HARD FUN
USING A MAKERSPACE AS A TOOL FOR STUDENT LEARNING

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An elementary makerspace provides students the tools to become tomorrow's innovators. Working with students in the makerspace, I have collected anecdotal evidence of the value of a makerspace to promote engagement, stimulate excitement for learning, encourage discovery, and develop perseverance and problem solving. But what do the experts say?

Abstract

This literature review explores the theoretical bases that justify a school makerspace, and discusses the uses of a makerspace to support student learning, develop 21st century skills, and promote school equity. This literature review will initially discuss constructivism, a theory of learning developed by Jean Piaget who claimed children build their knowledge through interactions with the environment. The work of various researchers who noted that makerspaces are constructivist environments will be cited. Next, the review of literature will discuss constructionism, a theory of learning and teaching developed by Seymour Papert, who believes that knowledge is most easily constructed when children build artifacts. Then, this literature review will discuss social constructivism, a theory of learning developed by Lev Vygotsky, who emphasized the importance of language and social interaction in learning. Writers suggest that the collaboration that happens in a makerspace is the type of discourse that leads to learning according to social constructivism. Choice theory, developed by William Glasser, states that human behavior is an attempt to meet basic needs, including freedom and fun, which can be found in a makerspace. Finally, this review of literature will discuss the theory of multiple

intelligences, developed by Howard Gardner, because a makerspace supports a wider range of learning styles that traditional schooling.

The review of literature lists various uses of a school makerspace including teaching curriculum and developing 21st century skills. Finally, it notes that makerspaces support inclusion of special needs students and help bridge the digital and achievement gap.

Definitions of Key Terms

1. **Makerspace:** a space where users share tools and ideas in order to construct physical or digital objects (Rendina, 2015). Early makerspaces were referred to by a variety of names including hackerspace, constructionist lab, fab lab, and engineering lab before the term makerspace became generally accepted (Hynes & Hynes, 2018).
2. **Tinkering:** autonomous construction-based learning to develop abstract concepts; play (Umaschi, et al, 2014).
3. **Constructivism:** a theory of learning described by Jean Piaget and others which states that knowledge is not transmitted directly but is instead constructed by the learner through interactions with the environment (Amineh & Asl, 2015).
4. **Constructionism:** a theory of learning and teaching articulated by Seymour Papert, a protégé of Piaget, which emphasizes learning through the actual creation of objects, physical or digital; learning through making (Papert, 1993).

5. **Multiple intelligences**: a theory of intelligence developed by Howard Gardner which states that intelligence is not a single general ability but a collection of capacities including Verbal/Linguistic, Logical/Mathematical, Visual/Spacial, Bodily/Kinesthetic, Musical, Intrapersonal, Interpersonal, Naturalistic, and possibly existential (Gardner, 1993).

6. **Project Based Learning (PBL)**: a pedagogy in which students learn through sustained inquiry on an authentic problem culminating in a public product. Students have voice and choice and the teacher acts as a facilitator rather than a sage. While definitions vary, several major criteria of project based learning are generally accepted. The project is the central structure and strategy of learning. The project is focused on a driving question which serves to develop a concept while solving a real world problem. The project is student driven and involves constructivist inquiry (Thomas, 2000).

7. **Hacker**: While the term has come to be associated with cyber criminals, its original meaning was benign and is still used in a positive way by technology hobbyists and makers. Hackers invent things, usually by deconstructing everyday objects and recombining or reengineering them into improved or repurposed objects, physical and/or digital. "A classic example is the disassembly of electronic devices and the reuse of their parts for the creation of new appliances" (Valente & Blikstein, 2019 p. 253). UNIX, the open source operating system, is a product of the hacker culture. Python, the open source computer coding language, is constantly expanding its library as users add, adapt, and share code in a collaborative manner. MIT graduate students are attributed with first using this term in this sense as well as many playful example of hacking (Izawa, 1996, Peterson, 1997).

8. **STEM:** Science Technology Engineering and Math; **STEAM:** Science, Technology, Engineering, Art, and Math (Garner, 2018).

Using a Makerspace as a Tool for Student learning

How can we transition our education system into the 21st century? Including a makerspace in public schools is a big step toward making education relevant to today's economy and society.

Makerspaces: innovation labs for today's students and tomorrow's workforce.

America built its supremacy on innovation. If the USA is to keep its edge, educators must encourage innovation in our students. How? Makerspaces in schools are a powerful tool with great potential to develop innovation and other 21st century skills in our students. "Future economic development and job creation are dependent on our ability to innovate and the maker movement exemplifies the kind of passion and personal motivation that inspires innovation" (Peppler & Bender, 2013, p. 23, quoting the New York Hall of Science). Makerspaces can help us reimagine schools to create a mindset of creativity and innovation (Peppler & Bender, 2013).

In his 2016 proclamation *National Week of Making,* President Obama declared

> 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. Let us renew our resolve to harness the potential of our time - the technology, opportunity, and talent of our people - and empower all of today's thinkers, makers, and dreamers (Obama, 2016).

What is a maker space? At its most basic, makerspace is self-defining: a place where people make things. Beyond that, definitions vary, agreeing only in that makerspaces can take a variety of formats from a simple rolling cart with craft supplies or LEGO robotics to a warehouse filled with the latest high tech fabrication tools (Rendina, 2015). Some would limit maker spaces to high tech fabrication (Hira & Hynes, 2018). MIT's Fab Lab is an example of a maker space limited to digital fabrication and computation. For others, anything goes, from cooking and crocheting to robotics and programming 3D printers. No matter how broad or narrow the scope, all maker spaces involve the sharing of both tools and ideas. Sharing equipment makes personal manufacturing feasible. The makerspace ethos encourages collaboration (Smith & Light, 2017).

> Simply put, Makerspaces are community centers with tools. Makerspaces combine manufacturing equipment, community, and education to enable community members to design, prototype, and create manufactured works that would not be possible to create with the resources available to individuals working alone. These spaces can take the form of loosely organized individuals sharing space and tools, for profit companies, nonprofit corporations, organizations affiliated with or hosted within schools, universities or

> libraries, and more. All are united in the purpose of providing access to equipment, community, and education, and all are unique in exactly how they are arranged to fit the purposes of the community they serve. (Hira & Hynes, 2018, p. 12).

Oliver (2016) defines makerspace by a number of core tenets or qualities:

> self-directed according to student interests (Educause 2013; Wyld 2014); supportive of curious play and creating with tolerance for failure and retrial (Britton 2012; Kurti et al. 2014a; Wyld 2014); encouraging of peer collaboration and sharing skills between experts and novices (Abram 2013; Britton 2012; Kurti et al. 2014a; Wyld 2014); physically-sited and open for ongoing project work that is both scheduled and unscheduled (Abram 2013; Educause 2013); and well-stocked with salvaged/sourced materials or common equipment for project work (Abram 2013; Wyld 2014). (Oliver, 2016, para. 5)

Makerspaces are the offspring of hackerspaces and the do-it-yourself movement and are the workspace for the maker movement. While Maker Media, publisher of Make Magazine and organizer of the first Maker Faire, likes to take credit for inventing the makerspace (see Dougherty, 2012), its roots are much deeper (Hira & Hynes, 2018). Several commentators have noted that "making" is intrinsically human (Hira & Hynes, 2018, Dougherty, 2012).

