Digital Fabrication in Education

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Abstract

Digital fabrication is quickly gaining a momentum that transcends its niche industrial roots into formal educational environments. This trend is akin to that found in the early adoption of previous other, now commonplace, technologies (such as personal computers); ubiquitous and promising. Thus, the rationale for this research then lies in the growing use of these digital fabrication technologies (especially 3D printing) for learning; the consequent pedagogical implications of which, warrant a critical look. By adopting a literature review approach, this paper first relays the theoretical underpinnings of making; the nature of and extended motives for researching digital fabrication then follows. The collected classroom case studies of fabrication in action later reveal that it stimulates logical thinking, concretizes understanding of abstract concepts, provides hands-on learning and can be beneficial cross-disciplinarily. These outcomes suggest that digital fabrication could potentially play a pivotal role in re-orienting traditional pedagogy towards a culture of making on the basis of technological constructionism.

Keywords: digital fabrication, constructivism, making, learning, emerging technologies

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'Making' has always existed in some form in our everyday world as we live, work and play. There seems to be an inherent and intuitive component of man that seeks to confer otherwise theoretical abstractions into empirical constructions (Smith & Tillman, 2015). From the early childhood stage, children have been known to be experimental and curious, tinkering with and poking the world around them. Informal learning environments, characterized by their exploratory flexibility and freedom, particularly champion this idea of learning through creative play, which consists of making and other constructivist activities. It is this formative inquisition that is honed by guided discipline into later life scientific innovations and/or artistic masterpieces.

Making things by one's self tends to be empowering for the students (Brennan & Resnick, 2012). Little wonder then that the notion of the maker culture being an alternative to traditional pedagogy is gradually shifting; formal education is becoming more progressive in its embrace. Championing the art and practice of 'making', the United States for instance, is leading a national imperative to encourage creativity and invention skills amongst students, especially those in STEM oriented disciplines. This position was upheld by the former President, Barrack Obama in an address to the National Academy of Sciences (Obama, 2009).

The series of activities that constitute the making process is no longer reserved just for artisans; technology's increasing affordability and affordances "enables anyone to make anything" (Smith & Tillman, 2015, p.133). Dialing in on this, one will notice what seems to be a deliberate and nascent consideration for the employment of technology-driven 'making' in mainstream education; how to integrate it into school curriculums, how to optimize the learning based outcomes and (chiefly of interest here), how to leverage the technological affordances thereof.

Derivative of the latter, is the digital fabrication concept, also sometimes incorrectly referred to as one of its composite subsets- ‘3D printing’. This literature review aims to investigate, based on some of the preliminary studies that have been conducted, ‘The Role of Digital Fabrication in Learning’. The sections that follow discuss the elicited findings which span the underpinnings, nature, research rationale, learning outcomes, integration concerns and future research agenda for digital fabrication.

Literature Review

‘Making’, outside of the educational purview, has some theoretical antecedents in several disciplines; mainly philosophy, physiology and psychology. In this light, one can consider some examples such as the Montessori Method of learning, which thrived on allowing children to make and manipulate things with their hands (Montessori, 2013), or similarly, Piaget, whose research extensively described the sensorimotor tendencies of young children and its relationship to cognition (Piaget, 1970). These examples are characteristically Deweyan, so named after John Dewey, who is famed for his pragmatic philosophy of education. Dewey advocated that learning be experiential, that learners be exposed to the realities of the knowledge they were acquiring - essentially, learning by doing (Dewey, 1909). That said, the arguably most credited modern ‘father’ of making and by extension, inventing things in education, was Seymour Papert. His seminal work in the theory of constructionism, propounded upon, of course, several constructivist perspectives - Piaget and Dewey inclusive (Halverson & Sheridan, 2014).

