Putting the "H" in STEAM: Paradigms for Modern Liberal Arts Education

Armanda L. Lewis

Abstract This chapter seeks to connect current debates about the value of traditional liberal arts education to emerging trends in the learning sciences that promote metacognition, active learning, and other 21st century skills. This paper proposes that STEAM (Science, Technology, Engineering, Arts, and Mathematics), an emerging K-12 approach that infuses the arts within STEM fields, has enormous potential to infuse the liberal arts with design thinking, collaboration, creative computing, and innovation while maintaining the level of deep reflection and critical thinking associated with humanist inquiry. While STEAM has yet to reach higher education in the same way that it has K-12 grades, it is argued that the trends in K-12 foreshadow coming trends in higher education. STEAM within higher education looks at movements that address interactivity, innovation, and inquiry in the form of interactive media design studios, makerspaces, and digital humanities initiatives. This chapter will examine artifacts produced thus far and propose further empirical research studies within higher education to advance what we know about emerging technology-enhanced learning environments and their role in disciplinary knowledge formation. A secondary goal is to create a stronger dialog between K-12 research and higher education trends that have their roots in pre-college initiatives.

Keywords Humanities · Liberal arts · Creative computing · Maker

Introduction

Current debates in higher education consider the types of educational experiences regarded as valuable for future professional success and well-being. On one hand, the pragmatic side of vocational and professional preparation is contrasted with the cultural aspects of a liberal arts education, a broad form of educational preparation that exposes students to traditional bodies of knowledge within the arts, humanities, and sciences (The Carnegie Foundation, 2010). On the other hand, there is a

A. L. Lewis (✉)
New York University, New York, USA
e-mail: al861@nyu.edu

X. Ge et al. (eds.), *Emerging Technologies for STEAM Education,*
Educational Communications and Technology: Issues and Innovations,
DOI 10.1007/978-3-319-02573-5_14

disciplinary divide within liberal arts education, with STEM- (Science, Technology, Engineering, & Math) related degrees associated with job creation and humanistic degrees regarded as essential for civic and moral preparation (Koblik & Graubaud, 2000; Pascarella et al., 2005). As evidenced by increased funding streams, rhetorical buzz, and curricular innovation, trends have emphasized STEM initiatives, positing that these fields hold greater potential for future professional success and cost benefit of an expensive degree (Selingo, 2013). As a result, humanistic disciplines have needed to re-articulate how they prepare students to thrive post-graduation.

The present focus is on STEAM (Science, Technology, Engineering, Arts, & Math) – an emerging approach that infuses the arts and design within STEM fields – within liberal arts education. STEAM initiatives found in liberal arts environments uniquely infuse humanist inquiry with STEM-related inquiry and technological know-how. Instead of STEAM paradigms that position arts and humanities as enhancements to core STEM knowledge, the liberal arts paradigms examined here will explore the ways in which the humanities, informed by STEM principles, can prepare students for the creative problem solving, collaboration, and computational thinking associated with 21st century digital literacy. The overarching aim of this review is to examine liberal arts STEAM curricula from a learning sciences perspective, argue for its potential to reconceive humanist education, and distill core cognitive, neural, and socio-cultural benefits of effective STEAM education. In doing so, this chapter will offer an overview of the movement in higher education, with an emphasis on the humanities, articulate cognitive and other types of development best supported by liberal arts, and analyze cases of innovative curricula. Important to note is that mention of liberal arts in the present chapter emphasizes humanities knowledge within liberal arts context.

Humanistic Education Within the Liberal Arts

Understanding the humanities within liberal arts education and ways that scholars and practitioners have viewed undergraduate education in response to broader socio-economic and pedagogical changes is necessary to contextualize STEAM initiatives within those spaces. A liberal arts curriculum historically has featured general knowledge deemed necessary and valuable to civic life, followed by specialization. The focus is on inquiry and self-motivated inquiry and deep understanding within a community of peers. Recent attempts to position liberal arts in modern times have either provided a defense for a threatened but valued form of lifelong preparation (Chopp, Frost, & Weiss, 2014; Newfield, 2009; Woodward, 2009) or argued for alternatives to traditional liberal arts education due to fundamental changes in societal needs (Davidson, 2008; Szeman, 2003; Thomas & Seely Brown, 2011).

Nussbaum (1997) traces the dual conception of liberal arts education to its Classical origins, with representations shifting from tradition-steeped instruction for the elite to a focus on timeless skills that prepare all to contribute to society. This manifests itself currently as an opposition between examples of socio-cognitive development, and technical and vocational training that prepares students for jobs and long-term financial security. Knowledge associated with liberal arts education, such as critical thinking, moral character, problem solving, and the ability for lifelong learning, are more difficult to quantify and often demonstrate themselves over time (Goldberg, 1971). The humanities form the foundation for this “cultivation of the whole human being for the functions of citizenship and life generally”, and can even be thought of as the essence of general education (Nussbaum, (1997, p. 9).

STEM fields are less threatened within the liberal arts due to the privileging of the scientific model of research, the overt linkage between quantitative disciplines and job opportunities, and the increase in scientists as public intellectuals (Miller, 2012). Humanistic fields, however, are facing an unprecedented mandate to justify their existence—What is it that humanists do? What does humanistic knowledge impart? How can this knowledge be explicitly tied to job skills? Why can’t the humanities be more like the sciences? Scholars defend the humanities as uniquely capable of promoting the capacity to reason analytically, the understanding of different perspectives or circumstances, and the use of imaginative problem solving. Critics, though, point to employment statistics or concentrate on how to infuse scientific methods and principles into the humanities (Pinker, 2013; Slingerland, 2008).

