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Abstract

Ever since the introduction of desktop computers in schools, the degree to which technology constrains or enables students' creativity has been explored in a number of guises and continues to color our understanding of the current trends in education. Because a central objective of educational technology is to redesign our tools and environments to enable new forms of teaching that make learning more efficacious, educational technologies offer new ways to think about and to measure creativity, teach creative thinking, and deepen creative expression. This chapter offers a broad survey of creativity research within this domain, presenting the definitions and constructs that are most important to the conceptualization of creativity with educational technologies and suggesting future considerations for the study of creativity in this area.

Introduction

With new tools come new opportunities for individuals to experience creativity. Ranging from new materials to new visual programming environments, virtual reality, apps, social media, online learning, robotics and more, technology is rapidly opening up new areas of study in the creativity literature. Ever since the introduction of desktop computers in schools, the degree to which technology constrains or enables students' creativity has been explored in a number of guises and continues to color our understanding of the current trends in education, including tinkering (Resnick & Rosenbaum, 2013), social networking (Donath & boyd, 2004), and computational flexibility (Smith, 2006).

The integration of digital technologies into educational domains is widely varied but far-reaching, spanning from pre-school to professional settings. Such integrations introduce new forms of creative expression to students, resulting in artifacts and practices that sit at the nexus of different forms of play, creative exploration, and

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disciplinary learning. For instance, prior research demonstrates how pre-school students playing with Squishy Circuits – a circuitry toolkit that includes playdough, LEDs, and other electrical components – transforms simple, sculptural-artistic play into a new activity that integrates the arts, technology, and other domains (Wohlwend, Keune, & Peppler, 2016):

> With rolled up sleeves, 4-year old Nate plunges star-shaped cookie cutters into flattened playdough. Calling each playdough star "rocket ships," he picks up a star and waves his arms across his body from left to right and up and down. He then grabs a Dora the Explorer keychain, casually flings Dora around his index finger and places her next to the star.
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> Across the table, 5-year-old Suparna, fairy wings strapped to her back and cinnamon across her face, holds an LED light in front of 4-year-old Aamir. Carefully, Suparna takes one of the leads into one hand while pulling on the other by tightly squeezing her thumb and index finger together. She looks up at Aamir, explaining "you have to spread them apart." Suparna sticks one lead of LED into Aamir's playdough snowman and the other into her own. Both figures are connected to a battery pack and the LED flickers, shining a dim glimmer upon the connected characters. Aamir squeezes the playdough tightly around the leads. The light brightens.
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> All at the same time, Nate, Suparna, and Aamir are crafting, playing, collaborating, and debugging with Squishy Circuits, an electronic toolkit and educational technology with creative potential. It builds on the conductive properties of salty playdough to invite colorful LEDs, humming motors, squeaking buzzers along their technological practices, to join the playful crafting with ordinary playdough.

The domain of educational technologies spans work in computer science and the arts, resting at the intersection of these two fields. Though researchers have argued that the construct of creativity differs between these two fields (Salgian et al., 2013), we can assert that a focus on educational technologies gets us to think more widely about how a tool or learning environment is designed to teach and cultivate creativity. Because a central objective of educational technology is to redesign our tools and environments to enable new forms of teaching that make learning more efficacious, educational technologies offer new ways to think about and to measure creativity, new ways to teach creative thinking, and new ways to deepen creative expression.

This is a vast area, not least because the boundary between educational technology and educational uses of commercial technology is hard to define. Because it would be impossible to review everything, this chapter focuses particularly on aspects of educational technology that include social media, robotics, online learning, and software, as well as new-media art platforms that allow for programming and other aspects of digital production. In the process, I will present a broad survey of creativity research within this domain, and present the definitions and constructs that are most important to the conceptualization of creativity, as well as how creativity is commonly measured, and offer future considerations for the study of creativity in this area.

Defining Creativity Within Educational Technology

Novelty and Usefulness

Like many other domains, research on creativity within the domain of educational technology has a pervasive focus on defining creativity in terms of novelty, flexible thinking, and usefulness (e.g., Baumer, Tomlinson, Richland, & Hansen, 2009; Jahnke, 2011). As Plucker and colleagues argue, creativity is "the interaction among *aptitude, process, and environment* by which an individual or group produces a *perceptible product* that is both *novel and useful* as defined within a *social context*" (Plucker, Beghetto, & Dow, 2004, p. 90, original emphasis). Mishra and Henriksen (2013) have further operationalized this definition by defining creativity for educational technology as a measurement along three independent axes – *novel, effective*, and *whole* – arguing that "creative products (be they artifacts or ideas) are not just new or interesting, they are useful, and they have a certain aesthetic sensibility, which is connected to and evaluated within a specific context – the whole!" (p. 11). This work provides a basis for rubrics and other ways of evaluating creative products that the authors argue is particularly useful in the field of educational technology (and is further described later in this chapter).