Whilst constructivism is a general learning philosophy that emphasizes the learners' ability to independently create their own knowledge and meaning, constructionism is a distinctive implementation of this school of thought. Papert's 'constructionism' is best summarized, in his own words, as "... a mnemonic for two aspects of the theory of science education…" He adds;

> From constructivist theories of psychology we take a view of learning as a reconstruction rather than as a transmission of knowledge. Then we extend the idea of manipulative materials to the idea that learning is most effective when part of an activity the learner experiences as constructing a meaningful product. (Papert, 1986, para 1).

The crux of this theoretical purview is that this hands-on, manipulable, malleable aspects of making is vital to learning. In essence, the maker culture is simply put - 'making and sharing'. Therefore, the digital fabrication treatment of it is (at least, as referenced herein), the 'deep' use of technology to make something digitally and share it physically. Depth here implies use that goes beyond the surface, harnessing the immersive aspects of the technology in question.

The Nature of Digital Fabrication

Digital fabrication originally regarded as a personal computing peripheral is increasingly becoming a focal point in and of itself (Eisenberg, 2009). This change heralds more creative control for the user, orienting them towards being also producers rather than just sole end-users of readymade artefacts. The novel aspects of this innovation environment offers learners direct physical control of multi-dimensional modelling, which could be two (2D) or three (3D) dimensional. 2D fabrication includes shapenets, pop-up books, shadow puppets, cultural kirigami and mathematical puzzles whereas the 3D options consist of creating wearable art, musical instruments and museum artifacts (Smith & Tillman, 2015)

For example pop-ups, which are gaining popularity in early childhood education settings, are just one of the many enactments of the digital fabrication movement; they are essentially “movable books” (Smith, 2012, p. 1072). They allow for exploration via the push, pull and press mechanisms built into the books. Naturally, the learners may also ascend into creating their own pop-ups; this will hone their engineering and design thinking skills. The mental process by which the young learners come to understand how to use or make these pop-up books is laced with wonder, curiosity, intrigue and surprise, thereby enabling the achievement of specific learning outcomes as well as positive associations with learning in general.

Some factors to consider as regards utilizing digital fabrication, especially with children are; the materials to build with, the subject matter for fabrication and the physical settings for fabrication (Eisenberg, 2011).

Materials. This could be wood, paper, yarn, acrylic. There is also the ABS plastic (synonymous with LEGOs) which is preferred for 3D printing. Other alternatives include wax, Styrofoam and aluminum.

Subject Matter. There are the technical disciplines e.g. architecture which involve a great deal of modelling or construction type activities. However, it does require some instructional resourcefulness to realize how fabrication might be employed in other subject areas without an obvious modelling/construction component like languages, arts and the like. Some creative examples could include recreating museum historical artefacts/objects (history) or creating street models (geography).

Physical Settings. It is apparent that communities congregate around larger fabrication devices. They have been seen to be deployed in libraries, afterschool maker clubs, museums, shop classes, laboratories etc. Where a 1:1 convention is advocated, personal fabrication devices are suitable (Eisenberg & Buechley, 2008).

Needless to say, safety, nature of the desired object and cutting capability/appropriateness of technology-to-materials will influence the decision of the overall fabrication set-up.

Rationale for Researching Digital Fabrication

Research on digital fabrication is nigh for many plausible reasons which rest on its evolutionary trajectory, peculiar novelty and pedagogical potential; each discussed in turn.

To start with, digital fabrication has been the most popular in industry because it required costly and extensive heavy duty manufacturing equipment. Likewise, more discourse has surrounded the industrial notion of fabrication than say its educational contextualization (Eisenberg, 2011). Now that personal fabrication can be carried out with a personal computer, Computer Aided Design (CAD) software and fabrication hardware (Tyler-Wood, 2015); Bull, Maddox, Marks, McAnear, Schmidt, Schrum et al. (2010) hypothesize that the introduction of digital fabrication into education will be similar to the trajectory of personal computing technologies, where they were first expensive and inaccessible but subsequently became ubiquitous.

