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Makification: Towards a Framework for Leveraging the Maker Movement in Formal Education

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Abstract

Maker culture is part of a burgeoning movement in which individuals leverage modern digital technologies to produce and share physical artifacts with a broader community. Certain components of the maker movement, if properly leveraged, hold promise for transforming formal education in a variety of contexts. The authors here work towards a framework for leveraging these components (i.e., creation, iteration, sharing, and autonomy) in support of learning in a variety of formal educational contexts and disciplines.

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At the first ever White House Maker Faire, President Obama said, “Today’s D.I.Y is tomorrow’s ‘Made in America’”, acknowledging the importance of the growing maker movement and its impact on our country (Obama, 2014). Many educational researchers share his excitement and view the maker movement as an innovative way to reimagine education (Halverson & Sheridan, 2014; Peppler & Bender, 2013; Vossoughi, Hooper, & Escudé, 2016). However, utilizing elements of the maker movement to improve student learning in formal educational contexts is a non-trivial task, and requires close examination of learning through making and how related strategies can be implemented effectively within our current educational environments

Halverson and Sheridan (2014) broadly define the maker movement as “the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" (p. 496). The maker movement is an evolution of earlier times in this country when many people thought of themselves as tinkerers, and popular publications such as *Make* magazine carry on traditions started by publications such as *Popular Mechanics* (Dougherty, 2012). Though the instinct to make and share the products of making is certainly not a new phenomenon, the ease with which makers can not only create complex and personalized physical objects but also share the processes and results with others is unique to the current historical moment. While the previous decades introduced the democratization of information through personal computers and the Internet, the current maker movement is ushering in the democratization of production of physical artifacts through emerging digital fabrication (Bell et al., 2010; Gershenfeld, 2012). Tools such as 3D printers, laser cutters, and digital die cutters provide consumers with the ability to fabricate artifacts with a level of precision that was in earlier decades solely the domain of professionals. As well, the rise of the Internet has allowed consumers the ability to share instructions, advice, and products of making globally with others through websites such as sketchfab.com, www.thingiverse.com, and www.instructables.com.

There is much about the maker movement that is relevant to the field of education, and there are components of the maker movement and maker culture that, if properly leveraged, could benefit formal education. Halverson and Sheridan (2014) suggest that learning in making is not interchangeable with schooling, and while organizations have made significant strides in bringing the maker movement to afterschool programs at museums and community centers, a more powerful application of this movement may lie in the integration into formal education (Dougherty, 2012). Research in this area is in its infancy, however emerging projects such as

Paulo Blikstein’s FabLab@School project are beginning to consider how elements of the maker movement can be adapted for formal K-12 settings (Blikstein, 2013; Halverson & Sheridan, 2014). To integrate elements of the maker movement effectively into formal educational settings, thoughtful inclusion of these technologies into classrooms and curriculum designs will be required. To that end, we begin to suggest here a framework for leveraging aspects of the maker movement in formal education that we term *makification*. Simply put, we define makification as the process of taking characteristic elements from the maker movement and infusing them into formal educational activities in a variety of contexts.

In the following sections, we first describe a theory of learning, constructionism (Papert, 1991), which underpins our thinking about employing elements of the maker movement into formal educational contexts. Second, we examine how the modern maker movement may extend this framework, and finally we begin to identify elements necessary for incorporating making activities into instructional activities designed explicitly to facilitate different kinds of learning. In doing so, we bridge theory with practice, and begin to illustrate a practical framework both to assist K-12 teachers in incorporating making into their curriculum and to provide a foundation on which to build further research in this area.

