PROJECT GOALS AND OUTCOMES

Faculty and staff from the University of Illinois-Urbana Champaign (UIUC) College of Education, the Illinois Informatics Institute, and the Champaign Urbana Community Fab Lab propose an **Exploratory DRK-12 Learning Strand project** called **Project MAPLE: MAkerspaces Promoting Learning and Engagement** to develop and study a series of metacognitive strategies that support learning and engagement for struggling middle school students during makerspace experiences. The makerspace movement has gained recognition and momentum, which has resulted in many schools integrating makerspace technologies and related curricular practices into the classroom. Given the paucity of studies to inform practitioners about what pedagogical supports help struggling learners engage in these makerspace experiences, this is an essential area of study. We focus on two populations of struggling learners in middle schools: (1) students with learning disabilities, and (2) students at risk for academic failure (e.g., students receiving academic support as part of a Response to Intervention (RtI) system). The rationale for focusing on metacognition within makerspace activities comes from the literature on students with LD and other struggling learners that suggests that they have difficulty with metacognitive thinking (Gersten, et al., 2001). The aims of this study are to answer preliminary questions related to (1) what learning barriers are present during the design-redesign and problem/project process common to makerspace and early engineering experiences, especially for struggling learners and (2) how can instruction that supports metacognitive strategies be integrated within typical K-12 classroom makerspace activities to address those barriers.

BROADER IMPACTS OF THE PROPOSED WORK

Collaborative workshops and computer-driven tools have existed for decades, however the combination of these with shared information resources, such as open-source software, documentation and instructional resources for small-scale, low-cost digital fabrication have led to what is often termed the "maker movement." This movement is distinctly defined by a sense of DIY (do-it-yourself) and DIWO (do-it-with-others) type ideologies that come together to form a culture of "making" and community of practice referred to as "makers." It relies on the many existing movements and ideas such as (1) customization as an alternative to mass-production, (2) negotiated, decentralized and open-access instead of closed-control systems, and (3) the cultivation of a sense of purpose and meaning found in stories of construction as a remedy to alienation from the means of production (Anderson, 2008; Neff and Stark, 2003; Frauenfelder, 2010).

There is a growing national dialogue about including makerspaces in K-12 as part of STEM education. Recently the White House launched a National Week of Making wherein they announced a call to action through an initiative called "A Nation of Makers" (White House 2016). So far this initiative has brought together hundreds of maker organizations and activities all over the United States and started to drive critical inquiries and collaborations, including a focus on how students learn to make, as well as make in order to learn. According to the New Media Consortium's (NMC) 6th annual NMC Horizon Report-2015 K-12 Edition (Johnson et al., 2015), "[s]chools are turning to makerspaces to facilitate activities that inspire confidence in young learners, and help them acquire entrepreneurial skills that are immediately applicable in the real world" (p. 39). An increasingly large body of literature focuses on identifying and measuring STEM-relevant learning activities in makerspaces (Peppler et al., 2016; Blikstein et al., 2016; Angevine & Weisgrau, 2015; Schneider, 2015). Even as the climate becomes more amenable to makerspace instruction, there remain few investigations of how makerspaces can be made accessible to a broad range of learners in *public* school settings. We believe this may, in fact, be the central-most challenge to the success of the maker movement, as creativity and innovation rely specifically on cognitive diversity and democratic inclusion (Kelly and Littman, 2005; Surowiecki, 2005; Robinson, 2011). This project, thus, has useful applications within K-12 education, which also continually faces the challenge of engaging many kinds of learners and therefore stands to benefit greatly from insights gained from working with LD and other at-risk populations. Additionally, our focus on these students addresses the NSF's charge to broaden participation of underrepresented populations in STEM. This project aims to translate and apply research on the use of metacognitive strategies in supporting struggling learners to develop approaches that teachers can implement to increase opportunities for students who are the most difficult to reach academically. Thus, **the major goals of this project are to 1) better understand the learning barriers to iterative design and problem/project process, 2) how to explicitly include metacognitive strategy oriented instruction within making activities, and 3) evaluate the effectiveness of those strategies by measuring engagement and learning.**

IMPORTANCE

Theoretical and Empirical Framework Makerspaces in K-12 Teaching and Learning: The inclusion of engineering and design practices into the Next Generation Science Standards (NGSS) focuses on improving students' preparation to participate in a technology-mediated global society (Hira, et al., 2014). These standards focus on finding practical and applied solutions to real-world problems (NRC, 2015). Concurrent to this standards-based movement has been the Maker Movement, which fosters creative solutions through innovative design (Bajarin, 2014). Within the context of K-12 instruction, these two movements are aligned as both encouraging problem solving, project-based learning (PBL), design solutions, student agency and autonomy, and high levels of hands-on engagement (Martin, 2014).

Makerspaces are where *making* takes place, and while *making* might be lexiconically defined as creating, designing and building, the literature also clarifies that makerspaces engage and excite learners through creative and iterative learner-driven construction geared towards producing personally-meaningful, shareable artifacts (e.g., Gutwill et al., 2015; Justice & Markus, 2015; Vossoughi et al., 2013; Blikstein et al., 2016). An important aspect of making is tinkering, which emphasizes play, personal interest, and a "generative process of developing a personally meaningful idea" (Bevan, et al., 2015, p. 99, also see Berland, 2016). *Making* is especially relevant as it changes how critical interactions occur with and around our creations; it is a means with which to drive a collaborative iterative design process. "Construction that takes place 'in the head' often happens especially felicitously when it is supported by construction of a more public sort 'in the world' – a sand castle or a cake, a Lego house or a corporation, a computer program, a poem, or a theory of the universe." (Papert, 1980, p. 142).

The relevance of makerspaces to learning in *public school* settings may be less clear given the current standards-based focus of schooling, but many see the opportunity for transformation around learner-driven inquiry and engagement (Resnick & Rosenbaum, 2013). The literature suggests a number of learning skills that can be developed in makerspaces, including persistence (Bevan, et al., 2015; Gutwill, et al., 2015), iteration (Vossoughi, et al., 2013), and multiple digital literacies (Blikstein & Krannich, 2013). Numerous researchers have documented how these learner-driven practices support student participation, learning, and conceptual understanding in scientific inquiry (e.g., Driver & Oldham, 1986; Minstrell & van Zee, 2000; Rivera Maulucci et al., 2014). To be sure, making adds a specific dimension of design and design-thinking that mirrors or echoes traditional forms of scientific and artistic investigation in which devices are built, tested, and used for purposeful activities and exploration. This spurs Blikstein and Krannich (2013) to suggest that learning through making promotes technology literacy, application of STEM knowledge, and practice with engineering design. Also of significance is that makerspaces have been found to promote diversity by being equally engaging to both boys and girls when the tools and projects are more about aesthetics and sharing, rather than function and competition (Kafai, et al., 2014), or to both artists and engineers (Blikstein, 2013; Peppler, 2013), and thus have the potential to broaden participation and promote equity and engagement in digital fluency (Hira, et al., 2014, Blikstein et. al 2016).

