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Abstract

In recent years, tablets have been shown to serve as incredible teaching tools in classrooms around the world. In mathematics education, divergent thinking, creativity, and play may play a key role in formation of adaptive thinking and math achievement. This qualitative, participatory action research investigated the use of an instructional model that provided minimal instruction in the use of tablets to create stop motion animation movies. This study focused on the themes and patterns that emerged as pre-service teachers integrate a design thinking philosophy as they explore creativity and divergent thinking through the creation of stop motion animation movies. This study employed a participatory action research design that examined the use of an instructional approach informed by design thinking that utilized tablets to enable pre-service teachers to create stop motion animation movies and examine pedagogical implications of creativity, divergent and convergent thinking.

Introduction

Divergent thinking is quickly becoming a buzzword in many educational contexts as we identify ways to prepare current learners for future demands. Divergent thinking refers to the propensity for the mind to generate ideas and solutions to problems outside of normally prescribed expectations (Leclerc, 2017). This thinking is sometimes labeled as "outside of the box" and is usually associated with creativity. Convergent thinking, on the other hand, requires the individual to restrict ideas to those that might be identified as most correct, or "best" for a specific problem. Exploring these connections between creativity, divergent thinking, and possible instructional uses for tablets will shed light on opportunities to improve Science, Technology, Engineering, and Math (STEM) education.

In mathematics education, divergent thinking, creativity, and play may play a key role in formation of adaptive thinking and math achievement (Wallace & Russ, 2015). Furthermore, divergent thinking is seen as a way to foster mathematical creativity (Kwon, Park, & Park, 2006) through encouragement of students to explore multiple solutions, devise new strategies, and come up with unexpected and original ideas (Guilford, 1967). Divergent thinking may also play a key role in achievement in mathematics education (Unal & Demir, 2009). STEM education may also be enhanced through the integration of arts, design, and the metacognitive skills associated with divergent thinking (Madden et al., 2013; McAuliffe, 2016). As students utilize tablets and mobile devices as portals into online and hybrid learning environments, a strong base of creativity and divergent thinking may be a key to achievement in STEM education (Greer & Mott, 2010; Staker, 2011).

In an age of ubiquitous change as a result of the Internet and other communication technologies, learner centered instruction provides opportunities to build higher order thinking, teamwork, and apprenticeship in STEM education (Bonk & Reynolds, 1997). The challenge is that as tablets and new, networked devices are placed in the hands of learners, efforts need to be made to harness the power of divergent thinking and creativity through the use of these devices (Wheeler, Waite, & Bromfield, 2002). Research suggests that the capacity for divergent thinking is operating at peak capacity during childhood (Land & Jarman, 1993; Schrag, 2016). We suggest that through the use of tablets and other devices, educators may have opportunities to develop and harness divergent thinking in learners to extend beyond childhood. Design thinking philosophies may provide opportunities to embed to iterative creative strategies used to solve complex problems in pedagogy (Mishra &

Koehler, 2006). The design thinking philosophy refers to a methodological process of using creative strategies to solve complex problems (Beckman, & Barry, 2007).

As we age toward adulthood, it is hypothesized that this propensity for divergent thinking decreases as we are indoctrinated into an educational system that values one answer or solution, and generally frown upon being wrong or failing (Boaler, 2015). This indoctrination may be due to school environments that build a reticence for students as they are scared to say or do the "wrong thing" in class (Wagner, Johnson, Fair, & Fasko, 2016). In these environments, teachers and peer groups establish social norms by keeping in-check behaviors and individuals that are incorrect or inappropriate (Moore, 2012). These systems of compliance and convergence are reinforced by grading policies that penalize students for being wrong, or failing. Non-normative behaviors are often frowned upon by the powers in charge of the group. These patterns of indoctrination may be the wrong direction to proceed in an Information and Communication Technologies (ICT) infused classroom in which students may often know more about technology use and need to serve as the leader of instruction (Levin & Wadmany, 2006). In these environs, the role of creativity, and forms of divergent thinking are often rejected in favor of playing the game and just getting through school.

As we develop pre-service teachers, it is often a challenge that students come from this system that values convergence and socializing of societal norms. In order to build these opportunities, pre-service and teacher development programs need to confront and problematize their own epistemologies about teaching, learning, and society. In this study, we believe that there is an opportunity to problematize student expectations about pedagogy through the use of tablets and the creation of stop motion movies. By working with adults who are training to work with children, perhaps we can have them examine creativity, and in turn the interaction between divergent and convergent thinking to help us think about how this impacts teaching and learning. For this purpose, we explored an instructional approach that incorporated tablets and the creation of stop motion movies to examine creativity, divergent, and convergent thinking with a population of pre-service teachers. One of the advantages of using a tablet for this work, as opposed to a mobile device or video camera is that the combination of a high quality camera and sophisticated software or applications in this form factor makes it easy for teachers and students to skillfully create work product.