In *The Value of the Humanities*, Small (2014) writes that humanistic knowledge is of value precisely because it is not necessarily practical, and must be understood and valued contextually, with an emphasis on dialectic meaning-making. This recalls Bruner’s (1991) thesis that solely cognitive models of the mind are lacking in nature since they fail to grasp the complexity and dynamic processes occurring between mind and society. In *The Marketplace of Ideas*, Menand (2010) calls for a re-articulation of the value of a liberal arts education on its own terms. Arguing that a broad humanist preparation encourages complex inquiry and creative problem solving, he seeks to address current rhetoric highlighting the vulnerable or impractical nature of liberal arts in the technological age. Additionally, by connecting the socio-cognitive benefits of such an education to those skills deemed necessary to succeed in modern society, Menand counters theorists that emphasize the need for liberal arts to incorporate scientific rigor, adopt social scientific methods, or become a marginal discipline in the face of more practical fields. In a more pragmatic manner, Chopp (2014) uses U.S. Treasury Department data to argue that many employers seek skills that the humanities already encourage, namely critical thinking, an understanding of diversity, and creativity.

Measuring Humanist Knowledge

While the many supporters and critics of humanistic knowledge within the liberal arts pose logical, philosophically-driven arguments, there is a dearth of empirical studies that report the changes in cognitive and socio-cultural knowledge that happen while engaging in humanistic through and inquiry. Traditionally, theorists have concentrated on how STEM disciplines can support non-scientific thinking. The studies that have attempted to measure the outcomes of humanistic knowledge within liberal arts education are few, but yield interesting results. Earlier self-report studies reported overall learning gains (Hayek & Kuh, 1998), increases in personal development (American Association of State Colleges and Universities, 1976), and greater levels of engagement in educational activities (Pascarella & Terenzini, 1998) by selective liberal arts students when compared with self-reports from students at other types of institutions.

The Center of Inquiry in the Liberal Arts (Pascarella et al., 2005) conducted a more comprehensive Wabash National Study of Liberal Arts Education, a multi-institutional longitudinal study examining good liberal arts practices, institutional ethos, impacts of liberal arts on intellectual and personal growth, and long-term effects of liberal arts education. Utilizing multiple instruments, the study provides some support for supporters of liberal arts education. Utilizing the Critical Thinking Test of Collegiate Assessment off Academic Proficiency and the Need for Cognition Scale and Positive Attitude toward Literacy Activities Scale to measure effective reasoning/problem solving and inclination for life-long learning, respectively, researchers reported statistically significant increases in reading comprehension, critical thinking, writing, openness to diversity and challenge, and intrinsic motivation (learning for self-understanding). Pascarella and Blaich (2013) expanded on results to develop deep learning scales to measure students' experiences with higher-order learning, integrative learning, and reflective learning; results indicate that deep learning experiences contribute to a significant degree the 4-year critical thinking gain, even after controlling for confounding influences and direct exposure to clear and organized instruction. These results hold when compared to those of research universities and regional institutions. Despite gains in these themes traditionally associated with liberal arts education, the same study reported significant decreases in math and science knowledge over the 4 years and when compared with students at other institutional types of institutions. What is vital is a way to integrate STEM and arts/humanities knowledge so that the existence of multiple domains does not adversely affect learning.

The Emergence of STEAM

STEAM, a largely K-12 initiative conceived to bridge the interdisciplinarity, creativity, and innovation found in both art and science, has garnered support from governmental and educational advocates (Ghanbari, 2014; U.S. Congress, 2011; Yakman, 2008). Duncan (2010) called for an integration of arts and humanities into STEM education for what he terms a "well-rounded curriculum. It is the making of connections, conveyed by a rich core curriculum, which ultimately empowers students to develop convictions and reach their full academic and social potential" (p. 1). With STEAM-dedicated conferences and a journal (STEAMConnect's ASCEND Conference, Northeastern Illinois University's Annual Conference, among others; *The STEAM Journal*), there are increasing examples of STEAM as a theory of STEM education seen through the lens of 21st century skills, which champions learning/innovation (critical thinking, creativity, collaboration), digital literacy (information and media understanding), and career skills (flexibility, leadership, cross-cultural skills) (Trilling & Fadel, 2009). From a pedagogical perspective, curricula lean heavily on constructivist principles, with an abundance of maker movements, project-based assignments, and collaborative, inquiry-based design experiments. Scholars see the arts as infusing inventiveness and adaptability into the analytical and computational thinking associated with being a scientist. The STEM to STEAM initiative (stemtosteam.org), developed at the Rhode Island School of Design (RISD), highlights such ideas in its official description:

> STEAM represents the economic progress and breakthrough innovation that comes from adding art and design to STEM (Science, Technology, Engineering and Math) education and research…To realize this potential, scientists, artists and designers must develop new ways of working together and new modes of research and education. This will keep America at the forefront of innovation, ensuring our sustained global leadership and cultural prosperity in the 21st century". (RISD Office of Government Relations, 2013, p. 1)

Paralleling the overall trend in higher education to emphasize the vocational benefits of education, STEAM rhetoric stresses skills that lend themselves to professional success, which translates to the ability to gain employment, increase job opportunities, and address the current focus on entrepreneurship (Fredette, 2013; National Research Council, 2007). Published research is growing, but there are three noticeable absences. One is that existing STEAM research is largely focused on K-12 education, with few overt discussions of STEAM within the higher education sector. Another is that studies tend to look at the role of the aesthetic arts rather than the humanities. Lastly, research has examined the approach's creative and economic potentials (Eger, 2013; Henriksen, 2014; Maeda, 2013) rather than probe the latest learning evidence about the cognitive, neural, and socio-cultural development that occurs in learners engaging in STEAM activities. Subsequent sections will look at such learning that happens in college age students.