Learning through Making: A review of the research on making and learning suggests seven learning dimensions or practices supported by making, especially when framed as an iterative design process: **(1) engagement** or **tinkering** (e.g., Blikstein, 2013; Brahms & Wardrip, 2014; Petrich, et al., 2013), **(2) intentionality** (e.g., Brahms & Wardrip, 2014; Gutwill, et al., 2015), **(3) digital fluency** (e.g., Peppler & Kafai, 2010; Kafai, et al., 2014), **(4) creativity** (Dorph and Cannady, 2013; Kafai, et al., 2014), **(5) iterative design thinking** (Blikstein, 2103; Brahms & Wardrip, 2014; Gutwill, et al., 2015; Kurti, et al., 2014; Sheridan, et al., 2013; Vossoughi, et al., 2014), **(6) collaborative intelligence** (Brahms & Wardrip, 2014; Kurti, et al., 2014; Blikstein, 2013; Davee, et al., 2015), and **(7) contextualized learning in STEM** (Blikstein, 2013; Davee, et al., 2015; Dorph and Cannady, 2014; Gutwill, et al., 2015; Peppler, 2013).

Despite this research that outlines the potential for increased learning and engagement, there are inherent challenges to implementing making within K-12. Because traditional educational models do not typically include open-ended learning (including tinkering, divergent thinking, and variance in iteration or process), some students find this level of open-endedness challenging. In fact, the literature on struggling learners in science inquiry highlights students' challenges with ill-defined open inquiry, numerical data, background knowledge, and complex reasoning (e.g., Brigham, et al., 2011; Villanueva & Hand, 2011). Thus, our research is critical if makerspace experiences are to be extended to a broad range of learners, including those who struggle.

Metacognitive Strategies for Struggling Learners and Making: Metacognition is often defined as "thinking about thinking" or having an awareness of one's own thinking processes and strategies (Brown, 1987). Although metacognition can be nebulous, Flavell's (1987) delineation of three interrelated aspects of metacognition is helpful and includes: (1) the person (e.g., knowledge of how a person learns, performs cognitive tasks, motivation, etc.), (2) the task (e.g., what needs to occur to complete a task), and (3) the strategy (e.g., knowledge of the processes that one needs to be an effective/efficient learner). Although there are other definitions of metacognition, this definition allows for a starting point for our project.

There is a great deal of literature that suggests a relationship between metacognition and learning outcomes in the STEM areas (e.g., Aydin & Ubuz, 2010). Struggling learners and students with learning disabilities often have poor understanding of their own learning, and thus lack an awareness of their own metacognitive processes (Gersten et al., 2001; Israel, et al., 2013). Gersten and colleagues explained, "While students with learning disabilities possess the necessary cognitive tools to effectively process information, for some reason they do so very inefficiently" (p. 280). This lack of metacognitive awareness creates problems for these learners in STEM learning because much of the scientific information related to solving real-world problems using data can be complex and abstract. Hence, they often struggle to understand how to apply their knowledge to new, complex situations.

The good news is that there is a large body of literature (e.g., Hora & Oleson, 2015; Schraw 1998; Zull, 2002) suggesting that metacognitive processes can be taught and that non-strategic learners can gain the skills necessary to become more aware of their learning. This literature breaks metacognition into two central components: **metacognitive knowledge** and **metacognitive self-regulation**. Metacognitive knowledge refers to what we know about our cognitive processes. Metacognitive self-regulation refers to activities and strategies learners use to monitor and control their learning.

Some of the characteristics of making that have been found to excite and engage students in learning (e.g., open-ended and self-directed exploration, tinkering, play) may appear to run counter to the idea of explicitly teaching metacognitive strategies to promote awareness and structure. However, because the motivation for making is often tied to non-structured freedom to explore, students who are non-strategic may find this type of exploration frustrating and not accessible. **We suggest, therefore, that making offers opportunities to improve metacognitive awareness while capitalizing on the natural desire of children to play and explore.** The key will be to help struggling learners to develop those strategies without squashing their excitement and interest in the explorative design process. Table 1 provides examples of how metacognitive strategies can be taught within makerspace activities.

The main intellectual contributions of our project will be to identify the metacognitive strategies implicit and explicit within existing makerspace activities and study those strategies found consistent in the literature within the context of middle school makerspace activities with struggling middle school students. To do so**, we will develop the metacognitive strategies in a manner similar to those used to teach metacognitive strategies in mathematics and science** (e.g., Rozenzweig, et al., 2011) using teaching practices such as think-aloud protocol, self-questioning, and modeling.

Table 1: *Representative metacognitive skills that support making*

Metacognitive Skill	**Definition in Makerspaces**	**Example Teaching Strategies**
Persistence	Overcoming frustration when design does not work as intended Learning through failure	Modeling how to learn from failure through "think-aloud" strategies (e.g., what do you do when you're frustrated?) Present example scenarios where final designs occurred after many failures
Expressing intentionality	Students make explicit choices about what components/ methods they use and explain their rationale (Brahms & Wardrip, 2014)	Teaching students to create short-term and long-term goals for their projects Provide feedback to students about design choices (e.g., can you identify problems which led to poor outcomes?)
Iterative design	Students plan incremental steps in their design, explore materials, and test/retest their design (Gutwill et al., 2015) Progressive comparison of multiple experiences	Provide students with scaffolds for changing one variable at a time during iteration and supports makers in testing the impacts of these changes Creates opportunities for students to provide feedback on the design of others

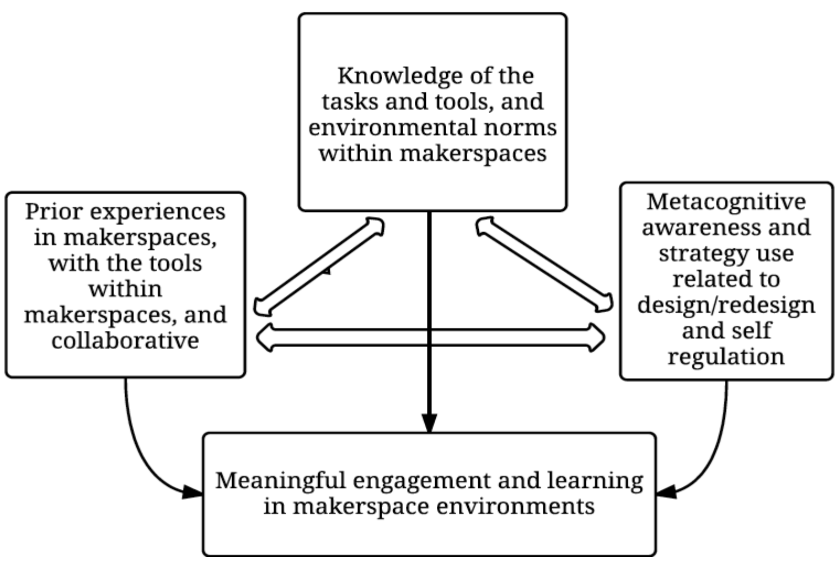
INTELLECTUAL MERIT

Although the pedagogical underpinning of makerspaces and metacognitive learning strategies seem far removed, these theoretical frameworks can come together in a pragmatic approach so that learners can make use of the metacognitive processes within the context of open-ended makerspace experiences. Our study will focus narrowly on establishing a foundational understanding of how to ameliorate barriers to engaging in design learning through the use of metacognitive strategies, but we see this project as the beginning of a trajectory of research focused on helping students become more successful in K-12 makerspace environments. Our aim is to begin to build an evidence base around new instructional practices for middle school students who are struggling learners so that they can experience more success during maker learning experiences.