This qualitative, participatory action research (Whyte, 1991; Merriam, 1998) investigated the use of an instructional model that provided minimal instruction in the use of tablets to create stop motion animation movies. Specifically, we focused on the following research question:

> What themes and patterns emerge as pre-service teachers integrate a design thinking philosophy as they explore creativity and divergent thinking through the creation of stop motion animation movies?

In this study, we utilized tablets (i.e., iPads) and a stop motion animation app to have participants create stop motion movies about the topic of “randomness.” We had participants create a movie explaining “randomness” as there have been numerous calls for making mathematics education authentic (see, for example, Turner, Gutiérrez, Simic-Muller, & Diez-Palomar, 2009). These calls in the mathematics literature seek to understand the random phenomena that are interwoven into the fabric of our physical and social worlds (Beltrami, 1999). An ability to distinguish between random and non-random phenomena, equips students with statistical tools to understand inequities in our society as well as institutionalized racism (Gutstein and Peterson, 2005). In addition, Batanero & Sanchez (2005) state that different interpretations of randomness “implicitly determine students’ behaviors and answers when confronted with chance situations or when having to put their probabilistic intuitions and knowledge in practice” (p. 20). Most of the research and instructional designs for exploring understanding of randomness involve probability experiments such as tossing a coin. Despite the importance of this topic in mathematics education, students, including pre-service teachers, hold many misconceptions about randomness including the most common one that randomness means lack of patterns (Batanero, Arteaga, Ruiz, and Roa, 2010). In this research, we invited the pre-service teachers to explore this concepts using stop-motion animation and offering no prompts on how randomness should be generated or defined.

Our investigation drew together several theoretical perspectives, including those from work on creativity in education, as well as divergent and convergent thinking. In addition to the theoretical perspectives that frame this study, several areas of previous research inspired the investigation. The instructional model was informed by tenets of design thinking, tablets and stop motion animation, as well as the use of storyboards to scaffold work process of participants.

Creativity

Creativity has been discussed in various fields such as marketing, psychology, the arts, and education. In regards to marketing, we conceptualize creativity in terms of products, creating new artifacts or ideas that are useful for a particular audience. It is understood that these "ideas must be new, unique, and relevant to the product and to the target audience in order to be useful as solutions to marketing communications problems (El-Murad & West, 2004, p. 188). In this capacity, ideas are intended to effectively appeal to various populations that are likely to purchase a product. In psychology, creativity has been identified as a construct and can be measured through various assessment instruments. These assessments can measure divergent thinking ability, in addition to an assessment of personality and attitude (Runco & Acar, 2001). In the arts, the conversation of creativity is centered around the creation of fresh works, new movements, and novel forms of art. While creativity is conceptualized differently across fields, a commonality has emerged of what creativity generally entails.

It is debated among researchers about how creativity should be observationally defined, considering the binary role creativity plays in education as both new and useful (Glăveanu, 2011). Creativity has been thought to be solely based on novel ideas. However, several researchers were unconvinced that creativity can exist without considering the usefulness of what is created (Runco & Jaeger, 2012). Csikszentmihalyi (1996, p. 314) argued that "creativity is a process that can be observed only at the intersection where individuals, domains, and fields intersect." Runco and Jaeger (2012) advocate for a paired requirement of creativity to be both original and useful. This paired requirement may also provide fertile ground for the disciplinarity and interdisciplinarity found in STEM education (Rhoten, O'Connor, & Hackett, 2009). This provides a view of creativity that must include the creation of novel artifacts or ideas as well as true utility for the creation.

As a fluid yet complex construct, creativity is considered a desirable quality in our society (Puryear, Kettler, & Rinn, 2017). Creativity has been associated with individuals gains in intelligence, emotional capacity, and academic performance (Henriksen, Mishra, & Fisser, 2016). Our society maintains a high regard for individuals with a creative yet efficient flare, or those that design inventive products that are advantageous of the profitable company or the busy family. Creativity has been historically associated with the concept of change, propelling society into new periods based on the birth of inventions or fresh ideas (Henriksen et al., 2016). Without creativity, we could hypothesize that we all would still be living in the "caveman" days with a primary focus on our existence and survival. Perhaps this evolution of creativity has contributed with technological advances in the 21st century, to transform the ways in which we think, write, communicate, and exist.