Ecological Nature of Creativity

Scholarship on creativity has also recognized the genesis and development of creative ideas as being part of a broader, socially determined process (Sternberg, 2003; Sawyer, 2006, 2007). Consistent with Csikszentmihalyi's (1996) model, creativity is becoming increasingly understood as a system, composed of individuals, knowledge domains, and a field of informed experts. Given the pervasiveness of Internet-enabled devices in youths lives, the acts of information acquisition and product sharing are largely done in a communal (at least virtually) context, placing a stronger role of the environment in shaping youths creativity. Peppler and Solomou (2011), for example, examined how environmental creativity is uniquely shaped by the kinds of networks afforded in today's online culture. This study explored the design of a social media environment to foster collaborative learning and creativity. The researchers designed two parallel virtual worlds where participants were encouraged to engage in 3D architectural construction. Despite offering users the same toolset for construction, the two worlds emphasized very different cultural values – one designed for high levels of creativity (i.e., players were encouraged to design highly original buildings, regardless of fiscal viability) and the other for low (i.e., players were encouraged to follow formulaic design practices as befitting in-game market demand). The resulting work within these environments reflected the cultural values designed into the system, indicating that the way in which we design our social media environments has implications for the creativity of the products users produce. Using chat and archival data of the 3D virtual environment, the researchers explored how architectural ideas spread within the online space (i.e., other users referencing or emulating a design), ultimately defining creativity in this domain as *a spreadable idea that is taken up by others* in the field, and that this lineage of ideas can be traced back to a single individual, the origin of the idea. Implications for measuring creativity as the spread of ideas taken up by others in the field offers a way of measuring creativity through an embedded assessment, utilizing embedded data metrics. Another possibility is to look at how the ideas transform and become appropriated through the spread of a creative idea and to examine the larger patterns or iterative evolutions of the ideas. These ways of defining creativity emphasize the importance of social networks in determining whether a creative idea is taken up by the larger field, contributing to the domain.

Designing Creativity-Enhancing Tools and Environments

The design of the technology itself plays a large role in shaping these outcomes. Several scholars have provided new frameworks for conceptualizing creativity within the domain of educational technology, paying particular attention to aspects of human-computer interaction and the types of creative activities they precipitate. For example, Shneiderman (2000) advances a proposal for a *genex (generator of excellence) framework*, which is a four-phase integrative framework for designing powerful technologies that enable users to produce creative work. Technologies that adhere to the framework enable users to collect (i.e., learn from prior works), relate (i.e., consult with peers and mentors at all stages), create (i.e., explore, compose, and evaluate possible solutions) and donate (i.e., publish and share results) in the production of creative work. Shneiderman further proposes eight activities that can be incorporated into the design of an environment to facilitate creativity, including users' ability to (1) search and browse digital libraries, (2) consult with peers and mentors, (3) visualize data and processes, (4) think by free association, (5) explore solutions, (6) compose artifacts and performances, (7) review and replay session histories, and ultimately (8) disseminate results (2000). Shneiderman's framework clarifies a future research agenda for the designers of human-computer interaction as well as the researchers who evaluate the creative expressions of individuals who engage with these technologies (cf. Albors-Garrigos & Carrasco, 2011).

Constructs Informing the Conceptualization of Creativity in Educational Technology

Creativity researchers have drawn upon a breadth of constructs important to the conceptualization of creativity in their analysis of educational technology, including surprise, problem solving, human agency, improvisation, and social capital. Several researchers have drawn on *surprise*, for example, as a central construct to the design and study of creativity within new educational technologies (e.g., Zheng, Bromage, Adam, & Scrivener, 2007; Rosen, Schmidt, & Kim, 2013). Educational technologies can promote surprise through the random presentation of materials as well as by users coming up with a new valuable idea. Researchers have dubbed this as p-creativity (for "psychological" creativity," which describes a surprising or valuable idea that is new to the person coming up with it, regardless if others had come up with the idea before. This is opposed to h-creativity (for "historical" creativity), which relates to surprising ideas not known to be had by anyone else in human history (Boden, 2004). Though not referred to as "surprise," Clements speaks of a similar phenomenon in terms of *mental reorganization* fostered through early educational technologies, arguing that such technologies necessitate "continuous reformations and modifications within a context of the invention and construction of one's own graphic projects" (1986, p. 310).

Another focus of work on creativity within educational technologies is the creativity that emerges through the *problem-solving* process, including "deciding on the nature of the problem, choosing performance components (lower-order components not as critical to creative thought) relevant to the solution of the problem, combining these performance components, selecting a mental representation, and monitoring" (Clements, 1995, p. 144). This is likely because educational technologies are frequently utilized in an intervention format, where challenges are posed and addressed through the introduction of the technology.

The interactive elements of new technologies have brought the role of *human agency* in our conceptualizations of creativity to the fore. Researchers like Charles and Shumar have grappled with the relationship between humans and computers, asserting that "much of social life is constrained structures that themselves are the product of past action both conscious and habitual and that these constraints are something that social actors must indeed face" (2007, p. 120). This draws on the earlier work of Emirbayer and Mische (1998), who emphasize the creative dimensions of human agency have a future focus and are tied to *imagination* and *improvisation* (as cited in Charles & Shumar, 2007). Linder and colleagues (2015) also recognize the importance of improvisation in the conceptualization of creativity, applying Fisher and Amabile's (2009) notion of improvisational creativity to the study of educational technology. In their view, technology brings about opportunities for improvisational creativity by allowing for free-form, spontaneous, and unrestricted thinking (Linder et al., 2015). Linder and colleagues define *free-form thinking* as involving: "(1) improvisational exploration of associations; (2) the emergence of new ideas, generated through building on previously known associations; (3) divergent wanderings to unexpected places; and (4) spontaneous synthesis of new understandings, relationships, and ideas" (2015, p. 285).