The Rise of STEAM in the Liberal Arts

While one can point to dozens upon dozens of formal and informal STEAM initiatives at the K-12 level, extant higher education examples remain few, though there has been an increasing call for curricular re-design to address 21st century skills preparation. Chopp (2014) proposes the curricular concept of knowledge design, which will be helpful in integrating current learning research. Knowledge design is "aimed at placing creativity and agility at the heart of learning and scholarship by embracing new learning platforms and recognizing the power of visualization and the remixing of knowledge" (19). The idea behind knowledge design corresponds with more active, student-centered, participatory learning techniques encouraged in the learning sciences, and the interdisciplinary and playful nature of the STEAM movement (Soloway, Guzdial, & Hay, 1994). It also parallels closely with rhetoric championing design thinking in teaching and learning (Kafai & Harel, 1991), the importance of cognitive acquisition and participation (Greeno, Collins, & Resnick, 1996; Sfard, 1998), and the integration of multiple media and modes in social, context-based learning environments (Brown, Collins, & Duguid, 1989; Jewitt & Kress, 2003).

Subsequent sections will highlight three types of STEAM initiatives within traditional liberal arts education that leverage interactivity, innovation, and inquiry: the interactive media, maker, and digital humanities programs. Specifically, the types of interrelated knowledge promoted by these programs include the development of complex cognitive processes (computational and systems thinking knowledge, transfer), socio-cultural capabilities (collaboration, multicultural growth, multimedia and multimodal communication), and know-how associated with entrepreneurship (adaptability and innovation). In contrast to K-12 STEAM movements that focus on using visual and other artistic forms to make sense of scientific fields, liberal arts movements that are STEAM-like leverage technologies and scientific methodologies to explore humanistic knowledge. The following examines Sarah Lawrence College's Games, Interactivity, and Playable Media concentration, various makerspaces, and Hamilton College's Digital Humanities Initiative.

Understanding the Humanities Through STEAM

The purpose of this section is to address ways that STEAM initiatives cultivate certain types of knowledge and learning within the liberal arts. Support is provided by recent findings from cognitive science, neuroscience, and psychology that highlight the improvement of mental models, socio-cultural learning, and relational thinking. The aim is to articulate cognitive and other types of development best supported by liberal arts, and how knowledge cultivated by humanist study enhances skills in STEM disciplines to create a well-rounded STEAM initiative. Traditionally, theorists have concentrated on how STEM disciplines are best supported by inquiry-based learning, project-based learning, and constructivist techniques. What does current research in the learning sciences have to say about learning with respect to maker, interactive media, and digital humanities programs?

All three areas, ideally, maximize project-based learning, collaboration, inquiry-based learning, deep learning and concept formation through artifact production. Through the act of production, the learner is in constant dialog with the subject matter and misconceptions are revealed and refined over time. STEAM naturally allows for these ideas that encourage multiple and iterative approaches to problem-solving within a complex learning environment (Bruner, 1991; Jonassen & Land, 1999; Spector, 2011). One reason that STEAM environments have such potential is that they maximize cognitive disequilibrium, a process of disruption in mental state due to error or surprise, and ideally reconciliation of that discrepancy through learning (D'Mello, Lehman, Pekrun, & Graesser (2014); Rescorla, 1988). Another rationale for supporting STEAM environments within liberal arts is creativity, which has been shown to enhance learning experiences for and is in line with 21st century skills (Csikszentmihalyi, 1997). While very little mention has been made specifically of STEAM as an approach within higher education, the following lessons in interactivity, inquiry, and innovation demonstrate that STEAM initiatives are already observable.

Lessons in Interactivity and Creative Computing: The Multimedia Design Studio

Interactive media programs that blend the arts and sciences are not new, as evidenced by long-time programs at MIT (Media Lab), NYU (Interactive Telecommunications Program), RISD (Digital + Media Program), and Carnegie Mellon (Digital Media Program) that take a playful and interdisciplinary approach to addressing and designing for real-world issues. What makes these and similar programs innovative is a resistance of disciplinary isolation and an acknowledgement that memorization of facts and rote procedural training is insufficient for future success (von Glaserfeld, 1989).

In various analyses of the types of learning that occur in multimedia design spaces, researchers (Ito et al., 2010; Knobel & Lankshear, 2010) identify collaboration, and creativity as key ingredients for productive media arts practices, gauged in these cases by the level of collaborative creativity and personal expression evident in final designs. In the liberal arts context, the multimedia design studio not only addresses issues of personal identity formation and expression, but is essential for core and emerging humanist knowledge to form.

Sarah Lawrence College, for example, has the newly formed Games, Interactivity, and Playable Media program, whose official aim is “to foster technical and digital literacy in the arts. Designed for experimentation, this initiative helps students establish digital proficiency while supporting the exploration of a wide range of new media forms and technologies… Students are encouraged to coordinate these project-based investigations of the digital throughout their studies in the humanities, including literature, philosophy, politics, sociology, theatre, and writing” (Sarah Lawrence College, n. d.). Unpacking this statement reveals a focus on literacies and more abstract competencies, rather than specific skills. The acquisition of knowledge and perspectives that span media and modes come together in open and project-based learning environments that are connected with increases in student agency over their own learning and creative problem-solving capabilities (Birchfield et al., 2008). The program also adopts rhetoric current in K-12 education that stresses learner-driven knowledge discovery; students must connect the general competencies associated with physical computing, multimedia production, or programming, and apply them to their own fields of interest. This requires the construction of learner ecologies (Barron, 2004), in which learners construct complex cognitive, social, and technological support strategies around specific topics of interest.