Constructionist Theory of Learning

While learning through making is compatible with several existing educational theories, many researchers consider constructionism (Papert, 1991) as a theory of learning which undergirds the use of elements from the maker movement for educational purposes (Halverson & Sheridan, 2014; Martinez & Stager, 2013; Vossoughi & Bevan, 2014). Constructionism holds that learners can construct knowledge specifically when they actively participate in the making and public sharing of a physical object (Papert, 1991). As such, it is aligned with Piagetian constructivist views of learning, which hold that the process of learning involves the active construction of knowledge and the continual revision of mental representations of that learning. Papert's constructionism is a "pillar" (Blikstein, 2013, p. 4) of constructionism, and, correspondingly, his work deeply informs the makification framework.

If constructionism is the undergirding learning theory behind makification, then it is important to focus on the two pillars of constructionism, making and sharing, as they relate to makification. The act of physically producing an artifact, as opposed to simply constructing a mental representation, affords the creator an opportunity to situate or contextualize that object into a broader system (Ackermann, 2001; Papert, 1991). This privileging of situated learning into a specific context, as opposed to the more abstract, detached, formal thinking favored in traditional epistemology, is consistent with modern theories of learning (Ackermann, 2001; Brown, Collins, & Duguid, 1989).

Concrete artifacts are, by their nature, more easily shared than abstract thinking. The process of sharing encourages the type of learning environment in which novices are not separated from experts, and, importantly, creates some of the conditions necessary for learning for both the novices and the experts (Papert, 1980, 1991). In this way, much of the power of constructionist learning environments comes from the development of and interaction in a community of practice (Wenger, 1999).

Learning and Activities within the Maker Movement

With growing interest in the types of informal learning that happens while engaged in maker activities, researchers have been studying various makerspaces, Maker Faires, and other communities associated with the maker movement. Noting the uniqueness of each space, researchers have observed that makerspaces are contextualized communities that suit their diverse members' interests and focus on a variety of activities and techniques, such as combinations of electronics, textiles and/or digital fabrication (Anderson, 2012; Dougherty, 2012; Hatch, 2014; Peppler, Maltese, Keune, Chang, & Regalla, n.d.-a). The literature also highlights core characteristics that define both the community mindset and the nature of activities that take place within makerspaces, including physical making that employs multidisciplinary approaches to solve problems (Halverson & Sheridan, 2014; Martin, 2015; Peppler & Bender, 2013), sharing ideas and artifacts with others (Anderson, 2012; Brahms, 2014; Sheridan et al., 2014), iteration that has a failure-positive approach (Brahms, 2014; Sheridan et al., 2014), and individual autonomy that empowers maker/learner choices and control (Dougherty, 2012; Educause Learning Initative (ELI), 2013; Gershenfeld, 2012; Kalil, 2010; Peppler & Bender, 2013).

The makerspace model works well in informal learning settings (i.e. afterschool clubs and summer camps). However, it is difficult to integrate within the rigid structure of the current formal education curricula and assessment. Martin (2015) cautions educators however, that if the critical elements of maker community and maker mindset are ignored, any attempt to integrate making into formal learning will become tool-centric and therefore will lose the essence of what makes "making" appealing to students. Moving forward, we must ensure that we embrace an approach that highlights the affordances of the mindset and community structure within the maker movement yet simultaneously allows for more deliberate learning objectives to be addressed. Though craft, art, and design are at the root of makerspace activities, if educators want to integrate these type of maker activities into formal learning contexts it is important to acknowledge the differences between these types of activities, both the purpose of the learning goals and the purpose of the creators' expression (see Figure 1).