Furthermore, educational technology, particularly social media, has accentuated the role of social networks in youths' learning and creativity. As such, several scholars have placed an increased emphasis on social capital and have even gone so far as to define creativity as a form of social capital needed for productive participation in a knowledge society (Dawson, Tan, & McWilliam, 2011; Lai & Hwang, 2014). In a way, these various constructs coordinate, helping us to understand how educational technology pushes our prior conceptualizations of creativity in new directions.

Measuring Creativity Within the Domain of Educational Technology

Since educational technologies can range from alternative modes of content delivery and engagement (e.g., video games) to new tools and materials for production (e.g., graphic design, computational textiles, robotics), a variety of research approaches have been applied to better understand the creativity of the user of the technology as well as the artifacts they create with it. The former body of research has focused primarily on traditional cognitive measures of creativity, such as the Torrance Test of Creative Thinking (TTCT; Torrance, 1972) and Guilford's Alternative Uses Task (1967), described in detail below. Such assessments have often been employed using traditional means: as pre- and post-test measures around an intervention using educational technologies (e.g., the students engage with a technology product, or they respond to each other or stimuli in a technology-filled environment) to measure the effects of the intervention on students' creative thinking.

Alternatively, several researchers have sought to assess the creativity of the products created with educational technologies using measures like the Amabile Consensual Assessment Technique (CAT) (Amabile, 1982). Many of these studies inherently emphasize that creativity can be exemplified in a variety of products, regardless of the nature of the technology in the educational intervention. Asserting that creativity can be expressed uniquely through technological means, recent scholarship has adapted rubrics like the CAT for technology-specific applications (Besemer, 1998; Besemer & O'Quin, 1999; Michael, 2001), or developed new methods of assessing creative expression in online environments that rely less on the development of products and more on creative actions and behaviors. Similarly, some research has sought to measure the impact of online networks on a person's creativity (Yang & Cheng, 2010; Dawson, Tan & McWilliam, 2011).

Some researchers have also sought to employ technology as an impartial assessor of youths' creativity, extending traditional assessment techniques with computational assessments that mine data for patterns of creative behavior (Baumer et al., 2009). Computational assessments open up new ways to quantitatively measure creativity as well as create more fluid ways for assessment to become integrated with students' play with technology, potentially fostering, as well as measuring, growth in student creativity. Below, three different approaches to the measurement of creativity are presented that vary by theoretical perspective and toolsets employed, including a survey of cognitive, artifact-based, and computational measures of creativity.

Cognitive Measures of Creativity

Researchers of educational technologies have long been interested in how students' creative thinking is shaped through the use of alternative modes of teaching and learning. The earliest uses of the computer in educational settings was met with both high expectations and skepticism. The first research to explore the efficacy of these technological interventions on students' creativity is documented in Douglas Clements's comprehensive review of how creativity was taught with computers (Clements, 1995). This review focused mostly on studies that had used educational technologies like the Logo programming environment (Papert, 1980) as well as some considerations of other programs, like Scardamalia and Bereiter's CSILE (1996) and LEGO/Logo (Resnick, Ocko & Papert, 1988). Pervasive across all the articles reviewed was the assessment of creativity using the TTCT (Torrance, 1972). Assessing verbal and/or non-verbal measures of creative thinking, these studies examined students' cognitive expressions of creativity as a result of the technologies used. Looking across these studies, Clements noted that the technologies that seemed to have the greatest impact on creativity included design features that encouraged higher-order thinking, control, and mastery. Beyond the software itself, the meta-review noted how the teacher's facilitation style in coordination with the educational technology can impact student creativity. Furthermore, this meta-review provided evidence that children were having the opportunity to express creativity across content areas – through knowledge-building in mathematics, through design or artistic expression, or through computer science.

The programming language Logo (Papert, 1980) was among the first educational technologies to be used in creativity studies. This early work examined Logo using the TTCT (cf. Clements, 1986; Horton & Ryba, 1986). The Logo programming language, which enabled users to control the path of a mechanical turtle (or, later, a graphic turtle on the screen) was designed to engage students in conceptually different ways of learning mathematics and science through computer programming and meta-reflection. Soon after Logo was introduced to schools, several researchers began a series of studies where they investigated the impacts of the Logo programming language on children's creativity and cognition. Early reports noted significant gains in creativity, noting that students using Logo more fully developed their graphic compositions in completeness, originality, and drawing style than students not doing Logo programming (Horton & Ryba, 1986). Around the same time, Clements compared computer-assisted instruction (i.e., instructional mediation presented on a computer) to Logo programming and to a control group, measuring the impacts of these approaches on first- and third-graders' creativity, operational competence, metacognitive skills, and achievement (1986). Children in the two treatment conditions took time out of class to either program with Logo or participate in computer-assisted instruction over the course of twenty-two weeks. To measure creativity, Clements used the Figural TTCT (1972), which assesses several mental characteristics (including fluency, flexibility, originality, and elaboration) through picture-based exercises. Findings indicated that the Logo programming group had higher posttest gains than the other groups on almost all measures. Gains were particularly prominent in the originality and elaboration dimensions.