Kurti, Kurti, and Fleming (2014) distinguish makerspaces from educational makerspaces. In their view, makerspaces outside an educational setting are adult playgrounds for thinking and whimsical construction where learning happens but is not the primary focus. Educational makerspaces, on the other hand, harness the "intellectual playground concept for the purpose of deeper understanding" (Kurti et al. 2014, para 4). Kurti, Kurti, and Fleming believe makerspaces have the potential to revolutionize education. In educational makerspaces, the lines between teacher and student are blurred as students help one another, becoming teachers themselves while the adult teacher observes from the sidelines (Kurti, et al. 2014). In their view, educational makerspaces must invite curiosity, inspire wonder, embrace failure as the first step to invention, and celebrate individual solutions (Kurti et al., 2014). Educatioal makerspaces "foster collaboration, diversity, and 'cross-pollination' across different materials, techniques, and expertise (Gilbert, 2017). Educational makerspaces can be used to increase student-centeredness, inclusion, relevancy, and to support curriculum (Hughes and Hughes, 2018)

Purpose

The purpose of this review of literature is to explore the educational value of a makerspace in an elementary school. The primary focus will be an examination of the theoretical foundations that support a makerspace. These include constructivism, constructionism, social constructivism, choice theory, and the theory of multiple intelligences. The secondary focus will be the uses of a makerspace. These include tinkering to build schemata in science, technology, engineering and math, extending lessons in other subjects, passion projects to increase engagement, and developing career paths and 21st century skills including communication, collaboration, critical thinking, creativity, and perseverance. Finally, this literature review will look at the effect of a makerspace on school equity.

Research Questions

This review of literature will address the following questions:

- What is constructivism and how does this theory of learning justify a makerspace?
- What is constructionism and how has it led to elementary school makerspaces?
- What is social constructionism and how does it justify a makerspace?
- What is choice theory and how does it play out in a makerspace?

- What is the theory of multiple intelligences and how will a makerspace support the nurturing of multiple intelligences?
- What are the uses of a makerspace in an elementary school?
- How can a makerspace increase engagement and support curricula standards?
- How can a makerspace develop 21st century skills?
- How can a makerspace put students on a career path?
- How can a makerspace help close the achievement gap and bring equity to Title 1 schools?

Theoretical Foundations of a Makerspace

Constructivism

Constructivism, a psychological theory of learning based primarily on the prolific works of cognitive psychologist and biologist Jean Piaget (1896-1980), has had significant influence on modern pedagogy (Walczak, 2019). Piaget's complex view of cognitive development rejects the idea that knowledge is transmitted directly into the brain of a passive student but is instead constructed by the active learner. "(K) nowledge is literally created by … children from whole cloth as experience interacts with their biological predispositions. … Knowledge is a by-product of interactions between heredity and environment, and construction is the medium of those interactions" (Brainerd, 2019, p. 194). Piaget's theory of cognitive development contrasted sharply with behaviorism, the leading theory before Piaget (Brainerd, 2019), although Amineh and Asl (2015) suggests that Piaget's theory encompasses several theories, including behaviorism, in that experiences constitute the stimuli that create a response in the mind of the learner.

Amineh and Asl (2015) suggest Piaget's theory built on the works of Dewey, Vygotsky, and Bruner, while Brainerd (2019) claims Piaget's ideas stem from his study of evolutionary biology. Whatever cross-pollination occurred, Piaget provided a fresh look at the way infants and children develop and learn (Brainerd, 2019).

Organization and adaptation

Piaget's constructivism has an underlying premise, based on Piaget's study of biology and work with children, that humans are born with innate, biologically based, tendencies. First, humans organize their thinking processes into psychological structures in order to find meaning and interact with their environment more efficiently. These structures, or schemata, are cognitive frameworks, mental models … networks of related input that helps humans make sense of the world. When humans encounter new input, we organize it into related schema. Overtime, our schemata become more complex and sophisticated (Woolfork, Winnie, and Perry 2003).

Second, humans adapt cognitive structures in response to new input from the environment. This adaptation can take the form of assimilation or accommodation (Cook and Cook, 2005). Assimilation is the collection and classifying of new but non-conflicting information into a schema (Prichard and Wollard, 2010). Assimilation adds to but does not fundamentally change the schema. At times, humans may change their perception of the environmental input in order to fit it into an existing schema (Woolfork, Winnie, & Perry). Accommodation, on the other hand, changes the schema to make it consistent with the new input from the environment (Yang, 2010). Old schemata are modified or new schemata are developed so that the new information can then be assimilated (Cook & Cook, 2005). Aloqaili (2011) distinguishes between assimilation and accommodation by noting that assimilation is a quantitative change that represents growth whereas accommodation is a qualitative change that represents development.

Equilibration

Equilibration is the central construct of Piaget's theory of cognitive development (Gallagher, 1977). Equilibration is the active, dynamic process in which the mind searches for psychological equilibrium and in the process, advances development (Piaget, 1964). It is the balancing of assimilation and accommodation (Bormanaki & Khoshhal, 2017). Equilibration is a process of self-regulation (Piaget & Inhelder, 1969). This process occurs at several levels. There must be equilibrium between the cognitive structures and input from the environment. There must also be balance between the subsystems of the subject's schema, for example between subsystems for classifications and number construction. Finally, there must be consistency between a subject's various schemata and the totality of knowledge, the big picture or world view (Bormanaki & Khoshhal, 2017).

A child's developing mind constantly seeks equilibrium between what is known and the new experiences and information coming from the environment, putting new input into existing or expanding schemata through assimilation and accommodation (Williams & Burden, 2000). When new input can't be made to fit, an uncomfortable state of disequilibrium occurs. The child then either ignores the new information, or is motivated to find a new way to harmonize the conflict (Woolfolk, Winnie, & Perry, 2003).

> According to **Piaget**, it is the quest for the equilibrium that prompts the learner to learn. When his or her prior knowledge is rendered contradictory, incoherent and/or inconsistent in the face of new experiences, the learner seeks to adapt and modify his or her knowledge to re-obtain his or her equilibrium and coherence in relation to his or her environment. (Proulx, 2006, p.1)

For the process of equilibration, and therefore learning, to occur, the child must be both capable and predisposed to do the following steps. First, the child must notice the elements that are in conflict. Second, the child must interpret the elements as conflicting, which can require a certain level of maturity. Third, the child must respond by progressing, not regressing. In other words, the child must seek to explain the conflict rather than ignoring it or rejecting the new input and clinging to the initial belief. Finally, the child must re-conceptualize the situation in a way that resolves the conflict, thus returning to a state of cognitive equilibrium (Bornmanski & Khoshal, 2017).

Makerspace: a constructivist learning environment

Piaget's theory of cognitive development was a theory of learning, not a theory of teaching. None the less, it should inform our pedagogy. Tan (2019) argues that makerspaces are effective constructivist learning environments when the makerspace ethos and hacker mentality are followed. Makerspaces provide the direct experiences that build schemata in areas such as science (Dhanapal, 2014), technology (Bolliger,), engineering (Drayton, 2019, Morocz, 2015), and math (Hoyles & Noss, 1987). But makerspaces have been used in other areas, including integrated arts (Hughes, 2017), writing, and even to teach Piaget's theory of learning (Beisser, 2003). Learning in a makerspace is "education at its finest—understanding gained through inquisitive tinkering, participatory experience, and hands-on learning" (Gustafson, 2013 p. 35).

> The maker movement has the opportunity to transform education by inviting students to be something other than consumers of education. They can become makers and creators of their own educational lives, moving from being directed to do something to becoming self-directed and independent learners. (Dougherty, 2011, p. 1)

A makerspace has the potential to create the disequilibrium that Piaget claims drives development. The tools and materials allow for the creation of a *discrepant event*, the happening of the unexpected. This perks students' attention and curiosity by stimulating the Reticular Activating System (RAS), a bundle of neuro-fibers where the spinal cord meets the brain which alerts the neo-cortex to take note. As students seek to accommodate the unexpected event into their understanding of how the world works, memorable learning occurs (Leyden, 1991).