Research Questions: There are limited pedagogical guidelines available to help teachers support struggling learners during makerspace experiences. **This study will thus take steps toward establishing a foundational base for research that will inform our understanding of how to best meet the instructional needs of struggling learners.** We will do this by focusing on the following research questions that are fitted to the resources and scope of an exploratory project:

1. How are struggling learners (including students with disabilities and those at risk for academic failure) engaging in maker experiences? What barriers exist for struggling learners in middle schools during makerspace activities?
2. How can metacognitive strategy instruction (including modeling, think-aloud protocols, and practice) support students with disabilities and other struggling learners to meaningfully engage in the design/redesign process within makerspace experiences?

We will answer these research questions through small-scale iterative studies in middle school settings that move from identifying instructional barriers to refining strategies to address those barriers. Our research team has already begun to collect data using a preliminary theoretical model and metacognitive strategies model, observing a variety of learners (including LD and special needs) in the context of makerspace summer camp activities in order to to identify difficulties and barriers to learning and engagement. Through this project we seek to further develop and refine metacognitive strategies aligned to our proposed strategic instruction approach as well as other similar content areas (such as mathematics problem solving (e.g., Deshler & Lenz, 1989; Rosenzweig, et al., 2011). Figure 1 provides a conceptual diagram of our theoretical framework highlighting the relationship between knowledge, skills, and metacognitive strategies necessary to meaningfully engage in making.



The goal of this project is to ascertain which metacognitive strategies show promise for increasing engagement and learning. Those identified strategies can be explored in future studies and will allow us to ask more sophisticated questions such as: (1) To what extent does metacognitive instruction related to iterative design support student learning and improve attitudes about making and STEM careers? and (2) How can maker experiences be integrated into traditional math and science instruction in a manner that aligns with the NGSS standards?

RESEARCH AND DEVELOPMENT DESIGN

Our project will include three distinct, but interrelated activities: (1) investigating barriers that students with learning disabilities and others at risk for academic failure face during makerspace activities, and (2) applying metacognitive strategies that have been shown efficacious in other areas (e.g., inquiry science) to makerspace activities in order to address the identified barriers, and (3) iteratively refining those metacognitive strategies within the context of middle school makerspace settings to see their effects on the learning and engagement of struggling middle school students.

Our research team will work with a distinguished advisory board to iteratively develop, evaluate, and revise the metacognitive strategies that will form an empirical basis for future research and development. We will employ a mixed-methods research design (Creswell, 2013) to examine the research questions using quantitative and qualitative data. This approach will enable us to triangulate findings and to provide findings that are both rigorous and rich. Data sources will include teacher interviews, student observations, video screen capture of computer-based making activities, and content analysis of student-produced artifacts as well as curricular materials. Our approach will be driven by an iterative process of examining metacognitive strategies on (a) persistence, (b) attitudes about makerspaces and the integration of metacognitive strategies into makerspace activities, and (c) the design/redesign and remixing within the context of multiple representative makerspace toolsets (see tables 2-4). Research sites will be all public middle schools in the Champaign-Urbana area, where we have been working for the past three years on fostering computational thinking, programming and makerspace experiences for K-12 students. Student populations targeted for this study include: (1) students with learning disabilities, and (2) students receiving additional academic interventions through Response to Intervention (RtI) systems due to academic risk factors. We will also disaggregate data by gender, socioeconomic status, and cultural background (see participant selection section for more information).

Makerspace Curricular Choices: It is important to work with models of makerspace curriculum that are both accessible and comparable, so our study can yield results that are applicable for a variety of school settings. Our first goal will be to fit makerspace learning experiences into existing curricular needs and STEM subject areas identified in collaboration with our partner schools. We will also ensure teacher objectives and interests inform our chosen activities and continually work with them throughout the development and execution process.

Many schools have already chosen to invest in makerspace technologies like 3D printing which are often limited to a single expensive printer for an entire classroom, or even school. They are often not available for use by students with disabilities, especially if they are taught in self-contained classes and if these classes require instructors with a great deal of time and specialized CAD design experience. We will provide an alternative to single-machine and expertise bottlenecks by drawing upon or developing entirely new introductory, easily scalable activities and selecting low-cost equipment good for group-based design. This may still involve photogrammetry-based 3D scanning or groups of reliable entry-level

3D printers but will certainly expand into other areas of rapid prototyping and fabrication that may aid in design learning. For instance, electronic cutters and simple microcontrollers like Arduino also offer a simple and affordable entry point into makerspace activities with the added benefit of greater potential for student ownership, exposure and investment. Participants can each have access to their own cutter during classroom activities and even take their small electronics projects home for homework or independent exploration. Equipment decisions like this are important because they support our core metacognitive strategies: regularized and supported access to makerspace technologies make it possible to more deeply engage with long-term prototyping projects that consequentially involve a lot of planning and failure, key elements that contribute to iteration, persistence and intentionality.

Our research team has received permission to collaborate directly and regularly with teachers in Champaign and Urbana schools to integrate and develop activities into existing classes. In Champaign this will include a system-wide STEM lab course that already focuses on extended design activities at the 7th and 8th grade levels and in Urbana an 8th grade all-students science class. The curriculum base will be informed by years of experience developing and hosting makerspace learning activities (ranging from 2-hour to multi-week workshops and camps) with similarly aged students at the Fab Lab. Table 2 provides a summary of past Fab Lab activities to help provide an idea of metacognitive targeted lessons. Actual lesson content and length will vary by location and teacher preferences.

Table 2: *Example Citizen Science, IoT and programming for automated data collection with Arduino*

Activity	Description
Exploring maker identities	Participants learn about "the Internet of Things" (IOT), Citizen Science and brainstorm ideas for civic data they'd like to collect. They then come up with systems/inventions, which are shared via storyboards. This activity includes emphasis on **intentionality**.
A sensor or component a day!	After learning Arduino fundamentals students use a different sensor or extension component each day: light, motion, temperature, motors, speakers, etc. They work with existing code to read data and send instructions to perform simple tasks, such as playing a simple MIDI song or creating a monster that moves. This requires **persistence** and **iterative** steps to achieve functionality.
Creating interactive inventions	Work in pairs to combine sensors to then plan and create simple microcontroller inventions. Examples include fluffy pom pom monsters that move when a motion sensor is triggered, or paper boxes that play a song when tossed or opened. This activity requires **intentionality** at the onset, **iteration** to add each sensor and **persistence** if (when) additions do not work as intended.
Analyze, share and refine data	Data collected from multiple sensor inventions is compiled together to make a classroom-wide experiment. Students discuss findings, validity and then repeat the experiment with **intentionality**, **iteratively** modifying the sensors or data processing in improved ways.