Sample courses, which could all be characterized as STEAM, include Introduction to Creative Computing, cross-listed with computer science, Kinetic Sculpture with Arduino and Playable Media for Mobile Devices, both cross-listed with visual arts, and New Media Literacies, cross-listed with literature. What is noticeable is the amount of required disciplinary crossover to meet the courses' learning goals and objectives. For the creative computing course, novice programmers complete weekly assignments that build into a set of practices that can be harnessed to complete a final project. The focus, in the spirit of Brennan and Resnick (2012), is on the development of computational concepts (ex. recursion), practices (ex. debugging and mashups), and perspectives (ex. points of view about the environment). Traditional computer science encourages logic and optimization, and the arts and humanities introduce the idea of messiness, viewpoints, and heuristics vital in real-world situations. Likewise, the two visual arts courses require artifacts designed for specific scenarios, and leverage current theories of play and embodiment that promote engagement and applicability (Csikszentmihalyi, 1997; Vygotsky, 1978). The new media course also requires a final multi-media project that situates humanist inquiry within real-world technological phenomena. One point in common with these courses is a recognition that "designing a learning environment begins with identifying what is to be learned and, reciprocally, the real world situations in which the activity occurs" (Barab & Duffy, 2000, p. 48). Another is the incremental nature of knowledge building, a scaffold technique that supports novices' knowledge construction.

At the New York City College of Technology-CUNY, a cursory analysis of students' work from emerging media courses indicates students' ability to refine concepts over the course of a semester, pull from different disciplines to accomplish a goal, and position themselves as practicing professionals. These indicate that learners are seeing themselves as members of a knowledge-based community and can articulate their roles as emerging experts of that knowledge (Bransford, Brown, & Cocking, 2000; Brown et al., 1989).

Lessons in Innovation: The rise of Makerspaces

Makerspaces, also called hacker spaces or innovation labs, broadly include constructionist, interdisciplinary fabrication environments in which learners explore a concept through the embodied exercise of creating a physical object. A growing focus on the learning that happens in maker spaces reflects an abundance of research in comparison with similar studies for multimedia design studios or digital humanities spaces. Maker initiatives, which happen in makerspaces, form part of the STEAM movement since design are necessary for the creation of a usable object. Constructionism encompasses constructivist tenets, with the added emphasis on active cognitive processing and making sense of a topic through the manipulation and construction of physical and virtual objects (Churchill & Hedberg, 2008; Kafai, 2006; Papert, 1980). The process is frequently iterative and collaborative, and involves the learner creating an alpha version, reflecting on its utility and appropriateness, and then refining further versions until the initial problem is addressed satisfactorily. Kafai and Resnick (1996) provides evidence of the various learning supported by constructionist environments, including creating linkages between discrete but related mental representations, socio-cultural-cognitive growth occurring through collective interests, and reflective cognition encouraged by iterative processes.

While constructionism more generally focuses on the creation of knowledge through any type of “object to think with”, maker initiatives focus more on the types of learning supported through physical manipulation and construction of artifacts. Spanning the areas of physical computing, wearables and crafts, engineering, and multimedia production, maker initiatives are often associated with DIY movements that promote agency, creativity, and resourcefulness. Recent research (Bequette et al., 2013; Buechley, Peppler, Eisenberg & Kafai, 2013; Kafai & Peppler, 2014; Peppler & Glosson, 2013) looks holistically at the negotiation and production of knowledge in these makerspaces. Blikstein (2014) chronicles an activity where students used 3D printing techniques to build monuments for female historical figures. Challenges include issues with workflow and division of labor, but positives included an integrated interdisciplinary experience. While the end goal was the development of monuments embodying historical knowledge and highlighting absences, a secondary accomplishment was the integration of mathematical and engineering knowledge. Successful STEAM initiatives showcase a seamless and logical integration of different disciplinary knowledge to accomplish a goal.

Several of these studies examine different e-textile makerspaces that blend engineering and crafts within a project-based learning environment. Norris (2014) provides evidence that the act of designing artifacts influences and is influenced by students’ valuing of self, supporting socio-cultural theories of learning that posit that the successful construction of physical artifacts affects judgment about one’s own capability and sense of self (Ackerman, 2004; Kafai & Harel, 1991). Peppler (2013) also supports e-textiles for identity formation, arguing that e-textiles “are ‘coded’ for girls, encouraging them to engage in computing by engaging their creative interests” (p. 40). She goes on to connect participation in e-textile construction to cognitive growth, specifically an increase in knowledge about the properties of electronic circuits. A paired-samples t-test revealed a statistically significantly higher on posttests evaluating students’ ability to produce a working circuit, as well as significantly higher knowledge about current flow, polarity, and connectivity.

The work being accomplished in the emerging multimodal learner analytics space yields promise for understanding maker spaces in psychological and even neural terms. From a psychological perspective, the project-based learning occurring in such spaces encourage metacognition around discrete intuitions about a topic. diSessa (2004; 2006) has written extensively about the misconceptions of novice learners around particular scientific topics. In the knowledge in pieces framework, diSessa theorizes that the learner’s body of knowledge undergoes a series of conceptual changes as separate elements composing that knowledge are continuously connected and reconnected to make sense of a phenomena. In studies their digital fabrication spaces, Blikstein (2014) and Worsley and Blikstein (2013) present initial results for “automated multimodal analysis of student expertise while they engage in building tasks” (Worsley & Blikstein, 2013, p. 94). Using object manipulation and gesture data analysis, automated models that successfully predict the level of expertise indicate the importance of coordinated, two-handed object manipulation. This coincides with neuroscience research that identifies two-handed interactions to be an essential part of successful and creative problem-solving since generating an idea and appropriate idea selection are key (Hoppe, 1988). Two-handedness is reflected through biometric readings that report brain activity in regions in both hemispheres, which as a collective have been associated with concept expansion and creative problem solving generation (Abraham, 2014; Abraham et al., 2012; Fink, Benedek, Grabner, Staudt, & Neubauer, 2007). Humanist inquiry is associated with grappling with different ways of viewing complex issues that have no inherent solution, and we would argue that maker activities make this cognitive exercise embodied. By necessity, makerspace projects, with an emphasis on fabrication and tangibles, would require this type of coordinated embodiment that could develop over time given properly scaffolded learning opportunities.