Constructionism

Constructionist learning in a makerspace

While constructivism is a theory of learning, constructionism is a theory of teaching (Noss and Clayton, 2015). Constructionism, coined by mathematician Seymour Papert, is often described as "learning by making", but Papert himself refused to define the term, claiming that would miss the point (Papert & Harel, 1991). Instead, Papert provides experiences in the form of stories so the readers can construct their own ideas In one story, a seventh grade class did Logo programming instead of math for the entire year but improved their math scores despite doing nothing that resembled school math (Papert & Harel, 1991). In another story, Papert recalls that he became fascinated with gears as a preschooler and played with them a great deal. Later, when he learned multiplication and eventually differential equations in school, he saw the problems in terms of gears because he had constructed a metal model of those concepts through his play. Papert, who worked with Piaget from 1958 to 1963 and became his protégé, notes

> 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 learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe. (Papert & Harel, 1991, p. 1)

Some researchers have questioned whether students learned more than how to use the latest devices to create artifacts in a makerspace (Valente & Blikstein, 2019). They observed that learning in a makerspace follows a different progression of steps than in a traditional transmission model of teaching. In a traditional setting, the teacher (1) presents a concept, usually with a definition, (2) provides an interpretation, often giving examples, (3) hopes this leads to comprehension, (4) and asks the student to apply the concept to problems. These steps- concept, interpretation, comprehension, action- are inverted in a makerspace. Learning begins with action, the construction of an artifact. Then the student reflects on the result, trying to understand what is being done and how it can be done better, sometimes with the help of a teacher. This leads to comprehension. Finally, the student will conceptualize the learning and return to action, debugging as further iterations are performed (Valente & Blikstein, 2019).

Valente and Blikstein (2019) concluded that curricular concepts beyond the making of objects could be mastered by students in a makerspace, but cautioned that a new relationship between teacher and students must be forged. The teacher should act as mediator, challenging students, and helping them discover and uncover the curricular concepts. "Through these interactions with the students, teachers can help students construct new knowledge, as well as reach a higher level of comprehension about what they are doing." (Valente & Blikstein, 2019, p. 260). The teacher no longer lectures as students build their own knowledge, but the teacher still plays a critical role and must skillfully perform two functions. The teacher must design rich environments and activities that provide opportunities for students to explore, integrating curricular goals into the projects students pursue. This will increase the quality of interaction between the learners and the products they create, prioritizing deep understanding. The teacher must also provide technical assistance when needed so the learners need not recreate knowledge and conventions that are readily available, treating learners as apprentices (Valente & Blikstein, 2019). This balancing act is not easy. Teachers are "designing for a moving target in all directions…" (Noss & Clayton, 2015, p. 288)

Noss and Clayton (2015) proposed several characteristics that make the construction of objects an effective strategy for the construction of knowledge. The first, and defining, characteristic is modeling. Whether it is math and physics concepts as represented by a catapult or logic as modeled by a computer program the child writes, the process of building, reflecting, and debugging a creation provides a mental model of a concept. This is learning "powerful ideas through use" (Noss and Clayton, 2015, p. 286). The second characteristic is accessibility to the modeling process, making visible the largely invisible processes and systems that control the universe and our lives and providing a glimpse into how this happens. The third component is layering. Mathematical and scientific principles and other abstractions can be embedded into projects in increasing complexity, requiring increasing problem solving skills. Learners have control over how deep they dive into the “why”, promoting agency. The fourth characteristic is” tapping into youth culture” (Noss & Clayton, 2015 p.287) by which they mean

doing activities that engage the learner. A subject such as math that might be viewed as difficult and boring suddenly has new relevance when needed to create something the student desires to create. Constructionism makes knowledge visible by representing it in a language with which learners can express themselves (Noss & Clayton, 2015). This representation makes up the fifth characteristic. The sixth and final characteristic described by Noss and Clayton is collaboration. Effective student learning is promoted through long-term engagement in collaborative projects in which students take individual and collective responsibility (Noss & Clayton, 2015).

In order for constructionist learning to occur, a productive learning environment must be established (Stager, 1999). Stager defines the context of productive learning as “an environment and set of experiences that would lead students to construct knowledge through the act of engaging in long-term personally meaningful work”. (Stager, 2005, p. 3) Stager recommends multi-age groupings, interdisciplinary curriculum, student faculty collaboration, project based learning, hands-on activities, computer access, and uninterrupted time. The consequence of project development is knowledge construction (Stager, 2005).

Papert (1991) articulated eight “big ideas” behind the constructionist learning lab. First, we learn by doing. We learn better when learning is part of doing something we find interesting.

We learn best when we use what we learn to make something we really want. Second, technology is a building material that allows us to make more interesting things. This is related to his eighth big idea which states we live in a digital world where knowing digital technology is as important as reading and writing to children's futures. Until then, students can use computers to learn about everything else. Papert's third big idea is "hard fun". We work and learn best when we enjoy what we are doing, but enjoyment doesn't have to be easy. "The best fun is hard fun" (Papert, 1999, p.1). The next big idea is learning to learn. Papert (1991) rejected the idea that the only way to learn is to be taught, and encourages students to take charge of their own learning. Fifth, take the proper amount of time. In a traditional school, time is highly structured. Papert believes students must learn time management to prepare for life. The sixth big idea is the most important: "you can't get it right until you get it wrong" (Papert, 1999, p.1). Nothing important works the first time. Learning occurs when the student analyzes an imperfect result and goes through the iterative cycle of debugging and improving. Students need the freedom to fail forward. Finally, "do unto ourselves what we do to our students" (Papert, 1999, p.1). Every difficulty is an opportunity to learn. "The best lesson we can give our students is to let them see us struggle to learn" (Papert, 1999, p.1).

Social Constructivism

Makerspace Collaboration: Social Constructivism in action

Like Piagetian constructivism, social constructivism asserts that knowledge is constructed by the learner but focuses on a different aspect of knowledge construction – the input. Developed by Lev Vygotsky, a contemporary of Piaget working separately in Russia, social constructivism claims that reality does not exist until it is constructed through human activity (Aminec & Asi, 2015). Knowledge is a human product that is socially and culturally constructed (Aminec & Asi, 2015 citing Ernest, 1999 and others). Learning, on the other hand, is an internal process within the individual (Churcher, Downs, & Tewksbury, 2014). Social constructivism stresses that learning is not passive but an active social process constructed through interaction and collaboration (McMahon, 1997). The primacy of language as the means of social interaction is greatly emphasized (Louis, 2009). Language is used both as an interpsychological tool to create

knowledge and as an intrapsychological tool to construct meaning (Churcher, Downs, & Tewksbury, 2014).

According to Vygotsky, three conditions must exist for learners to advance their cognitive development. First, the activity must be within the Zone of Proximal Development (Louis, 2009). This is the challenge zone of hard fun described by Papert. The activity is beyond what the learner already knows so that new learning can occur, but within the range of activities the learner can accomplish with help. The makerspace environment is one of collaboration, not quiet. While participants may struggle with challenging projects, they never struggle alone but can seek assistance from both facilitators and more experienced peers, providing the kind of social interaction the theory of social constructivism demands.