A follow-up study compared third graders working in Logo to students engaging in a prescribed, computer-supported creativity enhancement process – which included brainstorming, composing, revising, and editing – as they composed writings with a word processor and illustrated using with a graphics program (Clements, 1991). The students who used Logo were encouraged to use procedural thinking and cognitive componential processes thought to be crucial to creativity. These processes were conveyed through "homunculi" – characters that used these processes, including "Detective Selective," "Problem Decider," "Representer," and "Strategy Planner" – and were often called upon to help remind students of what they could do to help them accomplish their goals. Clements again measured creativity using the Figural TTCT as well as the Verbal TTCT, a test that employs word-based exercises to assess three mental characteristics (i.e., fluency, flexibility, and originality). The Logo group's total score on the figural posttest was significantly higher than the other two groups' scores, and both the Logo and creativity comparison group scored significantly higher on the verbal test than the control group.

Despite the tremendous development in educational uses of technology, many of today's studies continue to use derivations of the TTCT to measure creativity. Lewis (2009), for example, measured the impact of educational technologies that support design and intention activities on children's problem-solving ability, divergent thinking, combination thinking, and metaphorical thinking.

In addition, studies have used other time-honored cognitive measures of creativity (or a mix of cognitive measures), including the Guilford Alternative Uses Test (Guilford, 1967). In this test, examinees are asked to list as many uses for a common household item as possible. Scoring comprises four components: originality, fluency, flexibility, and elaboration. In a 2007 study, Zheng and colleagues used both the Guilford Alternative Uses Test as well as the TTCT to examine a new model, based on research on the value of "surprise," to help generate greater creativity in children. Based on constructivist theory, the researchers asserted that surprising outcomes challenge previously held beliefs (i.e., disequilibration), thus engaging people's curiosity to explain what caused the surprising outcome and changing their schema. Zheng and colleagues applied this model to the design of an interactive artifact called EYE-JUMP (i.e., a jump rope with LEDs that produces persistence-of-vision images) that would produce surprising outcomes in children. They tested the interactions with this artifact to measure its effects on surprise and on creative idea generation. In this study, the TTCT was used to measure creativity/divergent thinking before and after playing with the technology. Guilford's Alternative Uses Test (1967) was used to ask youth to come up with alternate uses for a beaker (pre-test) and a towel (post-test). Answers were scored using four categories from Torrance: Fluency, Flexibility, Originality, and Elaboration. Results indicated that children who played with EYE-JUMP came up with ideas that were significantly more creative, but only in the Originality dimension.

Accumulatively, this work helps to dispel popular notions – especially those that emerged when the first technologies were introduced in schools – that technology has a negative impact on creativity (Cordes & Miller, 2000). While this may be true for some technologies, particular design features have been shown to have a significantly positive impact on students' creativity over time.

Measuring the Creativity of Technology-Produced Artifacts

Several educational technologies are designed to foster learning through production, whether it be circuitry-enhanced electronic textiles or interactive digital stories. In these instances, many researchers have sought to measure creativity through an examination of the artifacts youth produce. A foundational assessment of the creativity of artifacts used in the field of educational technology is the CAT developed by Amabile (1982). This test measures creativity using an assortment of (typically) expert judges, who assess creative works individually and in isolation. Their views are then collected and collated so that an overall rating or measure can be established.

Within the field of educational technology, Amabile's work has guided many examinations of youths' creative productions. For example, in an early study on the potential extrinsic constraints of the computer on children's creativity, Hennessey tasked a set of expert judges to use the CAT to measure the creativity of geometric shapes produced by children (Hennessey, 1989). Similarly, Peppler and colleagues (2011) employed the CAT in the examination of youths' e-textile (e.g., fabric artifacts that make use of computation and electronic circuitry through microcomputing and conductive thread) creations. The researchers tasked novices and experts to sort and assess the creativity of those artifacts. These investigations sought to determine the extent to which expertise was necessary to assess creativity. The study determined that expertise was not needed within the emerging domain of e-textiles and that novices and experts bear a great deal of resemblance when judging the creativity of e-textile artifacts. Given the range of new emerging technology domains, this study affirms the usefulness of the CAT for assessing the creativity of products created using new educational technologies.