Some notable makerspaces at large institutions, including the Invention Studio at Georgia Tech, are characterized as startup and innovation incubators that evoke current higher education trends that promote entrepreneurship and invention. Within liberal arts colleges, one key difference is that the focus of the makerspace is often on the acquisition of knowledge, specifically the process by which information is acquired and understood on the learners' own terms. The technology is similar between spaces, with microcontrollers, programmable software and interfaces, 3D printers, and more available. Wheaton College's Whale Lab is termed a "making/fabrication space meets interdisciplinary research lab", while Davidson College's Campus Maker/Innovation Space seeks "to invigorate intellectual inquiry and collaboration across conventional academic boundaries", and the University of Mary Washington's ThinkLab, a lab space that introduces emerging technologies to the community and aggregates pedagogical innovation harnessing those technologies. Rhetorically, these examples encourage interdisciplinary discovery, disciplinary knowledge building over professional end goals, and a community of practice around making.

At Thinklab, blog entries from the freshman seminar, Makerbots and Mashups, chronicle a series of micro-failures, common in the design world. In one assignment, teams of two create sets of chess pieces and write posts highlighting the "what went wrong" aspects of going from conception to implementation, to iterative refinement. Students demonstrate an articulate awareness as they reflect on actions taken. Other assignments include deconstructing a t-shirt and making some new wearable, and a final project integrating the technologies. In "Final Project Fail!", one student remarks "I originally wanted to make an octopus plush toy with LED lights on its tentacles. Well, after spending four class periods sewing and cutting, the LED lights did not light up… I have decided I am going to sew a couple LED lights on the octopus's head. Making the octopus's head was hard because I did not know how to sew a circle, so I stuffed fluff in a piece of cloth and used string to tie the end. I will have to somehow figure out how to sew the head onto the tentacles. This is going to be a challenge!" (Jessicahwu, 2013). In this case, the learner lists numerous challenges, but perseveres to come up with a final product. This artifact has morphed from the original specifications, but demonstrates the learner's level of creativity to come up with solutions to those specifications that she was unable to address. During this process, she is gathering a set of schema and problem-solving approaches that she can leverage in the future.

In this vain, another student adds, "There was certainly a lot of error involved on my part during the course. In a very non-scientific way, I would just quickly try different things until something worked. This applies to 3D printing, seeing how different sensors react to various things, etc. It was frustrating at times, but I eventually just accepted that I would probably have to try a few different approaches every time for almost anything I did" (Brett2016, 2012). This cognitive strategy of informed tinkering, of attempting strategies until the best one is revealed works towards what we know about how novices progress towards expertise (Bransford et al., 2000). In addition to encouraging schema development, maker learning opportunities promote collaboration. One student blogs that "collaborating with fellow students played a huge role in creating my projects" (Wboadurg, 2012), and goes on to describe the process of finding peers for collective design sessions or for assistance.

These quotes represent the more obvious advantages of this type of hands-on seminar, including the encouragement of collaboration and creativity, embodied interactions with design concepts, and exposure to emerging tools. Despite these pluses, there are several areas of improvement. There is no indication that the skills learned in the freshman year are integrated into the curricula of subsequent years. The assignments leaned heavily on those that would be most appropriate for the visual arts, without considering rich opportunities for disciplinary engagement like tying activities to issues in literature, political science, and biology. Maker experiences will make liberal arts education richer only if they are tied to core disciplinary issues.

Lessons in Inquiry: The Digital Humanities

STEAM has the potential to infuse within liberal arts education rich opportunities for interactivity and innovation that mesh with the socio-economic pressures about professional preparation and learning trends promoting 21st century skills. Recalling the core knowledge and skills typically associated with the humanities, deep inquiry and critical thinking are at the top. The humanities have evolved throughout history. Most recently, the humanities have grown to incorporate new tools and methods that reflect, in part, the enormous quantity of humanistic work and exegesis and the growth of digital tools. The digital humanities as term has multiple meanings (Gold, 2012), but generally refers to the use of digital and computational tools to make sense of and glean patterns from humanist data that ranges in medium.

Hamilton College has pioneered a humanist model for supporting teaching and research initiatives through the Digital Humanities Initiative (DHi), described as "a collaboratory… where new media and computing technologies are used to promote humanities-based teaching, research, and scholarship across the liberal arts" (Hamilton College, n. d). Based on the principle of the atelier, DHi offers more general skills training, but within the framework of specific projects. Participants are given phased support, with the idea that, over time, faculty will have more agency and can play more active roles in the learning and development process. This approach has several implications. In keeping with good instructional technology practices, the emphasis is kept on the research in question, and technologies are only a means to addressing that research. This means that uses of technologies are situational and grounded. In keeping with current theories of learning (Bruner, 1991), faculty are provided scaffolded learning experiences with technology so that knowledge construction is incremental and manageable. Another is based on active learning principles, and the notion that humanist knowledge can be practical through the use of technology.

The digital humanities as STEAM movement highlights the innovative, iterative, and multi-method nature of modern humanist research. DHi accomplishes this resource-wise through configured physical space (technology-enhanced on-site spaces), and through communication technologies that create a digital network of scholars and information.

An essential aspect about the digital humanities as STEAM movement is the incorporation of scientific training and methods into humanist inquiry. Large-scale collaboration has long been a requisite for the advancement of scientific knowledge, while the humanities have developed largely through specialized collaborations. Recently, as evidenced by DHi and other initiatives, humanists scholars have embraced collaboration and the progress that can occur only through joint inquiry. Another parallel to scientific training is inquiry-based learning, in which students take an active role in developing hypotheses and experiments. In the humanities, this takes that form co-directed projects between faculty and students, shown to increase student interest and understanding of complex topics. Yet another is the use of quantitative methods as a way to manage large amounts of data.