While creativity has been handled in high regards in history, it should be clear that creativity is not an "all-or-nothing" ability. Previous beliefs about creativity hypothesized that creativity was gifted only to select individuals while others were born without any creative potential (Kaufman & Beghetto, 2009). However, this theory has been challenged in a myriad of ways, evident today in our educational system as educators can observe students' potential for creativity at one level or another across various subjects (Kaufman & Beghetto, 2009).

Creativity in Education

While creativity appears to be a "staple" skill needed for students of the 21st century (e.g., advancement in technology), we have to question how creativity is being incorporated and cultivated in the educational system (Hunter-Doniger, 2016). With the push in our society to integrate technology in the classroom at volumes larger than previous decades, effects of learner creativity should be examined for any potential of change including those of positive or negative changes. Henriksen et al. (2016) connect creativity with the abundant amount of technological growth. These researchers also encourage that teaching can act as the connecting link between creativity and technology. This can be identified through the push of STEAM (Science, Technology, Engineering, Arts, and Mathematics) in education (Herro & Quigley, 2016). Originally designed as STEM, the "A" was added when educators identified a lack in creative expression from students (Herro & Quigley, 2016). The conversation of STEAM illuminates the innovation between divergent thinking and problem solving (Maguire, Kang, Hogan, & McCarthy, 2016).

For example, Kim and Park (2012) discuss how all facets of a STEAM education can be demonstrated by building a Rube Goldberg Machine, a complex contraption where different devices are linked together so that activating one of them moves the whole system. Rube Goldberg's Invention not only combines science, technology, engineering, and mathematical concepts but also requires the builder to craft the design of the machine in an imaginative way. To design the Rube Goldberg Machine, individuals build the machine from the

ground up after developing a design and determining the materials needed before construction begins (Kim & Park, 2012). The preparation aspect of the project alone promotes creativity and imagination, allowing the individual the creative freedom to draft a machine and establish their position as the designer. In the design and development, creative abilities are not limited to the initial design of the machine, the process as a whole requires creative potential. Through this example, we can see that creativity can be fostered through educational activities, particularly those encouraged in the STEAM curriculum.

Fostering Creativity in the Classroom

There is a persistent claim in the literature on creativity that suggests that there is a connection between culture, creativity, and innovation (Westwood & Low, 2003). Culture is essential to learning and in order for learning to be meaningful, the central facets of culture should be embraced (Ladson-Billings 1996). This can be accomplished through innovative and creative thought. A benefit of creativity is that it can take things out of the abstract and make it more relative to real life (Herring & Hunter-Doniger, 2018). However, according to Haught-Tromp (2017), people tend to have difficulty starting work or initiating creative thought when there is an absence of any instructions, materials, directions, or examples. A foundational understanding must be present, but engineering constraints can lead to creativity.

Research shows that constraint has two parts that include limiting one element and then the process of seeking another possible solution or something else in the problem solving behavior (Haught-Tromp & Stokes, 2017). For instance, in mathematics constraint is known as a problem space that has an initial stage (the problem), search space (exploring possibilities), and a goal state (using the most effective process to find the solution) (Newell & Simon, 1972; Haught-Tromp & Stokes, 2017). Within the search space step lies the process of substitution in which less effective strategies are replaced with more effective ones to reach the goal state. When more complex problems call for creativity, the search space is filled with multiple choices with various outcomes and organized in such a way that most effective strategies are often used first. Tablets, and more specifically the use of stop motion animation applications on these devices, allows for iteratively stopping, starting, and revising the work product while creating content. It is for these reasons we decided to use stop motion animation creation on tablets as a means to explore the intersections of creativity and divergent thinking.

Researchers in education have identified the need for creativity and opportunities for divergent thinking to be embedded within the classroom. However, we must extend this conversation beyond formal education and how students' educational experiences can shape their futures. Kim and Park (2012) identified that a "knowledge-based society should focus more on developing individuals' diversity and creative talents capable of producing unique, practical and intelligent values rather than merely growing technicians or intellectuals" (p.115). This point extends us to question what our society values in its young people. Should the focus be on the development of individuals that think in new, innovative ways or perhaps those individuals that give the correct answer without deviating from what is needed. By examining how divergent and convergent thinking are accepted in the classroom, we can better understand how students explore complex problems to find solutions to ill-formed problems now and in their futures.