Instrument Adaptation Overview: Multiple instruments will be used to measure metacognitive processes found to be pertinent within the research process. We anticipate a focus on the following: **persistence (attitudes about making)**, **iteration (productive struggle)** and **intentionality (plan with incremental steps).** Our measures will be based on instruments either developed by our research team or others who study makerspaces. Table 3 summarizes expected variables and measurement instruments. Because of the exploratory nature of this study, it is difficult to know exactly what constructs related to metacognition we will be measuring as these will be revealed through the course of the study. As a result, we plan to work closely with expert members of our research team and the advisory board on validation and reliability issues.

1. Student Observation Protocols*:* Observations will focus on assessing engagement, persistence, intentionality and use of metacognitive strategies. We can learn a great deal by observing techniques and outcomes that may frustrate, challenge or satisfy participants. Protocols will be adapted from observation instruments currently used by our research team (e.g., Snodgrass, et al., 2016) as well as observation instruments being used in informal makerspace research (Blikstein et al., 2016). The observation guide we developed was adapted from the Scale for Teachers' Assessment of Routine Engagements (STARE; McWilliam, 2000), which encourages observers to look at what students are doing, how they are participating, what they can do on their own, and their social and communication skills. This protocol will be adapted to incorporate measures of students' use of metacognitive strategies, and components of the design/redesign process. The protocol will be adapted by exploring methodologies currently used to assess student engagement in makerspace activities. For example, Brahms (2014) used codes related to maker community learning practices such as (a) explore and question, (b) seek out resources, (c) customize, and (d) tinker, test, and iterate. Gutwill and colleagues (2015) classified learning in makerspace activities along four dimensions: (a) engagement, (b) iterative and intentionality, (c) social scaffolding, and (d) development of understanding. Several of these goals cross over to metacognitive processes as well. Along with protocol development, we will train our graduate assistants to use this instrument.

2. Collaborative Computing Observation Instrument *(C-COI)* Measures persistence, iteration and metacognitive strategy use*:* We will use ScreenCastify (a free screen capture software that records students' screens and audio of discussions with fellow students) when students are engaged in computer-mediated maker activities. We previously developed and validated a data analysis tool called the C-COI (Israel, et al., 2015b; Israel et al., 2016) to analyze video screencast data of students during collaborative computer-supported learning. The C-COI allows us to observe and analyze the on-screen behaviors of the students as well as the conversations that they have while they complete computer-based makerspace activities. Because of the time intensive nature of video data analysis, we will purposefully select a small sample of students for this video analysis. The C-COI will be used to measure (1) time on task/persistence, and (2) metacognitive strategy use. The C-COI also measures collaborative interactions although this is not its main purpose for this study. This instrument was developed collaboratively by experts in STEM education, collaborative problem solving, and computer science education. It has been piloted over the course of four years. This instrument will be adapted to specifically target the metacognitive strategies.

3. Teacher Interview Protocol: Measures barriers to learning and engagement in makerspace activities, and provides feedback on metacognitive strategy instruction. Our research team developed and piloted a makerspace instructor/facilitator interview protocol in the summer of 2016. This protocol will be used to gather information on teacher choices that aide the development of the metacognitive strategies embedded in the makerspace activities. Information from these interviews will help with the iterative development of the strategies. These interviews also focus on struggling learners' barriers, effectiveness of the metacognitive strategies, and challenges to implementation.

4. Student artifacts and artifact-based interviews: Measures iteration, intentionality, and metacognitive strategy use. It is important to assess the physical or virtual products students develop through the making process and ask students directly about their creations. We intend to both conduct both content analysis of the student products and artifact-based interviews (Brennan & Resnick, 2012). Content analysis of products treated as artifacts may reveal important reflections of student interests, perceptions and values that can help to inspire or inform future curriculum. Artifact-based interviews will allow us to investigate students' thinking processes and design choices identified during initial observations in a similar fashion as Brennan and colleagues have done for assessing computational thinking in their ScratchED work (Brennan and Resnick, 2012). In artifact-based interviews, students talk about their products and practices using their work as a guide for the conversation. Interview protocols for these interviews will be developed based on Brennan and colleagues' work to include questions such as: (a) Tell me about your product, (b) Did this work as expected? and (c) describe how you tested or made changes to your product. This will allow us to better understand participant thinking process as it is tied to physical outcomes and social implications. We will also treat curriculum materials used by students, such as planning worksheets, storyboards or other ideation content as potential artifacts available for analysis. Though they may not be exclusively created by a single learner they also provide insight into crucial thinking processes.

Table 3: *Variables and associated Variables*

Variables	Instruments
Barriers to engagement and learning	Student observations, C-COI, teacher interviews
Persistence	Student observations, C-COI, artifact-based interviews
Intentionality	Student observations, artifact-based interviews
Iteration	Student products, artifact-based interviews, C-COI
General use of metacognitive strategies	Student observations, C-COI, artifact-based interviews

Data Collection Sites: Three middle schools in Champaign Unit 4 School District as well as Urbana Middle School will participate in this study (see letters of commitment). We will primarily collect data in 7th and 8th grade STEM Lab classrooms in Champaign and 7th and 8th grade science classes in Urbana.

In Champaign each of the three middle schools has a quarterly rotation of STEM Lab classes. Each quarter there are approximately 180 7th and 8th grade students enrolled in these technology-based classes across all three middle schools. This rotation allows us to conduct studies throughout the academic year with new students, enabling rapid iteration on the strategy development process rapidly. In total over 700 students will go through the proposed STEM programming. Student demographic composition is approximately 45% female, 55% male, 44% African-American, 35% Caucasian/White, 10% Hispanic, 14% Asian, and 6% having two or more cultural backgrounds. Approximately 60 % of the students are considered low-income and 15% of the students have learning disabilities.

Urbana has a year-long science class with several units that are available at times for makerspace activities. The teacher of this class sees ~100 8th grade students in the school, including those at risk for academic failure with learning disabilities. Her students are 49% female, 51% male, 5% Asian, 39%

Black, 20% Hispanic, 30% Caucasian/White and 6% multiracial. Around 70% are considered low-income and 26% have learning disabilities.

Identification of Student Sample: We will examine the effects of metacognitive strategies that support struggling learners, with specific attention to students with disabilities and students at risk for academic failure (see Table 5). Although not the focus of this study, we will also disaggregate data based on socioeconomic status, gender, and cultural background as these variables are potentially confounding variables and important characteristics to consider for developing makerspace activities that have broad appeal to all learners. A main disability category we will focus on are **learning disabilities** (LD), which are neurological conditions that interfere with learning including reading, reasoning, and mathematical calculations (National Joint Committee on Learning Disabilities, 2001). This is an important population because LD is the largest category of students receiving special education services, with approximately 2.4 million U.S. school children having LD (Cortiella & Horowitz, 2014). We will also purposefully select students with other disabilities (e.g., autism spectrum disorder, emotional/behavioral disorder) to ascertain whether the challenges faced by students with LD are similar to those with other disability categories (i.e., autism spectrum disorder, behavioral/emotional disability) as well as the use of the metacognitive strategies with these learners. Lastly, we will also examine students at **risk for academic failure**, who do not perform on grade level academically and receive additional instructional supports through school-wide Response to Intervention (RtI) programs to help them become more successful academically. These students' difficulties result from many reasons not tied to a disability such as chronic absenteeism, difficulty learning academic content language, stressful family life, etc. This population of learners is important because they often fall through the cracks while struggling academically. The focus on these two groups of learners is critical due to the fact that they chronically underperform in the STEM areas as compared to their peers (NCES, 2011) and remain underrepresented in STEM fields (NSF, 2013). The rationale for examining and disaggregating data for a broad range of learners is that our hypothesis is that the metacognitive strategies developed through this project may be beneficial to a larger proportion of learners beyond those with LD or those receiving Tier 2 instructional supports.