The second requisite condition for learning is scaffolding. Vygotsky posits that as a learner completes a task, the greatest level of assistance is needed at the beginning but help should taper off as the student gains skill (Louis, 2009). In a makerspace, the facilitator can initially introduce principles, such as the engineering design cycle, and demonstrate skills, such as soldering or running unfamiliar equipment. As the work progresses the facilitator can make suggestions in debugging a piece of code or design if the learner is stuck to the point of frustration, and ask questions to help the student look at the problem in a new way. But then the facilitator should back off, letting the students construct their own knowledge. As students work, they can assist each other, explaining their own process and listening to other ideas. Peer collaboration can happen both within and between groups. The third condition for learning identified by Vygotsky is the use of psychological tools. These tools, such as oral and written language, symbols, maps, and the scientific method, are intellectual operations we use to examine and interact with our environment (Louise, 2009, Gredler & Sheilds, 2004). These psychological tools are both developed through social interaction and used in social interaction (Louis, 2009, Vygotsky, 1978). The student discourse that goes on in the collaborative setting of a makerspace supports these interactions.

Choice Theory

Based on his work with children, psychiatrist William Glasser developed a theory of human behavior known as Choice Theory. According to this theory, humans are internally motivated to meet five basic needs: survival, love/belonging, power/respect, fun, and freedom. Human behavior is a result of choices we make in order to meet one or more of these basic needs (Lečei & Vodopivec, 2014, Louis, 2009). Students can gain a sense of belonging by joining an after school makers club when they share a desire to try new challenges such as coding or robotics. Similarly, students experience belonging by doing collaborative group work (Keefe & Jenkins, 2002). Students gain a sense of power and respect when they accomplish a task that is challenging and outside the abilities of their parents and most students, such as 3D printing or video game design.

The fun and freedom of a makerspace

But the needs most relevant to a makerspace are freedom and fun. Glasser defines fun as nature's reward for learning something new (Louis, 2009, citing Glasser, 1978). "Fun is the genetic reward for learning…The day we stop playing is the day we stop learning" (Glasser, 1998 p. 41). Students generally identify "school fun" as activities that are active, not passive, and challenging, not repetitive (Louis, 2009). The tinkering that happens in a makerspace is both play and the construction of knowledge. Freedom in the school setting is the ability to make choices (Olutayo, 2012, Glasser, 1985). Since students generally choose their own projects, following their own interests and desires, they enjoy freedom in a school makerspace.

Nurturing Multiple Intelligences in a Makerspace

Based on his work with both gifted children and with adults recovering from strokes, Harvard educational psychologist Howard Gardner rejected the commonly accepted view that intellectual capacity is a single entity, intelligence quotient (IQ), that can be represented by a number. Instead, he proposed the Theory of Multiple Intelligences (MI). "An intelligence is defined as a biopsychological potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture" (Gardner & Moran, 2006). Gardner's emphasis is on the ability to "solve problems and Fashion products" (Gardner,1993). Gardner initially identified seven intelligences in Frames of Mind, (1983), then added an eighth and proposed a possible ninth. MI claims that all humans have all of the intelligences but that each individual has a unique intellectual profile with varying strengths and weaknesses (Gardner, 1998). The relatively independent faculties Gardner believes qualify as an intelligence each met the following criteria.

1.Potential isolation by brain damage. For example, linguistic abilities can be compromised or spared by strokes.

- 2. The existence of prodigies, savants and other exceptional individuals. Such individuals permit the intelligence to be observed in relative isolation.
- 3. An identifiable core operation or set of operations. Musical intelligence, for instance, consists of a person's sensitivity to melody, harmony, rhythm, timbre and musical structure
- 4. A distinctive developmental history within an individual, along with a definable nature of expert performance. One examines the skills of, say, an expert athlete, salesperson or naturali st, as well as the steps to attaining such expertise.
- 5. An evolutionary history and evolutionary plausibility. One can examine forms of spatial intelligence in mammals or musical intelligence in birds.
- 6. Support from tests in experimental psychology. Researchers have devised tasks that specifically indicate which skills are related to one another and which are discrete.
- 7. Support from psychometric findings. Batteries of tests reveal which tasks reflect the same underlying factor and which do not.
- 8. Susceptibility to encoding in a symbol system. Codes such as language, arithmetic, maps and logical expression, among others, capture important components of respective intelligences**.** (Gardner, 1998, p.1)

Gardner examined anthropological records, case studies of learners, biological science, cultural studies, and psychology to determine if each proposed intelligence met the criteria (Gardner 1998). The qualifying intelligences are as follows.

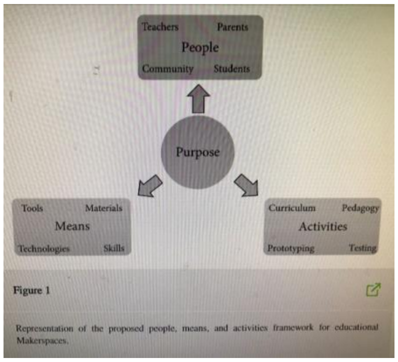
1. Linguistic intelligence is the mastery and love of words and language and the desire to explore them as seen in poets, writers, and linguists.
2. Logical-mathematical intelligence is the ability to assess objects and abstractions to discern the underlying relationships and principals, as performed by mathematicians, scientists, and philosophers.
3. Musical intelligence is the ability to discern pitch, rhythm, and timbre, not only in composing and performing music but in listening to it.
4. Spacial intelligence is the ability to perceive the visual world accurately and recreate the visual experience even without physical stimuli as do architects, artists, navigators, and chess players.
5. Bodily-kinesthetic intelligence is the ability to control body motions and handle objects skillfully as do dancers and athletes.
6. Intrapersonal intelligence is the ability to determine one's own moods, emotions and other mental states and use that as a guide for behavior.
7. Interpersonal intelligence is the ability to accurately ascertain the mental states of others.
8. Naturalist intelligence is the ability to recognize and categorize natural objects as do biologists and naturalists.
9. Gardner is considering the ability to capture and ponder fundamental questions of existence, as do philosophers and spiritual leaders, as an existential intelligence but is awaiting further evidence (Gardner, 1998).

Multiple intelligences and a student's individual intellectual profile can affect a student's preferred method of learning. When trying to grasp a mathematical concept or law of physics, a student with strong spacial intelligence but weaker linguistic intelligence, for example, may benefit more from constructing an object than listening to the teacher's explanation. Traditional schooling emphasizes linguistic and logical-mathematical intelligence (Kayal, 2007). While those intelligences are very much at play in a makerspace, so are a much wider range. Researchers have suggested that the emerging technologies found in a makerspace, as well as the variety of other materials and activities permit the use of multiple intelligences, thus assisting diverse learners (Ke & Bonk, 2008, Willis, 2007).

Uses of a Makerspace in an Elementary School

Makerspaces are arising in K-12 education as an alternative to traditional pedagogies so that students can engage in project-based learning, have agency over their school work, and explore new topics and technologies (Valente & Blikstein, 2019). To assist educators in determining best practices for a makerspace, Hira and Hynes (2018) proposed a conceptual framework. After studying many educational makerspaces, Hira and Hynes noted that all makerspaces involved people, materials, and activities but varied widely depending on their purpose and focus. A makerspace aimed primarily at supporting curriculum standards might emphasize specific activities although each student would execute the activity in their own way. A makerspace with the goal of developing career paths might emphasize the high tech equipment. A makerspace designed to spur creativity and agency might emphasize the participants and provide whatever tools and materials they need for their individual projects

(Hira & Hynes, 2018). A visual representation of their conceptual framework is set forth in

Figure 1. 