Divergent and Convergent Thinking

The nuance between divergent and convergent thinking is baked into the world and the ways in which we learn. The roots of pedagogy are informed by the ways in which we generate ideas (i.e., divergent thinking) and analyze ideas (i.e., convergent thinking). Divergent thinking is the ability to generate new and creative ideas by exploring numerous possible solutions before identifying one that works (Cooperrider, 2008). Divergent thinking includes messy stages of thinking in which the learner accesses and processes the ideas and perspectives of others to gain fresh perspectives and insights from which new ideas can be generated (Beckman & Barry, 2007; Benson & Dresdow, 2014). Convergent thinking is the ability to actively solve a simple, well-defined, accurate answer to a problem (Cooperrider, 2008). Convergent thinking is focused on action and outcomes of a specific learning task while reviewing the timescale (Watson & Geest, 2005). Capacity for divergent thinking may be improved through the careful use of digital texts and tools like tablets and mobile devices to solve real world problems in STEM education (Ni, Yang, Chen, Chen, & Li, 2014).

From a multidisciplinary STEM perspective, Paletz and Schunn (2010) identify the sociocognitive framework of divergent and convergent thinking as two distinct pathways. The divergent thinking pathway values collaborative processes including social participation, information and strategy sharing as well as resolution of

task or prototype conflict (Paletz & Schunn, 2010). The convergent thinking pathway includes processes focused on sharing collaborative mental models, and just enough participation to elicit sharing of information and communication norms (Paletz & Schunn, 2010). When defining convergent thinking, Runco and Acar (2012) expand on this understanding of convergent thinking by emphasizing that this cognitive process emphasizes correct, textbook-like solutions to problems versus original responses. In education, this is sometimes viewed as the "drill and kill" approach to teaching in which students are given the correct answer without opportunity to experience the learning process. This is contrast to divergent thinking which is sometimes viewed as "the intellectual operation responsible for creativity thinking" (Karwowski, Jankowska & Szwajkowski, 2017, p. 8). In fact, the literature on creativity often uses "creativity" and "divergent thinking" interchangeably (Williams, 2004).

Design Thinking

Design thinking is an approach to learning that focuses on developing the creative confidence of students (Kröper, Fay, Lindberg, & Meinel, 2010). Design thinking can be defined as "a team-based innovation method [that] helps deal with complex design problems by sustaining in-depth learning processes on problem perception and diverse solution paths" (Kröper, Fay, Lindberg, & Meinel, 2010, p. 1). "Design thinking not only helps in the creation of new ideas and knowledge, but it also serves to foster skills in making and doing, including skills required to deal with ambiguous situations as well as those related to working with other people and emphasizing with them" (Koh, Chai, Wong, & Hong, 2015, p. 11). In this approach, teachers and students work collaboratively to engage in hands-on design challenges that focus on the development of several key characteristics that influence creative confidence (e.g., empathy, bias toward action, ideation, metacognitive awareness, and active problem solving) (Watters & Ginns, 2000; Ertmer & Ottenbreit, 2010). In this study, the tablet provided an opportunity for participants to document learning and design choices over time.

Elements of STEM education are founded on the premise that students need to be able to consider, design, and prototype solutions to complex problems (Dym, Agognino, Eris, Frey, Leifer, 2005). It is generally accepted that design thinking is a process and there are multiple prototypes of understanding about the names and definitions of these stages in the process. For the purposes of this study, we followed the design thinking process as identified by the Hasso Plattner Institute of Design at Stanford University, also known as the D-School. The D-School design thinking process involves six steps that operate recursively (Beckman, & Barry, 2007):

- **Understand:** Students understand the problem by immersing themselves in the learning process. They talk to experts and conduct their own research. The goal of this stage of the process is to develop background knowledge through these experiments. This forms a foundation for learners to engage in the process.

- **Observe:** Students become keen observers of others involved in the learning process. They pay attention to how people behave and interact in the physical spaces and places while engaging in discussions about what others are doing, ask questions and reflect on what they observe. This goal of this stage of the process is to help students develop a sense of empathy in the learning process. Empathy is a key component in the design thinking process as students seek to understand and put themselves in other people's shoes and connect with how they might be feeling about their problem, circumstance, or situation.

- **Point of View:** Students become aware of each other's needs and developing insights into the learning process. The phrase "How might we…" is often used to define and discuss point of view. This is often paired with suggestions about changes that will have an impact on the experiences of others. The goal of this stage of the process is to define a problem statement for the activity.