Table 4: *Methods of Identifying Student Demographics*

Student Demographics	**Method of identification/ Types of School Records**
Disability	An Individualized Education Program for a primarily disability such as learning disability (LD).
Other Academic Risk Factors	Intervention supports through Response to Intervention (RtI) program, Presence of a behavior intervention plan, etc.
Socioeconomic Status	Eligibility for free or reduced lunch status
Gender & Ethnicity	General school records

Pre-Pilot Data Collection: Our research group has already begun to investigate a preliminary set of metacognitive strategies in collaboration with a CU Community Fab Lab camp series. Over the summer of 2016 we observed over 60 students engaged in 5 different week-long half-day summer camps, including RPG videogame design, e-textiles monster creation, artistic automation with Arduino and a design process studio. This set of camps included a video game camp specifically for participants receiving services for autism spectrum disorder. Data was collected using the same observation model proposed here and subsequently coded in Dedoose and cross-checked. Instructors were then interviewed about camper experiences and invited to talk about curricular materials that learners engaged with as part of their learning. Several additional metacognitive strategies were tentatively identified, including creativity, organization, self-compassion and others in addition to the trio defined in this proposal: iterative design, intentionality and persistence. Table 5 illustrates the likelihood of identifying proposed and additional emergent metacognitive strategies. We believe our preliminary research demonstrates the viability of our proposed model.

Table 5: *Presence of metacognitive learning strategy instruction*

Metacognitive Strategies / **Camp**	Collaboration	Communication	Creativity	Intentionality	Iterative design	Organization	Persistence	Playfulness	Self-Compassion
Art with Arduino			XXXX	XXXX	XX	X			
Camp Fab Lab II Design Studio	XXX	XXX	XXX	XXX	XXX				
Monster Maker	X	XX	XX	XX		X	XXX	XXX	X
RPG Video Game Design	X	X		XXX	XXX	X	XXX	X	
Special Needs RPG Video Game Design	X		XX	XX	X	X			

<u>Data Analysis by Research Question</u>: As we conduct analyses for all research questions, we will engage our lead contacts and expert advisors. We will work together to interpret findings, particularly as we interpret them for the revision of instructional strategies.

After analysis of pilot data we will develop initial supports and metacognitive strategies to facilitate increased engagement and learning for students at risk for academic failure. We will then pilot these metacognitive strategies and begin to iteratively refine them through a second pilot study. These progressive studies will result in a revised set of metacognitive strategies and support materials for implementing making experiences for struggling learners.

RQ1: How are struggling learners (including students with disabilities and those at-risk for academic failure) engaging in maker experiences? What barriers exist for struggling learners in middle schools during makerspace activities? To answer this question, we will purposefully select students across four middle school environments to **observe** during makerspace activities. During this research phase, we will conduct a pilot data collection to investigate barriers to learning during makerspace activities by observing students during diverse makerspace activities (like those proposed in Table 2). We will also **interview teachers** to better understand perceptions of the students' difficulties during the makerspace activities. **Screencast data** will also be used to carefully analyze the work of a purposefully selected group of learners including students with LD and those at risk for academic failure. We will conduct this analysis using the ***Collaborative Computing Observation Instrument (C-COI)*** (Israel et al., 2015) to enable us to track students' making activities including the following: independent problem solving, areas of emerging problems, persistence in computer-mediated makerspace activities, expressed frustration, and problem solving. **Artifact based interviews and content analysis** will then be used to discuss and examine evidence of iterative design.

Qualitative analysis of student observations, artifact based interviews, and teacher interviews. We will transcribe all the audio-recorded interviews, compile the observation notes, and calculate an approximate amount of time each student spent engaged in each makerspace activity using the observation notes and screencast data. We will conduct case studies by using explanation building (Yin, 2009) and because of the exploratory nature of this study, we will utilize Yin's four-step process for conducting explanation building within case studies. To conduct cross case analyses across middle schools we will use the procedures set forth by Stake (2006) and Yin (2009). First, the research team will read the individual cases, comparing their interpretations with one another and the data and discussing the explanatory statements until consensus is reached in order to confirm that our final explanatory statements are defensible and in alignment with data collected. Then, the research team will discuss the cases and use these to develop a cross-case assertion (Stake, 2006) about the barriers, support needs, and metacognitive strategy use of struggling learners across the case studies.

RQ2: How can metacognitive strategy instruction (including modeling, think-aloud protocols, and practice) support students with disabilities and other struggling learners to meaningfully engage in the design/redesign process within makerspace experiences? To answer this research question, we will undergo two additional cycles of data collection and analysis. This process will allow us to iteratively refine the metacognitive strategies based on the data that we collect and analyze. The development of the metacognitive strategies will be based on the literature from Question 1 (see Table 1) as well as best practices in metacognitive strategy instruction found effective in mathematics (e.g., Rosenzweig et al., 2011) and science (e.g., Veenman, 2012).

We will employ the same methodologies described to answer Research Question 2 as related to student observations, the use of screencast data and teacher interviews. Additionally, we will code student observation data to reflect whether and how the metacognitive strategies are being used by the students. The metacognitive strategies will be taught through a strategic instruction approach (Deshler & Lenz, 1989; Rosenzweig et al., 2011), which has been successful in teaching metacognitive strategies in other areas such as reading and math. This approach includes: modeling, think-aloud protocols, guided practice moving towards independent practice, and checking for generalizability.

Communication and Dissemination: UIUC has extensive experience sharing findings, with both conventionally academic as well as practitioner-oriented strategies. First, we will capitalize on existing outreach websites to include our curricula and strategies, alongside other resources associated with our project. Second, we will communicate research findings through presentations and publications in peer-reviewed practitioner and research journals. In addition to these approaches, we will also take steps to share our work with the field as it emerges. More specifically, we will periodically generate a research brief that describes our work in progress. We will also hold at least one webinar for those interested in accessible middle school makerspaces for diverse learners, focused on lessons we are learning and practical advice for bringing accessible and engaging makerspace instruction to broad audiences.