Secondly, "digital fabrication is the process of translating a digital design developed on a computer into a physical object" (Berry, Bull, Browning, Thomas, Starkweather & Aylor, 2010, p. 168). This stirs up novelty in the classroom in a manner unlike other emerging technologies; the peculiar advantage being that it is trans-medial, merging both virtual and physical manipulation skills (Smith, 2012). With this, learners can utilize appropriate technologies to create digital models which they can then print or transmit into a physical artefact. A typical scenario will require construction/customization using suitable modelling software i.e. setting the desired object's visual and dimensional properties (shape, color, scale etc). This is followed by a layered 'depositing' and/or 'cutting' of the raw material by the fabrication hardware as it builds into a tangible prototype. The manufacturing process as well as the meaningful application of the resulting artefact opens up new dynamic avenues for learning.

Lastly, the practice-based accounts that have been documented so far of digital fabrication indicate a demonstrated enthusiasm for this emerging technology; some positive postulations have been made about its beneficial role in education. Trumble (2017) concurs, adding that though there is this much interest around digital fabrication, there is also a concurrent need to know how it impacts students' skill development. Situated in this context, the onus herein is to, amongst other things, establish if the said benefits of digital fabrication for learning are ascertained or *simply*, postulated. One way to do this is to consider some case studies; an overview of which follows.

Case Studies of Digital Fabrication

The study by Kjellstrom, Tillman and Cohen (2012) examines the use of a 'models and modeling framework' in elementary level mathematics education. The lesson units, which were intentionally architected to employ real world problem scenarios, contained a series of activities on designing airplanes using digital fabrication techniques. No particular solution paradigms were enforced, offering the students any applicable liberties. Findings however revealed that the students often struggled to conjure up or adhere to appropriate mathematical strategies. This implies a dissonance between comprehension of theoretical and applied math; that is, regular classroom math with defined problem sets versus situations where there isn't an obvious and predictable solution. Because the latter more closely mimics how math works in the real world, digital fabrication now becomes a vehicle to address some of the weaknesses in that regard.

In a similar study, Corum and Garofalo (2017) investigated how including a digital fabrication component into a fifth grade arithmetic curriculum will impact the students' understanding of surface area and volume. The students' ability to complete tasks improved as did their recognition of three dimensional properties often absent in traditional two dimensional depictions. This is a rather welcome quest as surface area and volume are rudimentary concepts, often tested on national standardized tests. More than that, the outcomes obtained in this study underscore the correlation of concrete manipulatives such as digital fabrication to students' comprehension of seemingly abstract concepts.

Oliver and Houchins (2018) thereafter explored the intersection of making and computational thinking at an all-girls public school in the US through the establishment of an afterschool maker space club. Notably, observations were based on self-reported accounts; students were asked, at the conclusion of the digital fabrication process, to reflect on the series of steps they undertook and what they would opt to do differently. An analysis of their reflections revealed that though the computational thinking processes (decomposition, abstraction, algorithmic thinking, generalization/pattern recognition and evaluation) were not always linear/discrete, they were definitely evident in the students' maker activities. In essence, digital fabrication fosters computational thinking.

Other inquiries have yielded identically promising results. For instance, Trumble (2017) discovered that the digital fabrication experience improved the spatial visualization abilities of fourth and fifth grade students. This is consistent with the outcomes from studies by Katsioloudis and Jones (2015) as well as Smith (2018). Christensen, Knezek, Darby, Den Lepcha, Jiang, Kuo and Wu (2017) also noticed value-added content mastery by way of heightened interest, engagement and peer-to-peer interactions among participants who utilized digital fabrication technology in a science camp experiment on the solar eclipse. This notion of increase in creativity and interest was also noted previously elsewhere (Shealer & Shealer, 2014; Smith, 2013).