(Hira & Hines, 2018, Figure 1)

STEM Education

School makerspaces are most often associated with science, technology, engineering, and math (STEM). “Today’s focus on STEM projects seems irrevocably linked to makerspaces. Educators have seen students thrive when they experiment with tools and technology to create various objects” (Christ, 2019). An example is physical computing in which a physical object is designed, constructed then programmed to interact with the environment in some way via devices such as sensors, motors, and computers. Students “teach” their objects to behave and in the process learn concepts of embedded systems and design as well as coding (Przybylla, 2018). Through tinkering, prototyping and iterating, students construct and reconstruct knowledge (Przybylla, 2019, Stager, 2009). This, and virtually any makerspace project, involves engineering, an important strand in the national Next Generation Science Standards (NGSS).

Much has been written about the potential of makerspaces, and anecdotal evidence supports their effectiveness. However, at this point in time, there is limited data-based evidence on the effect of makerspaces on elementary student outcomes (Hira & Hynes, 2018). Related data indicates that the activities performed in makerspaces are beneficial. In a meta- analyses of

255 studies comparing the examination scores and failure rates of undergraduate students in STEM courses, active learning approaches were found to be more effective than lecture classes (Freeman, et al., 2014). Students in traditional lecture courses were 1.5 times as likely to fail or drop the course. Students in courses that used laboratories, workshop course design, group problem solving and other active learning strategies had average test scores 6% above students in lecture courses on the same tests and also scored higher on concept inventories (Freeman, et.al., 2014). The improvements were consistent across all the STEM disciplines (Freeman, et.al., 2014). While this meta-analyses involved college students and was not limited to makerspaces, it provides a window into the effectiveness of makerspace activities as a method to teach STEM in public schools.

A small but well-designed study was conducted on seven to ten year olds by Dhanapal (2014). In this study, science concepts were taught to fourth graders using three different methods: silent reading, power point presentations given by the teacher while students took notes, and hands-on activities. Pre and post-tests determined both student attitudes about learning science as well as mastery of concepts. The post test showed that all but one of the twenty-two students preferred the hands-on activities and had improved their attitudes toward science. There was a small but statistically significant 4.32% improvement in written test scores with the hands-on method of teaching (Dhanapal, 2014). These studies support the anecdotal evidence that makerspaces improve STEM education.

STEAM and Beyond

Makerspaces are not limited to STEM disciplines. Makerspaces are useful in both art education and education through art (Lu, 2019). Any object created in a makerspace can be made with artistic flair and creativity (Lu, 2019). Because the creation of art objects has always been central to art education, many educators claim that makerspaces are the natural progression of art education (Manifold 2017; Robbins & Smith 2016; Sweeny 2017). To test this claim, Lu (2019) conducted a research project on middle school, high school, and college art classes using makerspaces in the form of highly interactive virtual environments (HIVEs). These platforms integrated the creation of original art with the technical skills of coding. Lu found that, although a few students were initially daunted by the technical challenge, the students enjoyed working on the virtual platforms, believed they provided greater opportunities to express themselves, and thought their art skills had been enhanced (Lu, 2019). Lu (2019) recommends the use of makerspaces for art classes in schools but cautions that many art teachers will need technical assistance either from the district's IT department or from volunteers. Some communities will be more able than others to provide this support. Lu fears a "new digital divide" (Lu, 2019, p. 354) stemming not from lack of devices but lack of expertize.

Other subjects can be enhanced by creating in a makerspace. Several researchers found that makerspaces can support literacy (Lofton, 2017; Marsh, et.al.; 2019; Moorefield-Lang, 2015; Wohlwend, 2018). Mann (2018) reported that coding and computational thinking allow school-age children to apply the story elements of sequence of events and cause and effect and make connections to the real world. Gravel et al. (2018) found that the design process used in makerspaces helps students develop their abilities to identify, organize, and integrate information. Montgomery and Madden (2019) integrated STEM and English Language Arts (ELA) by using conflicts within the storyline of children's books as the problem-solving context for what they call novel engineering in which children use the engineering design process to build an artifact that represents the story. Trust and Maloy (2018) found that makerspace activities supported project based learning in history and social studies.

Education for the future

4Cs and a P – What Students Must Develop

Enhancing curriculum is not the only use for makerspaces; some educational planners believe developing 21st century soft skills is equally important (Lanci et al., 2018). Former U.S. Secretary of Education Arne Duncan stated that the 21st century increasingly requires “**c**reativity, **perseverance**, and problem solving combined with performing well as part of a team" (Larson and Miller, 2011, para. 2, citing Duncan, 2009, emphasis added). Larson and Miller (2011) state that these skills are not new but are “newly important” (para. 5). Traditional education conforms to the requirements of the industrial revolution but our economic and social systems have changed, and so must education (Chalkiadaki, 2018). “Countries invest in education on the expectation that it will contribute to their long-term economic well-being and sustainability. The problem, nowadays, is that although imperatives in the world of work have changed, education has not” (Chalkiadaki, 2018, p. 2). Schools must produce high quality human capital capable not only of using technology but contributing to technology. (WanHusin, et al., 2016). Schools should develop a workforce that can innovate, invent, and problem solve (WanHusin, et al., 2016).

Following an extensive review of literature on 21st century skills, Chalkiadaki (2018) examined the six most cited frameworks for 21st century skills and, from those, complied the list of skills set forth in figure 2.

Figure 2 - Compiled 21st century skills list:
creativity, divergent thinking, critical thinking, team working (especially in heterogeneous groups), work autonomy, developed cognitive and interpersonal skills, social and civic competences, responsible national and global citizenship, consciousness of interdependence, acceptance and understanding of diversity, recognition and development of personal attributes, interactive use of tools, communication in mother tongue and foreign languages, mathematical and science competence, digital competence, sense of initiative and entrepreneurship, accountability, leadership, cultural awareness and expression, physical well-being (Chalkiadaki, 2018, p. 6, Table 5).

Chalkiadaki (2018) found that the skills most often mentioned were those of creativity, innovation, digital literacy, and communication, especially within the context of information and communication technology.

California has joined the Partnership for 21st Century Skills (P21) (California Department of Education, 2013a). P21 developed a "collective vision for learning known as the Framework for 21st Century Learning" (California Department of Education, 2013b).

> This Framework describes the skills, knowledge, and expertise students must master to succeed in work and life: it is a blend of content knowledge specific skills, expertise and literacies. The essential skills for success in today's world include the following: Learning and Innovation Skills (**The Four C's: Critical thinking, Communication, Collaboration, and Creativity) …** Information, Media, and Technological Skills (California Department of Education, 2013b, emphasis added).

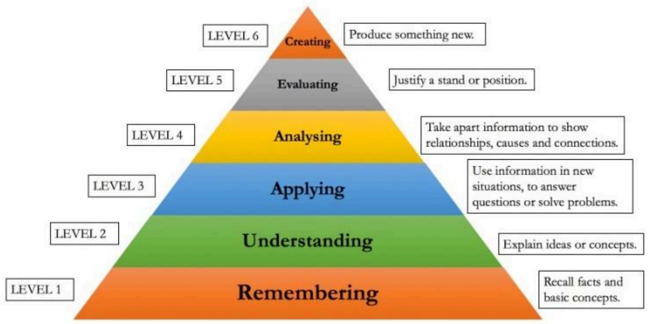
"21st century skills – including critical thinking and problem solving, computer and technology skills, communication and self-direction skills, are important to the country's future economic success" (Trilling & Fadel, 2009, p. 169).