Table 6: *Timeline of Project Activities*

Timeline	Fa 17	Sp 18	Sum 18	Fa 18	Sp 19	Sum 19
Advisory Board Meetings (face to face and virtual) **Feedback will occur in meetings & online	Feedback on research and implementa-tion plans		Data sharing, Refine strategies	Data sharing, Refine strategies		Data sharing Final report
Collaboration Team Meetings	We will meet weekly to plan research activities including literature review, data collection & analysis, communication with advisory board.					
Instrument Development and Refinement	We will begin to develop research instruments Fall 2017. We anticipate refining instruments throughout the study.					
Makerspace Experience Implementation Schools: E=Edison, J=Jefferson, F=Franklin, U=Urbana	**E, J, F, U** Observe for barriers (Oct/Nov)	**J, U** Pilot Phase (Feb/Mar)		**E, J, F, U** Research implementation		
Teacher Interviews	Barriers in maker activities	Initial metacog strategy		Updated metacog strategy		
Analyze Teacher and Student Data	Mixed methods data analysis will be ongoing beginning with the pre-pilot data of barriers to engagement in makerspaces in October of 2017 though analysis of the 2 subsequent pilot studies.					
Metacognitive strategies refinement Sessions		We will iterate the metacognitive strategies based on pilot data identifying barriers and through the 2 subsequent pilot studies.				
Writing and Dissemination		We will share resources, findings, and curricular materials throughout the project on the website, through conference papers and presentations, and webinars.				
External Evaluation	Feedback on pilot re-search plan	Observation of pilot implementation	Review of pilot phase, feedback on revised plans	Observation and interviews		Final report

RESEARCH TEAM AND PREVIOUS RESEARCH

This project will build on 6 years of hands-on and STEAM-focused community-wide engagement by the CU Community Fab Lab for academically diverse learners diverse learning environments. Previous research activities include several state and internal university grants related to capacity building, digital literacy and engagement of underserved populations as well as several projects tied to senior personnel. Additionally, the Fab Lab is a key collaborator on Bridging the Divide: Exploring Native Approaches to Science Through Analysis of Implementation of a Complex Information Technology in Alaska Native Communities (NSF #1345026, PI: M. Scott Poole). Additional details on these grant-funded projects are available on the website at http://cucfablab.org/community-engagement/grants.

<u>Results from Prior NSF Support:</u>

Maya Israel: DRL-1542828: $1,210,300, 10/01/15 - 09/30/17, Learning trajectories for integrated K-5 Computer Science and Mathematics. This recently funded NSF STEM+C Track 1 project seeks to develop learning trajectories that align computational thinking and mathematics instruction for a broad range of learners. *Intellectual Merit:* This project is producing hypotheses about goals and learning paths for elementary school computer science and is developing insight into the feasibility of a learning-trajectory based approach to the integration of computer science within mathematics instruction. *Broader Impacts:* This project's learning trajectories will be foundational for the design and development of instructional materials and assessments for computer science in grades K-5. This project has produced a preliminary database of empirical studies and initial mathematics lessons that include embedded computer science and computational thinking. No publications have resulted from this project to date.

Lisa Bievenue: CNS-1339270: $830,886, 01/01/14-12/31/2016, CE21: CS10K: CISS: Computing in Secondary Schools. Cleveland State University (CSU) is collaborating with the University of California San Diego (UCSD) on a CS10K project designed to provide computer science education professional development to high school teachers throughout the state of Ohio. Bievenue's role in this project is as external evaluator. *Intellectual Merit*: This project seeks to validate the CS Principles curriculum in Ohio, confirming similar research in California. *Broader Impacts*: This project is adapting and extending the CS Principles course developed at UCSD as part of the ComPASS project to enable a broader audience of teachers. No publications have resulted from this project to date.

EXPERTISE

PI Dr. Jeff Ginger is the Director of the CU Community Fab Lab and a program coordinator and adjunct instructor with the Illinois Informatics Institute and iSchool. Dr. Ginger will oversee the entire project and assist with curriculum development, professional training for teachers, implementation and research.

Co-PI Dr. Maya Israel is an assistant professor in the Department of Special Education. She specializes in increasing access and engagement for struggling learners, including those with disabilities, in Science, Technology, Engineering, and Mathematics (STEM) with a focus on technology-mediated learning. Dr. Israel will oversee metacognitive strategy development and school-based data collection and analysis.

Co-PI Lisa Bievenue is Assistant Director at the Illinois Informatics Institute, where she manages research and outreach activities, including at the CU Community Fab Lab. Ms. Bievenue will contribute to the research design and implementation with regard to learning in the context of making activities.

<u>Other Project Personnel:</u>

Rebecca Teasdale is a doctoral student in the Department of Educational Psychology studying evaluation and research methodologies for investigating makerspaces and making activities in library and museum contexts. Ms. Teasdale will work with Dr. Israel to collect and analyze school-based data.

Suzanne Linder is a teacher consultant with the Fab Lab, adjunct instructor at the Illinois Informatics Institute and has extensive background in makerspaces and teacher professional development. Ms. Linder will develop the curriculum and materials for the making activities to be implemented in the schools.

Johnell Bentz is the Assistant Head and Clinical Associate Professor in Special Education, and earned her PhD in Special Education from Vanderbilt University. Dr. Bentz will contribute to this project by helping develop metacognitive learning strategies for participants identified with disabilities.

PROJECT EVALUATION AND REVIEW

External Project Evaluation: An external formative evaluation will inform both the research and project management in order to assess and improve the research design and implementation to meet project goals and produce useful research. The evaluation framework is based on the National Research Council's report (2002) on the scientific bases for educational research using a mixed methods approach with heavy reliance on qualitative data in order to develop a complete understanding of how and why. Year 1 deliverables include written review of the initial pilot research plan, quarterly formative reports, and a post-pilot phase review. Year 2 deliverables include review of revised research and implementation plans, quarterly formative reports, and a final summative report. Analysis will be based on a combination of 1) review of the research design and data collection instruments, 2) review of pilot research and implementation plans, 3) observation of all variations and iterations of implementation and data collection, including a comparison analysis of implementation plans and actual implementation, 4) teacher and researcher interviews, 5) review of research data analyses and reports.

Michele Perry, M.A. is a retired special education teacher who also has 15 years of experience leading mixed method research and evaluation efforts on K-12 learning assessment, as well as external project evaluations for large urban and statewide K-14 education projects (Illinois, California, Texas). Her expertise is in qualitative data collection and analysis.

Advisory Team: The project team will draw heavily on the expertise of an external advisory team to evaluate the project's efforts and provide critical formative feedback on project performance and outcomes that will inform its work. Direct feedback from the advisors to the project will be based primarily on their review of documents and other products provided by the project team and will be provided via written comments, conference calls, and virtual meetings.

Dr. Jennifer Greene works in the domain of educational and social program evaluation and seeks to advance the theory and practice of alternative forms of evaluation, including qualitative, democratic, and mixed methods evaluation approaches. Dr. Greene will advise the project regarding both research and evaluation methodologies. Dr. Greene will support instrument development and research design.