And though the aforementioned case studies appear to congregate around mathematics education; it can be arguably held that nearly all disciplines, both STEM and non-STEM, are underpinned by some degree of mathematical thinking skills. Thus a win for math on the bridge of digital fabrication is really a win for all. That said, the purview herein certainly isn't exhaustive. Digital fabrication has been considered for other intents such as; enhancing the learning effectiveness in a medical course on anatomy (Lim, Loo, Goldie, Adams & McMenamin, 2016), narrowing the achievement gap for historically underrepresented groups e.g. African-American males (Tillman, An, Cohen, Kjellstrom & Boren, 2014), promoting inclusion for marginalized populations through customization/personalization of learning material (Jo, 2016) and as a useful pedagogical tool for the teacher (Maloy, Kommers, Malinowski & LaRoche, 2017; Novak & Wisdom, 2018).

Integrating digital fabrication into schools.

Adequate infrastructure in the form of hardware, software, a collaborative space and a maker-driven curriculum is necessary to support digital fabrication (Berry et al., 2010), in order to effectively achieve the demonstrated outcomes. Teacher and student perspectives must be considered during integration in formal learning environments. There must be cognizance of teachers' competences and students' interest in digital fabrication activities. Relatedly, the curriculum positioning of abstract concepts in real-world applied contexts must be given due diligence, if student learning is to be prioritized

A lingering instructional concern may be how to assess non-traditional digital fabrication activities in the context of a formal educational environment. In this vein, Tillman (2011) offers using a fourth-grade algebra activity, a simple rubric for performance assessment. This progressive scale from 0 to 4 for; 0-not scorable, 1-beginner, 2-intermediate, 3-advanced, 4-master, is based on increasing demonstrated task competence.

Discussion

The role of digital fabrication in education is multifaceted. On the one hand, as evidently shown, it is pedagogically beneficial. Familiarity with digital fabrication tools and techniques from an elementary level are not only vital for achieving immediate learning outcomes but also prepares students for later life professional pursuits particularly in careers where making is elemental (Smith, 2012). On another, subtle yet salient note, it could transform pedagogy itself; anchoring an all-inclusive view of intelligence beyond standardized testing – which is centered on intellectual work (Robinson, 2015). Digital fabrication is instrumental in offering a commendable channel for learners with expressive tendencies (Tyler-Wood, 2015), this extends to students that would otherwise feel sidelined by the conventional curriculum.

On the heels of this, there is an overall need to develop more strategies for integrating digital fabrication activities into pedagogy (Tillman et al., 2014). Consequently, predating the actual introduction of the technological infrastructure in the classroom should be the more important notion of intentionality. All of the considerations (administrative, instructional, logistical etc) that go into making an environment conducive for learning must be imbued with a maker-driven intent. A classroom for instance, should be structured such that it invites students (this is especially applicable amongst young learners), to interact physically with the surrounding learning artefacts e.g. e.g. assembling, crafting, moulding, stacking etc (Smith, 2012). Shop classes where young adults can get their hands active ought to be reinstated and the idea that skills obtained therein are only valuable for vocational programs done away with.

Digital fabrication builds upon a constructivist philosophy, marrying mind and matter with contemporary technological advancement. A progressive adoption in education implies an explicit admission that knowledge and commodity in this sense are complimentary not rivalries. Isn’t this alignment of theory and practice worth pursuing? Therefore, future research ought not to dwell on the operational machinations of digital fabrication, but rather build upon the pedagogical successes recorded thus far. This will require perhaps developing more appropriate measurement instruments, uncovering empirically driven strategies to optimize its efficacy and establishing a framework for a learning theory of technology and trans-medial construction.

Conclusion

At its core, digital fabrication is basically ‘high tech end-to-end making’ not much unlike industrial manufacturing in the years of yore. This literature review examined the role it plays in education. Though the characteristics and applications have been documented, it is its embodiment and extension of ‘making’ that has been accentuated here. Digital fabrication has been shown to influence learning outcomes by situating pedagogy in real world contexts and enhancing the overall learning experience. The distinctiveness of this technology empowers students to create using a multimodal fabrication process; this emphasizes analytical and design skills that are applicable across many disciplines and beyond the classroom walls.

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