10. Screenshot of Scratch

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