Rabiah Mayas, Ph.D. is involved in the design and implementation of Chicago's Museum of Science and Industry's program evaluation and research, coordination of digital learning initiatives, development of public programming for youth and adults, and facilitation of the integration of cutting-edge scientific content throughout Museum programming. She also directs the Museum's Wanger Family Fab Lab. Dr. Mayas earned an M.S. and a Ph.D. in Biochemistry and Molecular Biology at the University of Chicago and a B.S. in Biochemistry and Molecular Biology from the University of Maryland Baltimore County.

Matt Marino, Ph.D. is an associate professor of Exceptional Education at the University of Central Florida. He is a former science and technology teacher. His state and federally-supported research focuses on design and implementation of technology-enhanced STEM curricular materials for struggling learners, including students with disabilities. He has a background in both metacognitive strategy instruction and technology-mediated learning for students with disabilities and other struggling learners.

Lorie Becraft is a teacher at East Peoria Community High School. She has created a makerspace club and new makerspace class at her high school and received several community grants to make these programs a reality for her students. She will provide practical teaching applications and feasibility of classroom implementations based on her experiences with teaching and learning in the makerspace setting.

References Cited

Anderson, C. (2008). *The Long Tail: Why Future Business is Selling Less of More*. New York, NY: Hyperion Books.

Angevine, C. & Weisgrau, J. (2015, September 24). Situating makerspaces in schools. *Hybrid Pedagogy*. Retrieved on November 27, 2015 from http://www.hybridpedagogy.com/journal/situating-makerspaces-in-schools/

Aydın, U., & Ubuz, B. (2010). Structural model of metacognition and knowledge of geometry. *Learning and Individual Differences*, *20*(5), 436-445.

Bajarin, T. (2014, May 19). Why the Maker Movement is important to America's future. *Time Magazine.* Retrieved on November 27, 2015 from http://time.com/104210/maker-faire-maker-movement/.

Berland, M. (2016). "Making, Tinkering, and Computational Literacy." In *Makeology* by Peppler, K., Rosenfeld-Halverson, E., & Kafai, Y.B. (eds). New York; Routledge, 196-205.

Bevan, B., Gutwill, J., Petrich, M., & Wilkinson, K. (2015). Learning through STEM-rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education*, *99*(1) 98-120.

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLab: Of Machines, Makers and Inventors* (pp. 2–22). Bielefeld: Transcript Publishers.

Blikstein, P., & Krannich, D. (2013, June). The makers' movement and FabLabs in education: Experiences, technologies, and research. In *Proceedings of the 12th International Conference on Interaction Design and Children* (pp. 613-616). ACM.

Blikstein, P., Martinez, S.L., & Pang, H.A. (2016). Meaningful Making: Projects and Inspirations for Fab Labs and Makerspaces. Torrance, CA: Constructing Modern Knowledge Press.

Brahms, L. & Wardrip, P. (2014, December). The learning practices of making: An evolving framework for design. Children's Museum of Pittsburgh. 20 pp. Retrieved on November 29, 2015 from http://makeshoppgh.com/wp-content/uploads/2015/02/MAKESHOP-Learning-Practices-formatted_FINAL_Feb-2015.pdf.

Brahms, L.J. (2014). Making as a Learning Process: Identifying and Supporting Family Learning in Informal Settings. Dissertation, University of Pittsburgh. Retrieved from http://d-scholarship.pitt.edu/21525/1/L_Brahms_ETD_2014.pdf.

Brennan, K., & Resnick, M. (2012, April). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American Educational Research Association, Vancouver, Canada*.

Brigham, F. J., Scruggs, T. E., & Mastropieri, M. A. (2011). Science education and students with learning disabilities. *Learning Disabilities Research & Practice*, *26*(4), 223-232.

Brown, A. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. Weinert & R. Kluwe (Eds.). *Metacognition, Motivation, and Understanding* (pp. 65-116). Hillsdale, NJ: Erlbaum.

Cortiella, C., & Horowitz, S. H. (2014). The State of Learning Disabilities: Facts, Trends and Emerging Issues. *New York: National Center for Learning Disabilities*.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Davee, S., Regalla, L. & Chang, S. (2015, May). Makerspaces: Highlights of select literature. Maker Educational Initiative. Retrieved from MakerEd website: http://makered.org/wp-content/uploads/2015/08/Makerspace-Lit-Review-5B.pdf

Deshler, D. D., & Lenz, B. K. (1989). The strategies instructional approach.*International Journal of Disability, Development and Education*, *36*(3), 203-224.

Dorph, R., & Cannady, M.A. (2014). Making the future: Promising evidence of influence. A report submitted to Cognizant Technologies by The Research Group, The Lawrence Hall of Science, University of California, Berkeley.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science.

Flavell., J. H. (1987). Speculation about the nature and development of metacognition. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, Motivation, and Understanding* (pp. 21-29). Hillsdale, NJ: Erlbaum.

Gersten, R., Fuchs, L. S., Williams, J. P., & Baker, S. (2001). Teaching reading comprehension strategies to students with learning disabilities: A review of research*. Review of Educational Research*, 71(2), 279-320.

Gutwill, J.P., Hido, N., and Sindorf, L. (2015). Research to Practice: Observing Learning in Tinkering Activities. *Curator: The Museum Journal*, *58*(2) 151-168.

Halverson ER, Sheridan K. (2014). The maker movement in education. *Harvard Educational Review*, *84*(4): 495-504.

Halverson, E. R., & Sheridan, K. (2014). The Maker movement in education. *Harvard Educational Review, 84*(4), 495-504.

Händel, M., Lockl, K., Heydrich, J., Weinert, S., & Artelt, C. (2014). Assessment of metacognitive knowledge in students with special educational needs. *Metacognition and Learning*, *9*(3), 333-352.

Händel, M., Lockl, K., Heydrich, J., Weinert, S., and Artelt. C. (2014). Assessment of metacognitive knowledge in students with special educational needs. *Metacognition Learning,* 9, 333–352.

Hira, A., Joslyn, C. H., & Hynes, M. M. (2014, October). Classroom makerspaces: Identifying the opportunities and challenges. In Frontiers in Education Conference (FIE), 2014 IEEE (pp. 1-5). IEEE.

Hira, A., Joslyn, C.H., and Hynes, M.M. (2014, October). Classroom Makerspaces: Identifying the Opportunities and Challenges. *2014 IEEE Frontiers in Education Conference*, 1677-1681.

Hora, M. T., & Oleson, A. K. (2015). Peering inside the black box of undergraduate study habits: The centrality of self-regulated learning in a digitized world. *WCER Working Paper No. 2015-3.* Wisconsin Center for Education Research. Retrieved from http://www.wcer.wisc.edu/publications/workingpapers/Working_Paper_No_2015_03.pdf

Israel, M., Maynard, K., & Williamson, P. (2013). Promoting literacy-embedded, authentic STEM instruction for students with disabilities and other struggling learners. *Teaching Exceptional Children*, *45*(4), 18-25.

Israel, M., Pearson, J. N., Tapia, T., Wherfel, Q. M., & Reese, G. (2015). Supporting all learners in school-wide computational thinking: A cross-case qualitative analysis. *Computers & Education*, *82*, 263-279.