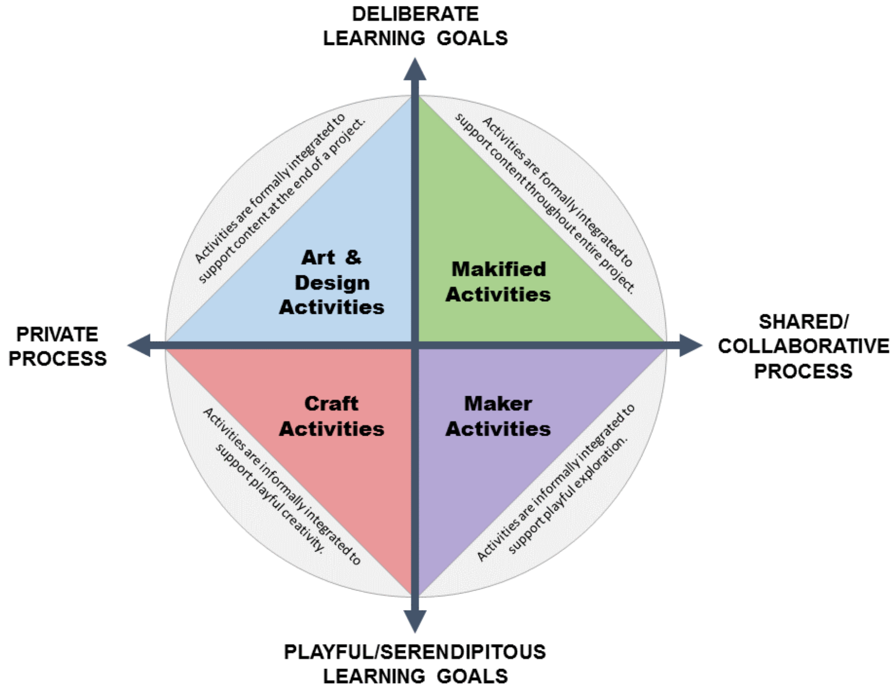

Figure 1. Observational differences between “makification” activities and maker-related activities.

Pure constructionism needs freedom and minimal restrictions (standardized regulations), which is difficult to come by in today’s climate of crowded curricula and high-stakes testing. In order to be successfully integrated into formal learning, makification activities cannot be add-ons—e.g., individual “craft” projects that do not have deliberate content learning goals, or “art and design” projects added to the end of a larger project in order to have a creative hands-on component. To have the greatest potential impact on learning, these projects must proceed from a maker mindset (Blikstein, 2013), deliberately rooted in content, situated within a collaborative learning environment, and formally integrated through the entire project.

Need for a Framework

The ability to articulate how and why emerging technologies and pedagogies can improve student learning is a necessary and difficult first step in incorporating these elements in formal educational contexts, and likewise there is a "growing demand from educators and policymakers for definitions, measures, and guidelines for design that capture the qualities of making as a learning process" (Brahms, 2014, p. iv). Peppler and Bender (2013) have also called for greater collaboration between education experts and practitioners from the maker community to "build bridges between tacit knowledge cultivated through making and the explicit and abstracted formalisms valued in education and assessment" (p. 27). A framework provides a common language to use, and a foundation on which research can build. While the constructionist theory of learning provides a starting point for this framework, the modern maker movement, along with emerging technologies, extends what is now possible in K-12 environments, and it is the synthesis of these ideas that we use to begin to develop the makification framework.

Increasingly, K-12 schools are creating maker spaces outfitted with the latest maker technologies (Peppler & Bender, 2013), and often these spaces are situated within STEM labs or libraries (Moorefield-Lang, 2014). Simply equipping a school's media center with a 3D printer or offering robotic clubs after school will do little to systematically leverage the affordances of the emerging maker technologies to improve student learning. Instead, what is required is an understanding of the essential elements that transform current maker activities into effective learning activities. Indeed, to utilize these tools effectively in order to increase student learning, there should not be a *technocentric* focus on tools (Papert, 1988), but instead one that is on the process and the product (Halverson & Sheridan, 2014). Noted by other researchers (Brahms, 2014; Halverson & Sheridan, 2014), a current need in this area is to define best practices and to better understand how to utilize making for the purpose of learning

In the following section we begin to identify and detail core elements that are particular to making in educational contexts. This list is not exhaustive, but instead is offered as a foundation on which to build. We view these four elements (creation, iteration, sharing, and autonomy) as ones derived from the community and mindset inherent to the maker movement, informed by constructionism, and we posit they provide a foundation for student learning through the use of maker activities.