Can makerspaces help develop 21st century skills? Studies to date indicate makerspaces are an effective strategy (Doorman et al., 2019; Ejikeme & Okpala, 2017; Lanci, 2018). In a qualitative study involving 5th and 6th graders, Sheffield et al. (2017) found that a sustained makerspace experience improved perseverance, collaboration, communication, and problem solving, as well as providing an engaging and interdisciplinary method to develop STEM concepts. In a study of 125 thirteen and fourteen year old students, WanHusin et al. (2016) found that creating hands-on STEM projects improved Likert scores on a survey designed to assess digital age literacy, inventive thinking, effective communication, productivity and spiritual values which were defined as appreciation for science and math and their usefulness to

solve real-world problems. The makerspace experiences of 291 year 5 and 6 students were studied by Blackley et al. (2018) who found improvement in the 21st century skills of critical and creative thinking, problem solving and collaboration skills, and further found that the students became empowered learners, knowledge constructors, and creative communicators through working in the makerspace.

The 3Rs – What Teachers Must Insure

Today, teachers are urged to plan with the 3Rs in mind: rigor, relevance, relationships (McNulty et al., 2007). Can makerspaces help teachers provide the new 3Rs? Both Bloom's revised Taxonomy (Anderson & Krathwohl, (2001) and Webb's Depth of Knowledge place creating at the highest level of thinking as seen in figure 3 .



(Fastiggi, undated, https://technologyforlearners.com/applying-blooms-taxonomy-to-the-classroom/). Bloom's taxonomy categorizes the cognitive skills needed to do a task; Webb's depth of knowledge relates to the depth of content knowledge and skills needed to complete the learning activity (Hess et al., 2009). At Webb's highest level, extending thinking, the students plan, create, modify, and produce (Hess et al., 2009). Makerspaces, where students do just that, supply rigor. Students make authentic artifacts, usually based on their own interests, which provides personal relevance. Students often address real world problems or create real world applications, which provided relevance. The makerspace ethos of sharing and collaborating can build relationships.

Shop 2.0

"With access to a range of high-tech and low-tech tools and activities that provide learning experiences relevant to technical fields, makerspaces promise to present contexts for gaining relevant hands-on experiences that could lead directly to careers" (D'Urzo et al., 2016, p. 24). While pursuing passions, students can also develop an entrepreneurial spirit (Hui & Gerber, 2017; Loertscher, 2012). Makerspaces attract more individuals into product design. (Van Holm, 2015). Makerspace activities that involve coding develop skills that are in high demand

(Dishman, 2016). Coding skills are not limited to the tech industry but are needed in an expanding range of industries from manufacturing to hospitals to finance (Dishman, 2016). Coding skills put students on a track to high incomes and are growing at a faster pace than the market average (Risen, 2016). Similarly, some areas of engineering with connections to makerspace activities are in high demand including robotics engineers, electrical and electronics engineers, and embedded systems engineers (Keller, 2019).

Working Toward Equity

The Maker culture seeks to democratize technology and manufacturing (Barton et al., 2017). Students of color, low income students, and girls are underrepresented in STEM, the area that is seeing the greatest job growth and economic promise. Can makerspaces help bridge the achievement gap in STEM? Makerspaces at Title 1 schools can provide access and exposure to STEM activities and technology for underrepresented groups (Barton et al., 2017). Makerspaces have been used to help low income students avoid the summer slide as they provide engaging enrichment activities (District Administration, 2017). Organizations such as Girls Who Code and the Femineers seek to decrease the gender gap in STEM. However, Ryoo and Barton (2018) cautioned that makerspaces must be carefully designed to value the culture, experiences, perspectives, and language youth bring to their learning if makerspaces are to fulfill their potential to break down barriers and support youth in challenging sociohistorical narratives and complex power dynamics" (p. 4). Marvin et al. (2018) found that explorations involving small projects and giving students agency over what constituted making led to more equitable engagement and the creation of locally relevant artifacts. Designing the environments, pedagogies, and activities that make up a makerspace is not easy and is an ongoing, iterative process (Marvin et al. 2018). As Marvin et al. (2018) stated, “We were building he plane as we flew it” (p. 44).

Makerspaces can also assist students with disabilities or different abilities find their voice and talents. Stager (2005) reports on the Constructionist Learning Laboratory (CLL), an alternative learning environment serving incarcerated youth at the Maine Youth Center, a state prison for adjudicated youth. All the student inmates had failed at school and school had failed them. Most were diagnosed as having various learning disabilities. Seymour Papert and two colleagues were given total freedom to design the CLL, instructed only to design a model of a school for the future. The first thing Papert did was eliminate all traditional notions of curriculum or assessment. Instead they provided a constructionist lab, a makerspace, where students spent five hour daily blocks of uninterrupted exploration and creation. The lab had a wide variety of tools, technology, and supplies. The learning objective was to make something you are interested in and make it work as intended. And make they did, creating everything from a gopher-cam to a working phonograph consisting of Legos, paper, a sewing machine needle, wires, batteries and a small motor whose speed was reduced by properly worked out gear ratios requiring some advanced math. In the process, the juvenile inmates reconnected with their ability to learn and reveled at the talents they discovered in themselves. No behavior issues, vandalism, or thefts occurred in the lab. Instead, learning happened (Stager,2005; Stager, 200).

Conclusion

Makerspaces can be a useful tool to improve student outcomes. This literature review discussed the theoretical foundations and uses of a school makerspace. The constructivist theory of learning supports the use of a makerspace as a learning environment because a makerspace offers students experiences with which to build and develop schemata. The constructionist theory of learning and teaching, a branch of constructivism, is a natural foundation for a makerspace since students learn by making. Social constructivism, which emphasizes the importance of social interaction and language in building schemata, also justify makerspaces for they are places of collaboration, sharing, and networking. The popularity of makerspaces with students is explained by choice theory because students are given the freedom to make their own choices, pursue their own interests, and build their own communities.

Makerspace activities can support acquisition of curricular concepts as well as extend the curriculum through projects. Equally important are the development of 21st century skills- 4Cs and a P: communication, collaboration, critical thinking, creativity, and perseverance within an environment that celebrates and promotes innovation. The coding and other tech skills put students on a path to careers that are in demand and are generally well paid. Makerspaces assist teachers in providing the new 3Rs: rigor, relevance, and relationships. The process of creation provides rigor, the real world skills, real world problems and personal choice of activities provides relevance, and the collaborative environment provides relationships.

Makerspaces in Title 1 schools have potential to help bridge the various gaps that exist in society. Makerspaces provide the enrichment activities that low income students would not otherwise have. They provide students opportunities to learn in a variety of modalities, using a variety of intelligences, appealing to a variety of learning styles, and tethering learning to a variety of areas in the brain. They can be engaging and fun, providing motivation to learn.

But makerspaces are not easy to design and manage. The facilitator must constantly adapt the space to the needs and interests of the particular students and keep each individual in their zone of proximal development.

Much has been written about makerspaces and a great deal of anecdotal evidence about their effectiveness has been amassed. But there is still scant data-driven evidence based on well controlled scientific studies. This lack of data should be addressed in future research although the task will be difficult due to the very nature of makerspaces.

Epilogue

Eight years ago, when I first started my science club at my school, I did all the work and the students had all the fun. This was not sustainable. The educational system had just finished the high-stakes bubble-in test era and students were intellectually crippled by it. When I gave them a challenge they were back in 60 seconds whining “I can’t do it. Help me.” Since then, the students have evolved and so have my clubs. Now, if a challenge arises, students throw themselves on the floor, heads together, and figure it out for themselves.

Reference List

Aloqaili, A. (2012). The relationship between reading comprehension and critical thinking: A theoretical study. *Journal of King Saud University-Language and Translation,* 24(1), 35-4

Amineh, R. & Asl, H. (2015). Review of constructivism and social constructivism. *Journal of social sciences, literatureand and language,* 1(10 9-16.