Israel, M., Ramos, E., Wherfel, Q. M., & Shehab, S. (2015) Collaborative Computing Observation Instrument (C-COI). Board of Trustees of the University of Illinois at Urbana-Champaign. Available at http://mste.illinois.edu/c-coi/.

Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2015). NMC Horizon Report: 2015 K-12 Edition. Austin, Texas: The New Media Consortium. Retrieved from http://www.nmc.org/publication/nmc-horizon-report-2015-k-12-edition/

Justice, S. & Markus, S. (2015). *Educators, gender equity and making: Opportunities and obstacles*. FabLearn 2015: Conference on Creativity and Fabrication in Education, Stanford University, Palo Alto, CA.

Kafai, Y. B., Lee, E., Searle, K., Fields, D., Kaplan, E., & Lui, D. (2014). A crafts-oriented approach to computing in high school: Introducing computational concepts, practices, and perspectives with electronic textiles. *ACM Transactions on Computing Education (TOCE)*, *14*(1), 1.

Kelly, T., & Littman, J. (2005). The ten faces of innovation: IDEO's strategies for beating the devil's advocate & driving creativity throughout your organization. New York: Currency/Doubleday.

Kurti, R.S., Kurti, D.D., & Fleming, L.I. (2014). The environment and tools of great educational makerspaces. *Teacher Librarian, 42*(1), 8.

Learning Activation Lab (n.d.). STEM Learning Activation Survey [Measurement instrument]. Available from http://www.activationlab.org/tools/

Martin, L. (2015) "The Promise of the Maker Movement for Education," *Journal of Pre-College Engineering Education Research (J-PEER)*, **5**(1), 30-39. http://dx.doi.org/10.7771/2157-9288.1099

McWilliam, R. A. (2000). Scale for Teachers' Assessment of Routines Engagement. *Engagement of every child in the preschool classroom*, 168-170.

Minstrell, J., & Van Zee, E. (2000). Teaching in the Inquiry-based science classroom. *Washington, DC: American Association for the Advancement of Science*.

National Center for Education Statistics. (2011). Nation's Report Card: Science 2009 (NCES 2011-451). Washington DC: Institute of Education Sciences. U.S. Department of Education.

National Joint Committee on Learning Disabilities. (2001). *Learning disabilities: Issues on definition*. In National Joint Committee on Learning Disabilities (Ed.), Collective perspectives on issues affecting learning disabilities: Position papers, statements, and reports (2nd ed., pp. 27–32). Austin, TX: Pro-Ed. Available from http://www.ldonline.org. (Original work published 1990)

National Research Council (2002). *Scientific Research in Education*, National Research Council: Washington, DC.

National Research Council (2015). Next Generation Science Standards. Retrieved on November 27, 2015, at http://www.nextgenscience.org/.

National Science Foundation, National Center for Science and Engineering Statistics. (2013). Women, minorities, and persons with disabilities in science and engineering: 2013. Special Report NSF 13-304. Arlington, VA. Retrieved from http://nsf.gov/statistics/wmpd/

Neff, G., Stark, D. (2004). "Permanently Beta: Responsive Organization in the Internet Era." In P.N. Howard, S. Jones. (Eds.), *Society Online: Internet in Context*. Thousand Oaks, CA: Sage Publications, 173-188.

Papert, S. (1980) *Mindstorms: Children, Computers, and Powerful Ideas*. New York: Basic Books.

Peppler, K. & Kafai, Y. B. (2010). Gaming fluencies: Pathways into a participatory culture in a community design studio. *International Journal of Learning and Media*, 1(4), pp. 1-14.

Peppler, K. (2013, September). STEAM-powered computing education: Using e-textiles to integrate the arts and STEM. *Computer*, *46*(9), 38-43.

Peppler, K., & Glosson, D. (2013). Stitching circuits: Learning about circuitry through e-textile materials. *Journal of Science Education and Technology, 22*(5), 751-763.

Peppler, K., Rosenfeld-Halverson, E., & Yasmin, K.B. (2016). *Makeology: Makers as Learners*. New York: Routledge.

Petrich, M., Wilkinson K., & Bevan, B. (2013). It looks like fun, but are they learning? In M. Honey & D. Kanter (Eds.), *Design, make, play: Growing the next generation of STEM innovators* (pp. 50–70). New York: Routledge.

Resnick, M., & Rosenbaum, E. (2013). Designing for tinkerability. In M. Honey & D. Kanter (Eds.), *Design, make, play: Growing the next generation of STEM innovators.* New York: Routledge, 163-181.

Rivera Maulucci, M. S., Brown, B. A., Grey, S. T., & Sullivan, S. (2014). Urban middle school students' reflections on authentic science inquiry. *Journal of Research in Science Teaching*, *51*(9), 1119-1149.

Robinson, K. (2011). *Out of Our Minds: Learning to Be Creative*. West Sussex: Capstone Publishing.

Rosenzweig, C., Krawec, J., & Montague, M. (2011). Metacognitive strategy use of eighth-grade students with and without learning disabilities during mathematical problem solving a think-aloud analysis. *Journal of learning disabilities*, *44*(6), 508-520.

Schneider, C. (2015). The rise of Maker Ed. Getting Smart, November 19. Retrieved on November 27, 2015, at http://gettingsmart.com/2015/11/infographic-the-rise-of-maker-ed/.

Schraw, G. (1998). Promoting general metacognitive awareness. *Instructional Science* 26**,** 113–125,

Sheridan, K. M., Clark, K., & Williams, A. (2013). Designing games, designing roles: A study of youth agency in an urban informal education program. *Urban Education, 48*(5), 734-758.

Snodgrass, M. R., Israel, M. & Reese, G. (2016). Instructional supports for students with disabilities in K-5 computing: Findings from a cross-case analysis.

Stake, R. E. (2006). *Multiple case study analysis.* New York: Guilford.

Surowiecki, J. (2005). *The Wisdom of Crowds*. New York: Anchor Books.

Veenman, M. V. (2012). Metacognition in Science Education: Defi nitions, Constituents, and Their Intricate Relation with Cognition. In *Metacognition in science education* (pp. 21-36). Springer Netherlands.

Villanueva, M., & Hand, B. (2011). Science for All: Engaging students with special needs in and about science. *Learning Disabilities Research & Practice,* 26, 233-240.

Vossoughi, S., Escudé, M., Kong F., & Hooper, P. (2013, October). Tinkering, learning and equity in the after-school setting. Paper presented at the annual FabLearn conference. Palo Alto, CA: Stanford University.

White House. (2016). “Compiled Diagnostic Statements” in *Nation of Makers*. Makerspace Organizers Meeting and Workshop held on August 24, 2016. Available online at https://docs.google.com/document/d/1g5uN7uVxu-wk7sV_tokE5--JAEkT8tUxdoP6PNAtbVo/edit#

Yin, R. K. (2009). Analyzing case study evidence: How to start your analysis, your analytic choices, and how they work. In R. Yin, *Case study research: Design and methods* (4th ed). Thousand Oaks, CA: Sage, 126-163.

Zull, J. E. (2002). *The art of changing the brain: Enriching teaching by exploring the biology of learning*. Stylus Publishing, LLC.