Principles of Makification

Creation

Hatch (2014) lists making as the first principal in his *Maker Movement Manifesto*, and describes making as fundamental to what it means to be human. Making is intrinsically cross-disciplinary in that the creation of artifacts typically requires knowledge of engineering, math, science, and technology, which contrasts with traditional school based disciplines which are typically isolated from each other. A primary challenge however, is to be able to articulate the learning outcomes from maker activities in terms of what is valued in institutionalized learning settings (Halverson & Sheridan, 2014). Bringing maker activities into formal educational settings often challenge conventional models of instruction and assessment. Making activities may not produce a single “right” answer, but instead produce several correct solutions to a problem (Kafai, Fields, & Searle, 2014).

The element of creation is typically considered solely in terms of construction. However, Boytchev (2014) suggests three phases of learning through deconstruction and construction. Phase 1 allows students to first deconstruct knowledge or artifacts into smaller and more easily comprehended parts. Phase 2 involves the construction of these smaller parts into the larger aggregated knowledge or artifact, allowing students to better comprehend the sub-processes or sub-components of the larger artifact or idea. Finally, phase 3 involves creatively organizing the sub-components into something new. This final phase aligns closely with the re-mixing and re-designing of existing artifacts that is characteristic of the maker movement and is facilitated through web sites such as sketchfab.com and www.tinkercad.com. This last phase is often termed *hacking* or *repurposing* by the maker community (Brahms, 2014).

Re-mixing and re-designing artifacts illustrates another aspect of makification which focuses primarily on the product as opposed to the process. The maker movement, through the use of artifact sharing web sites provides access to artifacts that before were kept solely by archeologists and anthropologists. Artifacts such as bullets used in the civil war, tools used in primitive civilizations, and bones of animals now extinct have been scanned by organizations and made public for teachers and students to learn from (Means, 2015). We term these *primary artifacts,* and much like primary documents, envision these primary artifacts as important for the teaching and learning of history. Because these digital primary artifacts can be both downloaded and, crucially, re-designed by students, they afford students an opportunity to develop an intimate understanding of the artifacts that is not possible without current maker technologies.

Iteration

The design process is central to makifying, and, as Kolodner et al. (2009) concluded in their description of Learning by Design, “Essential to learning from design activities is a culture of iteration” (p. 512). Iteration provides a pathway to encourage the types of higher-order thinking makification strives to support in students. They must apply prior knowledge to analyze and evaluate their own work as part of the iteration process, and the resultant increases in both content knowledge and in skill development and refinement creates the conditions necessary for transfer of knowledge (Kolodner et al., 2009). This culture of iteration is one that also includes great tolerance for failure. Just as is the case in informal maker spaces (Martin, 2015; Peppler, Maltese, Keune, Chang, & Regalla, n.d.-b; Sheridan et al., 2014), students in a makified classroom (and teachers who facilitate them) need to be comfortable with failure, and need to recognize them as opportunities for analysis and reflection (Blikstein, 2013).

The inclusion of digital fabrication technologies can extend the iteration process beyond what has been previously possible in classrooms. One of the main affordances of digital fabrication technologies is the ability to iterate designs rapidly. Students design artifacts digitally, fabricate them using tools such as 3D printers, digital die cutters, laser cutters, or CNC routers, then test those artifacts. Based on results of that testing, students can then make the appropriate alterations to their digital designs, and fabricate new artifacts. Because digital fabrication technology will reproduce designs with consistent and high degrees of fidelity, students can focus on the more meaningful work of altering targeted variables or elements of their designs, leading to more meaningful analysis and evaluation of their work.