Future Directions

This chapter has sought to connect current debates about the value of traditional liberal arts education to emerging trends in the learning sciences that promote metacognition, active learning, and other 21st century skills. Within K-12 spaces, researchers are beginning to produce empirical evidence that STEAM offer learning opportunities around design thinking, creativity, and innovation, while maintaining the deep cognition and reflection associated with humanist inquiry. While STEAM has yet to reach higher education in the same way that it has K-12, previous discussion has demonstrated the existence of conceptually similar initiatives that address interaction, innovation, and inquiry in novel ways than traditional liberal arts training. Reflecting pre-college STEAM initiatives that allow building, mashing up, or geeking out, higher education versions expand the field with unique visions of interactive and computational media design, digital humanities, and makerspaces.

Table 1 STEAM paradigms in modern liberal arts education

STEAM paradigm	Liberal arts STEAM type	Liberal arts example	Traditional humanist knowledge	Other forms of knowledge
Inquiry	Digital humanities: the intersection of humanities and computing to reveal patterns and new forms of knowledge	Hamilton college's digital humanities initiative	Critical thinking and humanistic analytic skills; metacognition; perspectival thinking; reading comprehension; textual analysis and writing	Computational thinking; design thinking; quantitative analysis skills; reductionist perspectives; visualization
Interactivity	Interactive and computational media: the integration of visual arts techniques, digital film production, and creative computing for a designed, real-world experience	Sarah Lawrence college's games, interactivity, and playable media program	Editing; ethical and moral understanding; heuristics; metacognition; perspectival thinking; synthesizing capabilities	Debugging; iterative design thinking; optimization; play; situated cognition; visualization and mashups
Innovation	Makerspaces: interdisciplinary fabrication environments where learners undertake projects in an iterative fashion	Campus maker/innovation space at Davidson college; ThinkLab at University of Mary Washington; and the Whale Lab at Wheaton college	Civil character; metacognition; perspectival thinking; synthesizing capabilities	Embodied learning; iterative design thinking; play; situated cognition

Table 1 summarizes the three principal STEAM liberal arts paradigms of inquiry, interactivity, and innovation. While the interactivity represented in interactive and computational media studios is observed at the younger levels, liberal arts versions make overt connections between STEM and humanist knowledge and themes, and promote active learning and reflection. The three makerspaces examined are less conceptually tied to specific disciplinary knowledge, perhaps due to the newness of the concept of open and atelier-style learning environments within the wider college community. Much potential remains, though, for creating maker learning opportunities that require students to confront and negotiate domain knowledge. Digital humanities efforts integrate most logically with traditional humanist inquiry, and are in the best position to transform the discipline from within.

For all three paradigms, there remain few overt linkages to learning sciences research, specifically empirical evidence of conceptual change, the impact of the socio-cultural on domain knowledge acquisition within these interactive learning environments, and detailed content analysis of learner artifacts. This paper has attempted to lay the foundation for additional inquiry into constructivist learning environments within higher education, and present the ways in which these environments connect themselves discursively to broader discussions about the value of liberal arts education to promote various kinds of knowledge and skills. One future strand of research would be to explore the ways in which K-12 teachers trained in STEAM methods are preparing future generations who will expect and perhaps demand embodied, creative solving problem solving learning experiences in their curricula.

References

Abraham, A. (2014). Creative thinking as orchestrated by semiotic vs. cognitive control brain networks. *Frontiers in Human Neuroscience, 8*(95), 1–6.

Abraham, A., Pieritz, K., Thybusch, K., Rutter, B., Kröger, S., & Schweckendiek, J., et al. (2012). Creativity and the brain: Uncovering the neural signature of conceptual expansion. *Neuropsychologia, 50*(8), 1906–1917.

Ackerman, E. (2004). Constructing knowledge and transforming the world. In M. Tokoro & L. Steels (Eds.), *A learning zone of one's own: Sharing representations and flow in collaborative learning environments* (pp. 15–37). Amsterdam: IOS Press.

American Association of State Colleges and Universities. (1976). *Value-centered education and moral commitment*. Washington, D. C.: American Association of State Colleges and Universities.

Barab, S. A., & Duffy, T. D. (2000). From practice fields to communities of practice. In D. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 25–56). Mahwah: Lawrence Erlbaum Associates.

Barron, B. (2004). Learning ecologies for technological fluency: Gender and experience differences. *Journal of Educational Computing Research, 31*(1), 1–36.

Bequette, M., Brah, L., Fields, D. A., Halverson, E., Kafai, Y., Litts, B., Owens, T., Peppler, K., Santo, R., & Sheridan, K. (June 2013). *The MAKE movement and connections to the CSCL community*. Panel at the 10th International Conference of Computer Supported Collaborative Learning (CSCL 2013). Madison, WI.

Birchfield, D., Thornburg, H., Megowan-Romanowicz, M. C., Hatton, S., Mechtley, B., Dolgov, I., & Burleson, W. (2008). Embodiment, multimodality, and composition: Convergent themes across HCI and education for mixed-reality learning environments. *Advances in Human-Computer Interaction, 2008*. Article, 874563, 1–19.

Blikstein, P. (2014). Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs: Of machines, makers and inventors* (pp. 1–21). Bielefeld: Transcript Publishers.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn*. Washington, D. C.: National Academy Press.

Brennan, K., & Resnick, M. (2012). *New frameworks for studying and assessing the development of computational thinking*. Paper presented at the 2012 Annual Meeting of the American Educational Research Association (Vancouver, Canada April 13–17).