Researchers have also developed rubrics to guide the measurement of creative artifacts, which have over time been adapted for technology-specific applications. Besemer's Creative Product Semantic Scale (CPSS), for instance, offers a framework based on three dimensions: Novelty (i.e., the product is original, surprising, and germinal), Resolution (i.e., the product is valuable, logical, useful, and understandable), and Elaboration and Synthesis (i.e., the product is organic, elegant, complex, and well-crafted). The CPSS involves 55 adjectives applied to some aspect of the creativity of a product. Raters, who do not have to be experts, use a Likert-like scale to rate products along all 55 adjective dimensions using a semantic-differential rating scale (e.g., "surprising – unsurprising," "logical – illogical," or "elegant – inelegant") (Besemer, 1998; Besemer & O'Quin, 1999). Researchers have applied these scales toward the assessment of products in technology-rich environments. For instance, Michael (2001) used the CPSS to examine creativity in problem-solving, which is one of the main goals of educational technology. This study compared the effect of computer simulation on product creativity versus a hands-on activity. Sub-scales "Original" and "Useful" from the CPSS were chosen to be consistent with Moss's (1966) theoretical model, which characterizes creativity as a combination of unusualness/originality and usefulness. They found that those who utilized computer simulations generated more creative solutions than those using hands-on solutions. The low cost of computer simulations has implications for efficaciously scaling approaches to creativity across settings.

The CPSS was later adapted by Mishra and colleagues, resulting in the NEW (Novel, Effective, Whole) measure of creative artifacts, to be used for providing a structure to "guide judgement and give each project or artifact a fair, systematic, consistent and comprehensive assessment" (Mishra & Henriksen, 2013, p. 13; Mishra & Koehler, 2008). Undergirding this framework is the understanding that creative solutions are – or creativity is – a goal-driven process of developing solutions that are Novel (i.e., the product must be something that did not exist prior, and it often has the quality of being surprising or original), Effective (i.e., purposeful or useful), and Whole (i.e., the aesthetic dimensions of the work, such as attractiveness, understandability, and order, must be valued by the domain). Mishra advocated for this rubric to apply generally to the measurement of creativity in technology-rich settings (Mishra & Henriksen, 2013).

Researchers have also used both the CAT and the CPSS to triangulate their findings. In their study of creativity in educational technology interventions, Thang and colleagues (2008) asked children (ages 8–12) to either brainstorm or prototype solutions for a child with a broken limb who needs to attend classes online. The researchers engaged design experts (i.e., industrial design Masters students) to rate the creativity of the student's solutions using a combination of the CAT and the CPSS, and were later interviewed about the designs that were rated as most and least creative. Results demonstrated that brainstorming led to higher ratings of designs, though both methods generally led to creative designs. Brainstorming produced more designs that were rated as surprising and novel, while prototypes were rated more relevant and workable.

Computational Assessments of Creativity

Moreover, the study of creativity within the domain of educational technology opens up new possibilities for the measurements of creativity using computational assessments. One early example is derived from the use of Computational Metaphor Identification (CMI; Baumer et al., 2009), which is a computer program that searches a corpus of text and generates a list of categories of words that tend to appear together. This approach uses technology to draw potential conceptual metaphors to users' attention and encourage critical thinking, creativity, and reflection about metaphor. Baumer and colleagues used this technique to help students think of creative metaphors about cells. In the treatment condition, the researchers presented three metaphors gleaned from a CMI analysis of various relevant Wikipedia articles, while in the control condition they had students watch a video on cells. They then asked both groups to generate a new metaphor about cells and map as many organelles as they could using this new metaphor. Notably, the creativity (operationalized as novelty, uniqueness, and aptness) of the students' new metaphors was assessed quantitatively. Researchers used a mathematical formula to compare a metaphor's uniqueness to all other metaphors students identified. The metaphors were also coded for aptness based on whether all the mappings of the organelles fit in with the overall metaphor, and whether the metaphors were based on featural/surface similarities or functional similarities (more apt). Scores for uniqueness and aptness were combined into an overall creativity score by averaging the two scores and giving them equal weight.

Technology has also expanded the range of artifacts that can be mined for expressions of creativity. For instance, Jain and colleagues (2015) evaluated exploratory browsing (an alternative to search-bar-driven Internet browsing) as a unique way to express and cultivate creativity in the digital age. Examining a Twitter plug-in called TweetBubble – which opens up contextual info on usernames and hashtags without users having to leave the page they are currently browsing – the researchers measured whether users' search behaviors led to more exploratory browsing, a technique similar to "fortuitous searching" identified by Ito and colleagues (2009). Being able to explore in a creative way for new information is an educationally relevant "Mini-C" creativity practice that allows people to encounter and learn about new perspectives. The researchers modified Kerne et al.'s (2014) ideation metrics to evaluate TweetBubble users' fluency, flexibility, and novelty, as compared to users browsing with ordinary Twitter. Fluency was measured by total number of feeds browsed, Flexibility was measured by total number of distinct feeds browsed, and Novelty was measured by the relative uniqueness of feeds browsed compared to everyone else in the sample. Results showed that TweetBubble users' ideation metrics were much higher than those of users without access to the browser extension.

A separate study utilized data-mining techniques to create a personalized creativity learning system (PCLS), which is an adaptive, game-based approach to teaching creativity among college students (Lin, Yeh, Hung, & Chang, 2013). The experimental study found that when a hybrid decision-tree was employed, learners have above a 90 percent likelihood of attaining an above-average creativity score, further suggesting that technologies can be created to not only encourage greater creativity but also teach creativity. While just emerging, approaches like these are among several promising avenues of computational assessments of creativity to be able to track and measure creative output over time, as well as provide immediate data for prototyping tools and online environments.