- **Ideate:** Students are challenged to brainstorm a myriad of ideas and suspend judgement or evaluation of these ideas. The goal of this stage of the process is to creatively consider and develop many options for completing the work. Ideation is all about creativity and fun.

- **Prototype:** Students develop sketches, models, or possible implementations to convey ideas. Students are encouraged to fail early and often as they create prototypes. The goal of this stage of the process is to quickly and roughly create implementations of ideas.

- **Test:** Students implement and solicit feedback about prototypes created in the process. Testing involves a process of experimenting to see what works and what doesn't and then iterating. The goal of this stage of the process is to test prototypes and modifying work based on feedback.

Tablets and Stop-Motion Animation

In recent years, tablets have been shown to serve as incredible teaching tools in classrooms around the world (Thomas & Brown, 2011). Research has shown the effects in varied environments from early childhood education (Beschorner & Hutchison, 2013), to elementary and secondary classrooms (Vu, McIntyre, & Cepero, 2014), and teacher education (Kivunja, 2013). Schools systems have invested significant financial resources with the hopes that technology in the hands of students will improve the achievement gap and help the United States catch up to countries in STEM education (Thomasian, 2011). Even with these advances in the use and access of tablets, questions still remain about whether technology drives pedagogy (Chuang, 2013) and what are the best pedagogical uses of these devices (Philip & Garcia, 2013; Prieto, Migueláñez, & García-Peñalvo, 2013). Too often though, tablets are used as textbooks or a way to subdue unruly students with low engaging applications (Patten, Sanchez, & Tangney, 2006). In this study, we believed that we could tap into the potential of tablets (i.e., iPads) to put the power of creativity into the hands of the preservice teachers. By allowing the them to freely explore randomness using tablets, pre-service teachers could express themselves in stop motion animation and consider the effects for their future classrooms.

Educators have utilized the use of videos in the classroom, either watching them or creating them for students to view. Vieira, Lopes, and Soares (2014) state that the use of

> "videos [in the classroom] have an advantage of, when done objectively, explaining in a few seconds something that needs several pages when written. This, together with the fact that students may see them whenever they can and play it as many times as they need it, makes them a very powerful tool for enhancing learning efficiency" (p. 750).

Educational technologies designed to assist in video production have been shown to be "an excellent model for application of both content and process-based learning, with the goal of preparing technologically literate students in the area of communication technology" (Loveland & Harrison, 2006, p. 8). In this study, we consider that while students may benefit from watching video about pedagogy or content, perhaps they can benefit more from working behind the camera and producing this content.

Stop motion is an animation technique that physically manipulates an object to make it appear to move on its own. An object is moved in small increments between individually photographed frames and when the images are stitched together in a fast sequence, the illusion of movement is created. Stop motion animation has a long history as it has been used in film to document the movement of objects as if by magic. The ubiquity of mobile devices that come with fast processors, sophisticated software, and high definition cameras makes this process easier and more portable. More specifically, the use of tablets aids in the creation of stop motion movies in the classroom. The reason tablets (i.e., iPads) make this process easier is through the use of sophisticated applications (i.e., apps) that make it easy to frame the scene for the stop motion movie. The app will then allow you take each still photo of the image and then move the subject of the movie before taking another photo. The tablet also makes the creation of a stop motion movie easier than using a cell phone. The reason for this is that the tablet is usually bigger and can be used with a tripod, or mounted to a device to hold it during filming.

Movie creation can be an effective learning tool, but for some students may provide challenges. Stop motion animation, and specifically through the use of tablets provides an opportunity to lessen the learning curve in video production. An example of this is found in the work of Kamp and Deaton (2013) as they used stop-motion animation to demonstrate cell division, specifically mitosis. These researchers stated that "by asking students to create a stop-motion animation, students must consider every minute movement and how this movement might affect the cell, the organelles, and the clarity of their projects" (p. 147). In regards to production, groups of students created storyboards showing the process of mitosis and discussing what each stage entailed. Students used an iPad to take pictures of the cell division, capturing anywhere from 200 to 400 pictures per group.

Results of the study found an overwhelming positive response from the students: students stated that they enjoyed the activity as well as gained an understanding of mitosis as a process (Kamp & Deaton, 2013).