Anderson, L.W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of Educational Objectives*. (Abridged ed.). Allyn & Bacon

Barton, A. & Tan, E. (2017). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. Teachers College Record; Jun2017, 119 (6), p1-44

Beisser, S. (2003). Kindergarteners can do it-so can you: A case study of a constuctionist technology-rich first year seminar for undergraduate college students. *Information technology in childhood education*, 2003, p. 243-260

Blakley, S. (2018). Using a makerspace approach to engage Indonesian primary students with STEM. *Educational Research,* 28(1)

Bolliger, D. (n.d.). Creating constructivist learning environments. Educational and media technology yearbook, 2006 - books.google.com. https://books.google.com/books?hl=en&lr=&id=NEnxxLglzREC&oi=fnd&pg=PA119&dq=Bolliger+Doris+Creating+Constructivist+Learning+Environments&ots=I6t3f8e77l&sig=W_tqN_89u85qP9x681mAWqHScOM#v=onepage&q=Bo

Bormanaki, H., & Khoshhal, Y. (2017). The role of equilibration in Piaget's theory of cognitive development and its implication for receptive skills: A theoretical study. *Journal of Language Teaching and Research.* 8(1)

Brainerd, C. (1996). Piaget: A centennial celebration. *Psychological Science*, Jul96, Vol. 7 Issue 4, p191-195. 5p. 1 Chart. DOI: 10.1111/j.1467-9280.1996.tb00357

California Department of Education (2013) News Release https://www.cde.ca.gov.nr/ne/yr13/yer13rel33.asp

Chalkiadaka, A. (2018 Jul). A systematic literature review of 21st century skills and competencies in primary education. *International Journal of Instruction,* 11(3) pp. 1-16

Churcher, K., Downs, E., Tewksbury, D. (2014). "Friending" Vygotsky: A Social Constructivist Pedagogy of Knowledge Building through Classroom Social Media Use. *Journal of Effective Teaching*, v14 n1 p33-50

Cook, J., & Cook, G. (2005). *Child development*. Person education: Allyn & Bacon

Crist, C. (2019). Inventions everywhere: How STEM educators can spread the makerspace mentality throughout schools and districts. *District Administration,* 55(5) p. 18-21

D'Urzo, S., Foster, J., Keune, A., Peppler, K. & Stutzman, A. (2016). Makerspaces: Providing Pennsylvania with practical prefiguration. *Techniques,* October 2016. Acteonline.org

Dhanapal, S. (2014). A study of the effectiveness of hands-on experiments in learning science among year 4 students. *International Online Journal of Primary Education.* 3(1). http://www.ijge.info/ojs/index.php/IOJPE/article/view/223

Dhanapal, S. (2014). A study of the effectiveness of hands-on experiments on learning science among year 4 students. *International Online Journal of Primary Education,* 3(1)

Dishman, L. (2016). The future of work: Why coding is still the most important job skill of the future. *Fast Company.* 6-14-16

District Administration. (2017) Supplement TechXcellence, p22-22

Doorman, M., Bos, R., de Haan, D., Jonker, V. & Wijers, M. (2019). Making and implementing a mathematics day challenge as a makerspace for teams of students. *International Journal of Science & Mathematics Education,* Jun supplement 1, 17(1)

Dougherty, D. (2011). Learning by making: American kids should be building rockets and robots, not taking standardized tests. https://slate.com/technology/2012/06/maker-faire-and-science-education-american-kids-should-be-building-rockets-and-robots-not-taking-standardized-tests.html

Drayton, T. (2019). Beyond the maker movement: A preliminary partial literature review on the role of makerspaces in engineering education. *Proceedings of the ASEE Annual Conference 2019,* p. 3504-3513

Ejikeme, A. & Okpala, H. (2017). Promoting children's learning through technology literacy: Challenges to school librarians in the 21st century. Education & Information Technologies 17(3) pp. 1163-1177

Freeman, S., Eddy, S. McDonough, M., Smith, M., Okoroafor, N., Jordt, H.,& Wenderoth, M. (2014). *PNAS* June 10, 2014 111 (23) 8410-8415; https://doi.org/10.1073/pnas.1319030111

Gallagher, J. (1977). Piaget's concept of equilibration: Biological, logical and cybernetic *Topics in Cognitive Development.* Chap. 3. Springer

Gardner, H. (*1998). A Multiplicity of Intelligences. *Scientific American Presents* 15240223

Gardner, H. (1993). *Multiple intelligences: the theory in practice.* Basic Books

Garner, P. (2018). Innovations in science education: Infusing social emotional principals into early STEM learning. Cultural Studies of Science Education, Dec. 2018, Vol. 13 Issue 4, p889-903, 15p; DOI: 10.1007/s11422-017-9826-0,

Gilbert, J. (2017). *New Zealand Journal of Teachers' Work*, 2017, Vol. 14 Issue 2, p80-98, 19p; DOI: 10.24135/teacherswork.v14i2.232

Gravel, B. (2018 Dec). Navigating worlds of information: STEM literacy practices of experienced makers. *International Journal of Technology & Design Education*, 28(4). DOI: 10.1007/s10798-017-9422-3

Gredler, M., & Sheilds, C. (2004). Does anyone read Vygotsky's words? Commentary on Glassman. *Educational Researcher,* 33(2), 21-25

Gustafson, E. (2013). Meeting needs: Makerspaces and school libraries. *School Library Monthly, May/Jun2013,* 29(8), p35-36

Hess, K. Jones, B., Carlock, D. & Walkup. (2009). Cognitive rigor: Blending the strengths of Bloom's taxonomy and Webb's depth of knowledge to enhance classroom-level processes. Online submission. https://files.eric.ed.gov/fulltext/ED517804.pdf

Hira, A. & Hynes, M. (2018). People, means, and activities: A conceptual framework for realizing the educational potential of makerspaces. *Education Research International,* 6/3/2018,Vol.2018, p1-10. DOI: 10.1155/2018/6923617

Hughes, J. (2017). Digital making with “at risk” youth. *International Journal of Information & Learning Technology,* 34(2), p. 102-113

Hughes, J., & Harron, J. (2018). Spacemakers: A leadership perspective on curriculum and the purpose of K-12 educational makerspaces. *Journal of Research on Technology in Education,* Jul2018, Vol. 50 Issue 3, p253-270, 18p; DOI: 10.1080/15391523.2018.1461038

Hui, J. & Gerber, E. (2017). Developing makerspaces as sites of entrepreneurship. *Proceeding of the 2017 AMC Conference on ComputerSupported Cooperative Work and Social Computing* ,pp. 2013-2038. https://doi/101145/2998181.2998264

Izawa, E. (n.d.). Producing a hack at MIT: Engineering in action. http://hacks.mit.edu/by_year/

Ke, Z. & Bonk, C. (2008). Addressing diverse learner preferences and intelligences with emerging technologies: Matching models to online opportunities.*Canadian Journal of Learning and Technology,* 34(2)

Keller, A. (2019). Engineers are in demand, but who will fill them? https://www.machinedesign.com/automation-iiot/article/21837463/engineering-jobs-are-in-demand-but-who-will-fill-them

Kurti, T., Kurti, D. & Fleming, L. (2014). *TEACHER LIBRARIAN* 41(5)

Lanci, S. Nadelson, L., Villanueva, I., Bouwma-Gearhart, J.,Youmans, K. & Lenz, A. (2018). *Proceedings of the ASEE Annual Conference and Exposition 2018,* pp.1-12

Larson, L. & Miller, T. (2011). 21st century skills: Prepare students for the future. *Kappa Delta Pi Record,* 47(3), pp. 121-123