Studying Creativity across Educational Technologies

How we understand creativity in this area is tightly tied to the technology itself and how it's designed. As mentioned earlier, the field of educational technology is a broad collection of studies across several genres of digital media, spanning social media, software applications, virtual environments, wikis, and intelligent tutors. Since the expression of creativity varies by genre just as it does by domain, we stand to benefit from a review of the technologies not addressed above and the areas of creativity that they are shown to engender. Furthermore, understanding the notable gaps in this emergent field is also something that can help guide our future efforts in fostering and understanding creativity through the use of technology.

The Internet, Online Interaction, and Social Media

There is a group of scholars who have theorized that the Internet resembles many of the core characteristics of creative individuals, and that extended use of the Internet may inspire creativity in users by proxy (cf. Shoshani & Hazi, 2007). This work posits that the extended networks enabled through Web 2.0, social media, and the Internet may actually be democratizing creativity by exposing users to a wealth of information beyond what they would have access to in their local sites, as well as extended sets of digital tools. With access to a broad range of information upon which to inform innovation, users can jump off the ideas of others, become familiar with new connections, and build on the legacy of an idea in their own work. This theory plays out in microcosm through the educational use of digital scrapbooking (Swan, Tanase, & Taylor, 2010), interfaces/websites where users showcase aggregated content from across the Internet. It emerged in practice as not only a way to assess students, but also to demonstrate the processional nature of their creative process and to inspire other students who viewed it. While the researchers did not assess creativity per se, the tool was viewed as a way to demonstrate creative leaps in thinking that occurred as students followed new lines of inspiration.

Web 2.0 has also substantially changed the ways in which people interact and communicate online. With the rise of online and hybrid classroom models, some researchers have examined how these online interactions, ranging from synchronous to asynchronous communication, can be possible purveyors of creativity. For some, online interactions engender a new way of approaching societal structure and traditional means of communication. Charles and Shumar (2007), for instance, view creativity as a form of emancipatory agency, as something that helps people think outside of the predetermined structures of society, or that helps people engage with these structures in new ways. The researchers qualitatively report on two cases from students working on math problems within a synchronous chat environment. The structures of the chat environment, such as anonymity, equality, and a chat setting that is reminiscent of social instant messaging, seemed to allow students in these two cases to exercise creative agency in ways that would be unlikely within the structures of a classroom.

Furthermore, scholars have investigated how the use of social media in higher education can facilitate creativity in instruction. Allen and colleagues (Allen, Caple, Coleman, & Nguyen, 2012), for example, worked with university professors on the integration of Wikis, Ning, and Facebook into the classroom, asking the instructors to assess when they felt the most creative. Findings suggested that creativity was inherent in the teaching process when there was an emphasis on designing the learning activity and the environment, when instructors could be creative in the roles that they play in their teaching, and when providing and participating in social communities. Furthermore, the researchers believe that the social media tools themselves promoted the creative process by tasking instructors to experiment with unfamiliar modes of communication and participation. Through these studies, we see that creativity is not just enabled through the introduction of the technology but through subsequent shifts in our social practices.

Crowdsourcing Education

Educators today are often interested in individualized education, and crowdsourcing offers promising leads for that direction. Weld and colleagues (2012) explain potentials for crowdsourcing in education, and they claim that (1) crowd techniques will be required in order to deliver quality education in some areas; (2) existing techniques are ready for application to this new area; and (3) online education represents a new, relatively unexplored way of creating crowds. They discuss crowdsource peer-grading, and they argue that it may lead to more accurate assessments because it combines different people's opinions and expertise, and the high overlap would account for high reliability. They believe that there is great potential for crowdsourcing education, but they also argue that there are challenges at the level of the curriculum (e.g., deciding on the content to be learned), the personalization/engagement (e.g., sustaining long-term involvement with the forum), and providing rich feedback to students (e.g., implementing a system of votes/rewards to promote good academic performance). In spite of these challenges, a study by Duveger and Steffes (2012) demonstrates the reliability of crowdsourced grading in a marketing course. In their study, they prompted marketing students to create videos that explained the Millennial generation to the Baby Boomer generation, and they crowdsourced the grading to 60 external marketing students (i.e., the "crowd") and four external marketing professors. This composition of judges simulates the composition of crowdsourced judges in expanded online communities, and use of the CAT to evaluate the creativity of the videos replicates the rating process in the communities. The grading proved to be reliable because both groups rated the videos similarly in both content and creativity, and both were reliable with each other. Unlike previous studies comparing educators' grades to fellow students', the students were not harsher in their grading. This advances our understanding of creativity because it shows that a group of people with limited "special training" (e.g., students in a field who have not yet mastered that field) can rate creativity just as reliably and with just as much strictness/leeway as a group of educators.