Brett2016 (15. December 2012). Final reflection post [Blog post]. http://umwthinklab.com/2012/12/15/final-reflection-post-3/. Accessed 21 March 2014.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18,* 32–42.

Bruner, J. (1991). *Acts of meaning*. Cambridge: Harvard University Press.

Buechley, L., Peppler, K., Eisenberg, M., & Kafai, Y. (2013). *Textile messages: Dispatches from the world for e-textiles and education*. New York: Peter Lang.

Carnegie Foundation for the Advancement of Teaching. (2010). The 2010 Carnegie classification: Methodology [PDF file]. http://classifications.carnegiefoundation.org/downloads/2010classifications_logic.pdf. Accessed 15 March 2014.

Chopp, R. (2014). Remaking, renewing, reimagining: The liberal arts college takes advantage of change. In R. Chopp, S. Frost, & D. H. Weiss (Eds.), *Remaking college: Innovation and the liberal arts* (pp. 13–24). Baltimore: The Johns Hopkins University Press.

Chopp, R., Frost, S. & Weiss, D.H. (Eds.). (2014). *Remaking college: Innovation and the liberal arts*. Baltimore: The Johns Hopkins University Press.

Churchill, D., & Hedberg, J. (2008). Learning objects, learning tasks and handhelds. In L. Lockyer, S. Bennett, S. Agostinho, & B. Harper (Eds.), *Handbook of research on learning design and learning objects: Issues, applications and technologies* (pp. 451–469). Hershey: Information Science Reference.

Csikszentmihalyi, M. (1997). *Creativity: Flow and the psychology of discovery and invention*. New York: HarperCollins Publishers, Inc.

Davidson, C. (2008). Humanities 2.0: Promise, perils, predictions. *PMLA, 123*(3), 707–717.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and instruction, 29,* 153–170.

diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293–331.

diSessa, A. A. (2006). A history of conceptual change research. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 265–281). Cambridge: Cambridge University Press.

Duncan, A. (2010). The well-rounded curriculum [Press Release]. http://www2.ed.gov/news/speeches/2010/04/04092010.html. Accessed 1 April 2014.

Eger, J. (2013). STEAM…now! *The STEAM Journal, 1*(1): Article 8. http://scholarship.claremont.edu/steam/vol1/iss1/8/. Accessed 15 March 2014.

Fink, A., Benedek, M., Grabner, R. H., Staudt, B., & Neubauer, A. C. (2007). Creativity meets neuroscience: Experimental tasks for the neuroscientific study of creative thinking, *Methods, 42*(1), 68–76.

Fredette, M. (2013). Full STEAM ahead. *Transforming Education Through Technology, The Journal, 40*(10), 35–38.

Ghanbari, S. (2014). STEAM: The wave of the future embedded in ideals of the past. *The STEAM Journal, 1*(2), Article 27. http://scholarship.claremont.edu/steam/vol1/iss2/27/. Accessed 15 March 2014.

Gold, M. K. (Ed.). (2012). *Debates in the digital humanities*. Minneapolis: University of Minnesota Press.

Goldberg, M. H. (1971). *Design in liberal learning*. San Francisco: Jossey-Bass.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1996). Cognition and learning. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 15–46). New York: Macmillan Library Reference USA.

Hamilton College. (n. d.). Mission statement [Web page]. http://www.dhinitiative.org/about/mission. Accessed 1 March 2014.

Hayek, J., & Kuh, G. (November 1998). *The capacity for life-long learning of college seniors in the mid-1980s to the mid-1990s*. Miami, FL: Paper presented at the annual meeting of the Association for the Study of Higher Education.

Henriksen, D. (2014). Full STEAM ahead: Creativity in excellent STEM teaching Practices. *The STEAM Journal, 1*(2), Article 15. http://scholarship.claremont.edu/steam/vol1/iss2/15/. Accessed 2 March 2014.

Hoppe, K. D. (1988). Hemispheric specialization and creativity. *The Psychiatric Clinics of North America, 11*(3), 303–315.

Ito, M., Baumer, S., Bittanti, M., Boyd, D., Cody, R., Herr-Stephenson, B., Horst, H. A., Lange, P. G., Mahendran, D., Martínez, K. Z., Pascoe, C. J., Perkel, D., Robinson, L., Sims, C., & Tripp, L. (2010). *Hanging out, messing around, and geeking out: Kids living and learning with new media*. Cambridge: The MIT Press.

Jessicahwu. (18. April 2013). Final project fail! [Blog post]. http://umwthinklab.com/2013/04/18/final-project-fail/. Accessed 14 Feb 2014.

Jewitt, C., & Kress, G. R. (2003). *Multimodal literacy*. New York: Peter Lang Publishers.

Jonassen, D., & Land, S. M. (Eds.).(1999), *Theoretical foundations of learning environments*. Mahwah: Lawrence Erlbaum Associates.

Kafai, Y. B. (2006). Constructionism. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 35–46). Cambridge: Cambridge University Press.

Kafai, Y., & Harel, I. (1991). Learning through design and teaching: Exploring social and collaborative aspects of constructionism. In I. Harel & Y. Kafai (Eds.), *Constructionism* (pp. 85–106). Norwood: Ablex.

Kafai, Y. B., & Peppler, K. A. (2014). Transparency reconsidered: Creative, critical, and connected making with E-textiles. In M. Ratto & M. Boler (Eds.), *DIY citizenship: Critical making and social media*. Cambridge: MIT Press.

Kafai, Y. B., & Resnick, M. (Eds.). (1996). *Constructionism in practice: Designing thinking, and learning in a digital world*. Mahwah: Lawrence Erlbaum.

Knobel, M., & Lankshear, C. (2010). *DIY media: Creating, sharing and learning with new technologies*. New York: Peter Lang.

Koblik, S., & Graubaud, S. (Eds.). (2000). *Distinctively American: The residential liberal arts colleges*. New Brunswick: Transaction Publishers.