Lecei, A., Vodopivec,J. ((2014). Implicit theories of educators and William Glasser's choice theory. *Metodological Horizons,*9(2) p. 35-46. DOI: 10.32728/mo.9.2.2014.04

Leyden, M. (1991). Teaching science. *Teaching Pre K-8*, 21(5), p. 25-28

Louis, G. (2009). Using Glasser's choice theory to understand Vygotsky. *International Journal of reading theory,* 28(2)

Lu, L. (2019). Engaging digital makers through interactive virtual art makerspaces: Possibilities and challenges in art education. *International Journal of Education Through Art,*15(3)

Manifold, M. (2017). Making special, making art, or making things. *Studies in art education,* 58(4), pp360-364

Mann, L. (2018). Making a place for makerspaces. *Reference and User Services Quarterly,* 58(2) pp82-86

Marsh, J., Wood, E., Chesworth, L. Nisha, B., Nutbrown, B., Olney, B., (2019 Jul-Sept). *Mind, Culture& Activity,* 26(3) pp. 221-233

Martin, L., Dixon, C. & Sagit, B. (2018). Iterative design toward equity. *Equity & Excellence in Education*

McMahon, M. (1997). Social constuctivism and the world wide web – a paradigm for learning. *Asclilite Conference*

McNulty, R., Raymond, J. & Quaglia, R.(2007) Rigor, relevance and relationships. *School Administrator,* 64(8)

Montgomery, S., & Madden, L. (2019). Novel engineering: integrating literacy and engineering design in a 5th grade classroom. *Science Activities,*56(1) pp. 27-32

Moorefield-Lange, H. (2015 Jan/Feb). Making, Libraries, and Literacies. *Library Media Connection,* 33/4, pp. 30-31

Morocz, R., (2015). University maker spaces: Discovery, optimization and measurements of Impacts. *Proceedings of the ASEE Annual Conference & Exposition 2015*, p. 1-10

Noss, R., & Clayton, J. (1987). Synthesizing mathematical conceptions and their formalization through the construction of a Logo-based school math curriculum. *International Juornal of Mathematical Education in Science and Technology,* 18(4): 581-595

Noss, R., & Clayton, J. (2015). Reconstructing constructionism. *Constructivist Foundations,* 10(3) p. 285-288

Obama, B. (2016). Presidential proclamation – National week of making 2016. White House Office of the Press Secretary. https://obamawhitehouse.archives.gov/the-press-office/2016/06/16/presidential-proclamation-national-week-making-2016

Oliver, K. (2016). Professional Development Considerations for Makerspace Leaders, Part One: Addressing “What?” and “Why?”. *TechTrends*. 60:160–166 DOI 10.1007/s11528-016-0028-5

Papert, S. & Harel, I. (1991). Situating Constructionism. *Constructionism* , chap. 1. Ablex

Papert, S. (1991). Eight big ideas behind the constructionist learning lab. *Stager.org.* http://westoninnovations.pbworks.com/f/8bigideas.pdf

Papert, S. (1993). *Mindstorms: Children, computer, and powerful ideas* (2nd ed.). Basic Books

Papert, S. (1999). Eight big ideas behind the constructionist learning lab. http://westoninnovations.pbworks.com/f/8/bigideas.pdf

Peppler, K. & S. Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan,* Vol. 95, no. 3 pp 22-27

Prichard, A., & Wollard, J. (2010). *Psychology for the classroom: constructivism and social learning* (1st ed.). Roultledge: Taylor & Francis

Proulx, J. (2006). Constructivism: A re-equilibration and clarification of the concepts, and some potential implications for teaching and pedagogy. Radical Pedagogy, Spring 2006, 8 (1), p1-1, 1p

Pryzbylla, M. Empowering learners with tools in CS education: Physical computing in secondary schools. *Information Technology* 60(2). DOI: https://doi.org/10.1515/itit-2017-0032

Pryzbylla, M. Interactive Objects in Physical Computing and Their Role in the Learning Processes. *Constructivist Foundations*, 14(3) 3, p264-266

Rendina, D. (2015). Defining makerspaces: What the research says. *RenovateLearning*, April, 2015.

Risen, T. 2016. (2016 Jun 8). Coding isn't just for coders anymore. *US News and Worlds Report.* https://www.usnews.com/news/articles/2016-06-08/coding-isn't-just-for-coders-anymore

Robbins, P. & Smith, S. (2016). Robo/graphy: Using practical arts-based robots to transform classrooms into makerspaces. *Art Education,*69(3), pp. 43-51

Ryooa, J. & Barton, A. (2018). Equity in STEM-rich making: Pedagogies and design. *Equity & Excellence in Education*.

Sheffield, R., Koul, R., Blakley, S., Maynard, N. (2017). Makerspace in STEM for Girls: A physical space to develop 21st century skills. *Educational Media International*, 54 (2), pp. 148-164

Stager, G. (2000). Engineering for at risk youth. *Curriculum Administrator*. Oct2000, 36(9), p. 9

Stager, G. (2005). Papert's Prison Fab Lab: Implications for the maker movement and education design. IDC 2013, New York, NY, USA. https://www.makersempire.com/wp-content/uploads/2018/02/Paperts-Prison-Fab-Lab-Implications-for-the-maker-movement-and-education-design-Stager-13.pdf

Stager, G. (2005). Papertian Constructionism and the Design of Productive Contexts for Learning. *Plennary Session Paper – EuroLogo X* . http://www.stager.org/articles/eurologo2005.pdf

Sweeny, R. (2017). Makerspaces and art education places. *Studies in art education,* 58(4) pp351-359

Tan, M. (2019). When makerspaces meet school: Negotiating tensions between instruction and construction. *Journal of Science Education & Technology,* 28(2) p. 75-15

Thomas, J. (2000). A review of research on project based learning. http://www.autodesk.com/foundation

Trust, T., Maloy, R, (2018 Mar/Apr). Makerspaces and 3D printing: New directions in history learning. *Social Education*, 82 (2), pp.101-106,

U.S. Bureau of Labor Statistics. (n.d.) **https://www.bls.gov/ooh/architecture-and-engineering/home.htm**

Umaschi, M. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. Computers & Education, Mar2014, Vol. 72, p145-157, 13p; DOI: 10.1016/j.compedu.2013.10.020

Valente, J. & Blikstein, P. (2019). Maker education: Where is the knowledge construction? *Constructivist Foundations,* Vol. 14 N3. http://constructivist,info/14/3/252.valente

VanHolm, E. (2015). Makerspaces and contributions to entrepreneurship. *Procedia - Social and Behavioral Sciences*, 195 24 -31

Walczak, P. (2019). Why piaget does not philosophize? Critical discussion of Gareth B. Mathews with the Piagetan concept of cognitive development. *Childhood & Philosophy*, jan. 2019, pp. 01 – 25

WanHusin, W., Othman, O., Halim, L. Rasul, M., Osman, K. & Iksan, Z. (2016). Fostering students 21st century skills through project oriented problem based learning (POPBL) in integrated STEM education program. *Asia-Pacific Forum on Science Learning & Teaching,* 17(1), pp.60-77

Willis, J. (2007). Brain-friendly strategies for the inclusion classroom. *ASCD,* Alexandria

Wohlend, K. 2018 Jan). Playing to our strengths: Finding innovation in children's and teachers' imaginative expertise. *Language Arts,* 95(3) pp. 162-170

Woolfork, A., Winnie, P., & Perry, N. (2003). *Educational psychology* (2nd ed.). Person Education: Allyn & Bacon

Yang, Y., (2010). Cognitive conflicts and resolutions in online text revisions: three profiles. *Educational Technology and Society, 13(4), 202-214*