Re-Envisioning Art Domains Through Educational Technology

The introduction of technology into the classroom in some cases radically changes established domains of creativity. For example, tools enable novices to compose original music without using traditional instruments as well as enable painters to mix virtual paint without paying for materials or gaining prior experience in art class. To a certain extent, the evolution of every domain is inevitable whenever new media is introduced. Conversely, not every form of new technology ruptures paradigms; some technology actually reinvigorates interest in traditional domains and translates them into new digitally mediated forms (Peppler, 2014).

The frequent source of disruption in the arts domains is the introduction of new multimodal expressions made possible through the use of technology. For example, digital technology has extended print-based creative writing into new forms that synthesize art and multimedia components, including digital storytelling, animated stories, hypertext, kinetic poetry, computer-generated animation, digital visual poetry, and code poetry, among others (Rasula, 2009; Richey & Kratzert, 2006; Zervos, 2007). Creativity researchers have investigated how multimodal forms of communication can stimulate a broad spectrum of creativity through the incorporation of additional modes of expression (cf. Ohler, 2013), including increased divergent thinking (Wilburg, 1987) and free-form thinking (Linder et al., 2015).

Similar trends have emerged through the incorporation of technology into music education, as new applications are expanding the channels through which people perform and learn about music. The music education community has long lamented that many youths fail to connect the repertoire, instruments, and skills embodied in informal music activities to formal music education. In the past decade, rhythmic video games – the hugely successful Guitar Hero, DJ Hero, and Rock Band franchises by Harmonix are especially salient examples – have dominated this informal music space for teens. A 2011 study demonstrated that extended play in Rock Band positively correlated with the assessment results of youths' traditional music abilities, providing evidence that youths playing rhythmic video games see a connection between the two ways of notating music (Peppler et al., 2011). Although there are obvious differences between learning to play a guitar and learning to use a peripheral device shaped like a guitar, Brown University ethnomusicologist Kiri Miller (2009) argues that performing a song in a game environment such as Guitar Hero or Rock Band is an authentic music performance. Furthermore, creativity researchers have lauded computer-based tools for their ability to immerse non-trained music students in the creative process (Rosen, Schmidt, & Kim, 2013).

Similarly, new domains unique to the medium of the computer – including video - game design, media arts (the blurring of computation, media, and Information Communication Technologies), and Do-It-Yourself (DIY) fusions of sculpture, robotics and crafts – are changing the nature of creative expression through educational technology. Work on the popular Scratch online community, a visual programing community for sharing interactive stories and games online, has looked at fostering social and collective creativity in the online environment (Aragon et al, 2009), providing a framework for successful creative collaborations. Specifically, systems that support social creativity must facilitate sharing and play, and their design must consider the effects of repurposing, augmentation, and behavior adaptation.

There is also a growing body of work examining the creative use of computation that extends between the screen and the physical world. Salgian and colleagues reported on the measurement of creativity in an interdisciplinary undergraduate computer science class, where students from diverse fields had to collaboratively design a robot that could conduct an orchestra (Salgian, Nakra, Ault, & Wang, 2013). Quantitatively, the researchers administered the Abbreviated Torrance Test for Adults (ATTA), Amabile's CAT, and a self-assessment based on creative activities and accomplishments, adapted from Hocevar (1981). Survey reports on perceptions of creativity from the students before and after the class showed that the collaborative design activity helped students appreciate how diverse ideas from a multidisciplinary group can stimulate creativity.

Other researchers have similarly studied collaborative robotics design activities as a source of creativity, but have brought the design principles of tools and activities that support critical and creative thinking to the fore in their analysis. DiSalvo and colleagues (DiSalvo, Louw, Coupland & Steiner, 2009) systematically compared the role of custom-built creativity support tools and associated activities in the process of enabling imaginative and resourceful robotic designs. Although the domain of robotics can become a powerful form of creativity in its own right, the researchers outline a series of general design principles for encouraging creativity in robotics, such as keeping activities open and allowing for speculation. They further argue, "as makers of technological fluency, we look to group processes that demonstrate social creativity around robotic and sensing technologies and the facility to imagine and translate non-technical goals into technical solutions" (DiSalvo, Louw, Coupland, & Steiner, 2009, p. 246).

Across this work, particularly in the arts, there is a review of creative work without much attention paid to expanding the literature on creativity. Furthermore, the research on creativity has overlooked many of the burgeoning areas of educational technology, including the new digital and media art forms. Considering the amount of transformation occurring in these fields, this area is ripe for more exploration.

Future Considerations Within This Domain

Educational technologies offer new opportunities to shape and design learning environments and to enable new forms of teaching that enhance creative outcomes. As such, educational technology offers a multitude of new directions for the field of creativity research. For example, the ability to create novel and immersive contexts – such as augmented reality, social media applications, new computational tools, and video games – allow the field to design and test the impact of the environment on creative behavior (Amabile et al., 1996; Kerne et al., 2014). For each of these designs, researchers can investigate the design features of the environment that enable, or conversely constrain, creativity. Findings from such investigations can, at a more global level, inform how we (re)design our everyday online experiences, tools, and learning environments (e.g., apps, mobile platforms, social media tools) to encourage greater creativity in and out of school.