Sharing

Sharing is implicit within the makified classroom because each student is empowered to share their own unique knowledge and experiences (Anderson, 2012; Brahms, 2014; Sheridan et al., 2014). The concept of collaborative learning is what cognitive scientists refer to as distributed cognition, or the learning power of group intellectual efforts (Sawyer & DeZutter, 2009; West & Hannafin, 2011). Sawyer (2007) notes that, “[c]ollaboration drives creativity because innovation always emerges from a series of sparks, never a single flash of insight” (p. 7). With this in mind, students engage in peer feedback throughout numerous phases of the project as they share ideas and answers, which is uncommon in many traditional teaching models.

Working in tandem with the collaborative learning process in the classroom, the rise of communication technologies allows for students to explore digital communities of interest and share their completed artifacts with the world beyond the classroom. Within these online maker communities of interest, makers can share aspects of the making process, like digital designs and how-to videos, and can exchange knowledge and support for ongoing projects. Additional capabilities of these online communities afford individuals the opportunity not only to share their creations digitally, but also to download others' creations, which they can then remix and digitally *reshare* with the maker community. Now individuals can access primary sources as 3D files from NASA (i.e. landscape of the Moon), Smithsonian X3D (i.e. original prototypes, etc.) and can engage with artifacts with which they were previously unable to interact due to geographic locations and other barriers. However, simply accessing and fabricating digital files is not the same as making. In a makified learning environment, students would use the primary artifact as a starting place from which to create and (just as importantly) to share something novel: an artifact, augmented, remixed, or recontextualized in some way that leverages and embeds the students' content and skills.

Autonomy

One of the defining characteristics of the maker movement is that it is essentially personal; makers work on self-directed projects, and while both the process and product of their work is offered for public consumption, the work itself is often intended for a client base of one. Indeed, one of the primary affordances of the technologies currently driving the rise of the maker movement is that they foster personalization—Gershenfeld (2012) refers to personalization as the “killer app” (p. 46) for both computing and digital fabrication.

Students’ ability to personalize their own work, combined with the greatly increased access to the tools of production afforded in a makified classroom, can create a ripe environment for fostering student autonomy. The benefits of increased student autonomy are numerous: Researchers have observed increases in motivation, engagement, development, learning, performance, and psychological well-being as a result of increased support for student autonomy (Reeve, 2009).

A makified classroom could foster autonomy in two primary ways. First, students would be responsible for choosing their own making activity within the context of the broader learning objectives set by the instructor. This would help to foster a sense of ownership over the project, which can lead to enhanced motivation (Savery, 2006). In addition, students could work with instructors to define what would constitute success within an activity. A makified environment, then, would be one which fosters autonomy by providing the students a degree of ownership over decisions regarding the product, the process of creating the product, and the ultimate assessment of the work.

Conclusion

In this paper we have developed the initial *makification* framework for how teachers can makify in-school teaching and learning experiences. There are in fact existing models of teaching that evoke some of these characteristics (i.e. Learning by Design, Problem-Based Learning, Project-Based Learning, etc.); however, what we propose is deeply rooted in the process of *making as learning* and authentically connected to content with *deliberate learning goals*. We acknowledge that existing curricular demands are already overflowing with requirements and there is not much extra time for adding new content (Bell et al., 2010); however, we posit that thoughtful consideration for deliberate learning outcomes can make the necessary connections to curricula while also allowing for the more progressive hands-on learning that Papert asserts can provide transformative learning.

Heeding the cautions of researchers who have explored making in informal settings, we want to point out that the promise of the maker movement rests in its uniquely diverse communities with the encouragement of divergent mindsets that engage in multidisciplinary approaches to solve problems that are personally meaningful with potential to enrich meaning to those around them once they are shared (Halverson & Sheridan, 2014; Martin, 2015; Vossoughi et al., 2016). Though implementing this kind of curricula has its logistical challenges in more formal educational contexts such as the school classroom, we believe that this is the kind of teaching and learning which can prepare students to solve the problems of the future. We believe that by presenting and iteratively developing the makification framework, we can begin make connections between informal maker culture and purposeful instructional design in a way that might make implementing these activities in classrooms more feasible and perhaps more worthwhile as well.

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