Maeda, J. (2013). STEM + Art = STEAM. *The STEAM Journal, 1*(1), Article 34. http://scholarship.claremont.edu/steam/vol1/iss1/34/. Accessed 26 Jan 2014.

Menand, L. (2010). *The marketplace of ideas: Reform and resistance in the American university*. New York: W.W. Norton.

Miller, T. (2012). *Blow up the humanities*. Philadelphia: Temple University Press.

National Research Council. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, D. C.: The National Academies Press.

Newfield, C. (2009). Ending the budget wars: Funding the humanities during a crisis in higher education. *Profession,* 270–284.

Norris, A. (2014). Make-her-spaces as hybrid places: Designing and resisting self constructions in Urban classrooms. *Equity & Excellence in Education, 47*(1), 63–77.

Nussbaum, M. (1997). *Cultivating humanity: A classical defense of reform in liberal education*. Cambridge: Harvard University Press.

Oxtoby, D. W. (2014). Breaking barriers and building bridges in teaching. In R. Chopp, S. Frost, & D. H. Weiss (Eds.), *Remaking college: Innovation and the liberal arts* (pp. 77–84). Baltimore: The Johns Hopkins University Press.

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

Pascarella, E.T. & Blaich, C. (2013). Lessons from the Wabash National Study of Liberal Arts Education. Change: *The Magazine of Higher Learning, 45*(2), 6–15.

Pascarella, E. T., & Terenzini, P. (1998). Studying college students in the 21st century: Meeting new challenges. *Review of Higher Education, 21*(2), 151–165.

Pascarella, E. T., Wolniak, G. C., Seifert, T. A. D., Cruce, T. M., & Blaich, C. F. (2005). Liberal arts colleges and liberal arts education: New evidence on impacts. *ASHE Higher Education Report, 31*(3), 1–148.

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

Peppler, K., & Glosson, D. (2013). Learning about circuitry with E-textiles in after-school settings. In M. Knobel & C. Lankshear (Eds.), *The New Literacies Reader*. New York: Peter Lang Publishing.

Pinker, S. (6 August 2013,). Science is not your enemy: An impassioned plea to neglected novelists, embattled professors, and tenure-less historians. *The New Republic*. http://www.newrepublic.com/article/114127/science-not-enemy-humanities. Accessed 17 Feb 2014.

Rescorla, R.A. (1988). Pavlovian conditioning. It's not what you think it is. *American Psychologist, 43*(3), 151–160.

RISD Office of Government Relations. (2013). STEAM by US region [PDF file]. http://stemtosteam.org/wp-content/uploads/2013/07/STEAM-by-US-region.pdf. Accessed 1 March 2014.
Sarah Lawrence College. (n. d.). Games and interactive media [Webpage]. http://www.slc.edu/undergraduate/clusters/games-interactive-media/. Accessed 11 Nov 2013.
Selingo, J. (2013). *College (Un)Bound: The future of higher education and what it means to students*. New York: New Harvest.
Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. *Educational Researcher, 27*(2), 4–13.
Slingerland, E. (2008). *What science offers the humanities: Integrating body and culture*. Cambridge: Cambridge University Press.
Small, H. H. (2014). *The value of the humanities*. Oxford: Oxford University Press.
Soloway, E., Guzdial, M., & Hay, K. (1994). Learner-centered design: The challenge for HCI in the 21st century. *Interactions, 1*(22), 36–48.
Spector, J. M. (2011). Learnign to solve problems in the digital age: Introduction. In D. Ifenthaler, I. P. Kinshuk, D. G. Sampson, & J. M. Spector (Eds.), *Multiple perspectives on problem solving and learning in the digital age* (pp. 1–8). New York: Springer.
Szeman, I. (2003). Culture and globalization, or, the humanities in ruins. *CR: The New Centennial Review, 3*(2), 91–115.
Thomas, D., & Seely Brown, J. (2011). *A new culture of learning: Cultivating the imagination in a world of constant change*. Lexington: CreateSpace.
Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times*. San Francisco: Jossey-Bass.
U. S. Congress. (2011). 12th Congress, 1st Session. H. Res. 319 [PDF file]. http://www.gpo.gov/fdsys/pkg/BILLS-112hres319ih/pdf/BILLS-112hres319ih.pdf. Accessed 1 Nov 2013
von Glasersfeld, E. (1989). Cognition, construction of knowledge, and teaching. *Synthese, 80,* 121–140.
Vygotsky, L. S. (1978). *Mind in society*. Cambridge: Harvard University Press.
Wboadurg. (14. December 2012). My thoughts on the semester [Blog post]. http://umwthinklab.com/2012/12/14/my-thoughts-on-the-semester/. Accessed 12 Feb 2014.
Woodward, K. (2009). The future of the humanities—in the present and in the public. *Daedelus, 138*(1), 110–123.
Worsley, M., & Blikstein, P. (2013). *Towards the development of multimodal action based assessment*. Proceedings of the Third International Conference on Learning Analytics and Knowledge (LAK ’13), Dan Suthers & Katrien Verbert (Eds.). ACM, New York, NY, USA, 94–101.
Yakman, G. (2008). ST∑@M Education: An overview of creating a model of integrative education [PDF file]. Unpublished. http://www.steamedu.com/2088_PATT_Publication.pdf. Accessed 14 Jan 2014.

Armanda L. Lewis currently serves as the Director of Educational Technology for NYU’s Faculty of Arts & Science, where she provides leadership and planning for the effective and strategic use of emerging technologies and supports a wide range of educational technology projects to promote increased interactivity, global awareness, and creativity. She holds a doctorate in literature and is currently completing a Ph.D. in educational technology, specializing in technology-enhanced language acquisition, design patterns, and learning analytics.