Because the domain of educational technologies places a heavy emphasis on the design of the environment, a new emphasis is placed on how we can design new educational technologies to embody and further refine how an individual engages in the creative process. A number of researchers are currently investigating this possibility. For example, engineers are designing new technologies to encourage convergent and divergent thinking, to present an array of similar solutions to push novel thoughts, and to leverage peer review and iterative refinement, among other processes with known impacts on creative outcomes (Benjamin et al., 2014; Zhao et al., 2014). Although to some extent we can leverage design in all domains to better encourage creativity, educational technologies make the role of the designer more visible in the process, affording the learner opportunities for critical reflection on how technology design decisions are made (Kafai & Peppler, 2011; Resnick & Siegel, 2015).

The design of educational technologies also reflects the cultural, historical, and social values of its creators and enables and constrains creativity through the communication of these values. In this way, creativity can be seen as a cultural endeavor, shaped and persisted through the actions and values of many people (Peppler & Solomou, 2011). The design of social media or online environments can serve as a public manifestation of the creative values of a community, and innovations that happen within those communities (or not) are inextricably linked to and confined by the values that the community holds. The educational use of Web 2.0 capabilities – embodied in gaming environments, Twitter, and YouTube, among others – is moving greater areas of the Internet beyond transmission-only spaces and into dynamic environments that thrive on the thought transactions and contributions of a community of participants.

Furthermore, social technologies allow us to investigate the systemic nature of creativity, extending what recent scholarship asserts about the development of creative ideas as being part of a broader, socially determined process (Sternberg, 2003; Sawyer, 2006, 2007). This view builds upon Csikszentmihalyi's systems model of creativity, where individuals build on culturally valued practices to produce new modifications of the domain, which, if prized by the community, becomes part of what constitutes the ever-adapting domain. Social technologies alter the relationship between the various components of this system, given that many are designed to sidestep the panel of experts as a proxy for the "field," instead giving individuals themselves the power to rate, promote, and give cultural heft to the contributions of other individuals. In this way, creative contributions within the community are not determined by experts (Kaufman et al., 2008) but are crowd-sourced (e.g., through ratings on Amazon.com). This fundamentally changes the nature of how we view and assess "creativity," calling into question who constitutes the "field," and expands the methodologies that we can use to investigate creativity. It also raises key questions about whether a YouTube video that receives the most views is indeed the most "creative" of contributions to the community.

Sometimes the environments in which the learning takes place can be quite expansive, changing the nature of how learners' creativity is incentivized and assessed. With the rise of Massive Open Online Courses (MOOCs) and Big Open Online Courses (BOOCs), peer-based assessment of quality and creativity is becoming an increasingly prominent part of some students' educational experience. Much of our understanding about the role of crowdsourced knowledge in academia is informed by the work of researchers who have examined the collective intelligence of online crowds in determining creativity. Crowdsourcing is a method of collaboration in which organizations can leverage the activity level of outside users and expanded communities for the purpose of completing tasks, such as generating new content or evaluating existing goods. While crowdsourcing ratings and user-generated content is commonplace in online commerce, its applicability to educational settings is becoming increasingly explored (cf. Duverger & Steffes, 2012; Kittur, 2010).

As the field of educational technologies continues to expand, new genres are emerging that expand beyond video games and app-based kinds of technologies and engagement. While the arts, for example, have had several centuries to cement emerging traditions into the established visual and performing art forms, the new media arts enable types and genres of educational technologies that often defy categorization and are interdisciplinary in nature. This will pose some difficulties moving ahead for all research, but particularly for the fields of creativity research. This review, for example, was challenging in many respects to pull together as the field of "educational technologies" is actually an umbrella of several types of technologies that don't yet have their own genre. Future research should not only aim to help determine how creativity is being defined and conceptualized within these novel contexts as well as tools used to measure creativity in this landscape, but also to further our understanding of this diverse landscape. As the field of educational technology continues to evolve, how do we define the boundaries of the domain between commercial and educational use? Furthermore, are there clusters of technologies that bear more similarities than others? This is particularly important as we begin to think about how social media and online networks are transforming this domain, in addition to the blurring boundaries between in- and out-of-school learning. Particularly problematic is the fact that many studies in this area come from the leveraging of commercial technologies, where we have little to no control over systematically testing the design features in order to inform our emerging theories.

It is also interesting to note that the field of educational technologies (and others involving newer forms of technology that are now ubiquitous, like film) seems to suggest that we need to further consider history in this domain, and perhaps more so than other domains. For example, research using the Consensual Assessment Technique has started to fairly consistently document that novices and experts don't demonstrate the same kinds of consistent differences of opinion than in domains that have longer histories (Plucker, Holden & Neustadter, 2008; Plucker, Kaufman, Temple & Qian, 2009; Peppler, Fields, Kafai & Glosson, 2011). Might this be an artifact of the short history of technology-rich fields, or the expansiveness of technology (for example, more people see movies than read poetry)? Further, longitudinal studies are needed to establish the extent to which this will change over time, as the technologies themselves become less novel, as large corporations begin to control this landscape, and as the technologies themselves evolve.

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