Storyboarding and Design Thinking

Storyboards were chosen as a method for this study to encourage the students to think critically and have a visual representation of their ideas on paper in a logic sequence. In early stages of production, or problem solving, storyboards are used for visually describing the story and the script (Shin,, Kim, , & Park, 2005). Within the restrains of the stop motion the researchers wanted to provide a tool to promote divergent thinking, but allowing for pragmatic practice in depicting the notion of randomness. Storyboards allow for learner control where the learners take charge of the instructional and their learning environment (Orr, Golas, & Yao, 1994). Additionally, stop motion summary techniques like storyboarding can helpful, because of the long processing time, typically containing ten photos per second, therefore it is beneficial for the students to plan before starting the creating process (Furini, Geraci, Montangero, & Pellegrini, 2010). The design thinking model was essential to this project as it focused our work on the development and iterations of novel solutions to problems, while aligning well to the participatory action research design we utilized.

After introducing the notion of randomness, the students were asked to explain it using stop motion animation. From this point the action and development on the part of the participants was dictated by the design thinking process. The students began to brainstorm the possibilities by activating divergent thinking and creative solutions. The possibilities were numerous as the students engaged in discussions the storyboards were given as a tool to focus their thought process. Putting pen to paper assisted in making the students' ideas a reality as their sketches and prototypes began to take shape. The storyboards permitted mistakes to be made encouraging alternate solutions. Initially apprehensive about creating a stop motion video, the students approached the process with a newfound confidence after their first iteration. As they began developing content, the participants tested out how their initial ideas played out and modified these plans as they received feedback. The students continuously referred back to the storyboard as a guide navigating them throughout the entire process.

Method

This study employed a participatory action research design (Whyte, 1991; Kemmis, McTaggart, & Nixon, 2013) that examined the use of an instructional approach informed by design thinking that utilized tablets to enable pre-service teachers to create stop motion animation movies and examine pedagogical implications of creativity, divergent and convergent thinking. Participatory action research provides an orientation to inquiry that allows for planning and conducting of the research process with the individuals whose life-world and meaningful actions are under study (Reason & Bradbury, 2008). This study was conducted with the assistance of research assistants who were students in the same program as the research participants.

The study was conducted in two phases. In phase one, participants engaged in online and in-class discussions on issues around the use of technology use to engage students in a project based learning unit, during a semester long undergraduate level course. Data was collected via recordings of classroom work sessions and presentation of work products. Data was also collected from participants' online blog posts about the process as well as researcher field notes. In phase two, two class sessions were held near the end of the semester that focused on the creation of stop motion animation movies using iPad tablets. The second class session on stop motion animation was held during the next class session.

These sessions were video recorded to capture participant use of the tablets and stop motion movie apps, as well as their questions and reactions to the instructional model. More information about the instructional model is included in the next session. Data collected from phase two included video recordings of these class sessions, video recordings of the participants presenting and reflecting on their work process and product, their final movies and reflective posts, as well as researcher notes. Inferences made on the basis of each of the phase's results were analyzed to form meta-inferences at the end of the study (Tashakkori & Teddlie, 2003).

Context of the Study and Participants

The study was conducted with a convenience sample of pre-service teachers enrolled in a undergraduate level educational program at a small, public university in the southeast of the United States. The pre-service program

is an two year long program that spans four semesters of classes, each lasting 13 weeks. This study focused on the examination of creativity in order to facilitate pedagogical understandings of divergent and convergent thinking in the classroom. This class was held during the first semester in the sequence of courses in the program. This specific instance of the class was held in the spring semester of 2017.

The class was taught by the first author (O'Byrne), an assistant professor at the college. He is an assistant professor of literacy education that focuses on literacy practices of individuals in online hybrid spaces. He collaborated with the second and third authors (Radakovic and Hunter-Doniger), as well as three research assistants all from the same college. Radakovic is an assistant professor focusing on mathematics education in the context of K-12 and pre-service teacher education. Hunter-Doniger is an assistant professor of creativity and creative arts in education. The three research assistants helped with data analysis, conducting the literature review, and writing of this publication. The research assistants were invaluable members of the research process as they provided a research perspective from a lens much closer to the viewpoint of the participants in the study as informed by the participatory action research design of this study. The graduate and undergraduate researchers are in the same programs as the participants of this study. Fox is a graduate student in the Masters in Teaching in Special Education program. Kern and Parnell are undergraduate students in the Elementary Education program.

Participants.

The sample was comprised of six students enrolled in the Using Instructional Technology in Problem-Based Learning course taught by the first author. All names listed are pseudonyms. All of these students were in the first semester of a four semester teacher education program. Of the students, three were Early Childhood Education majors, two were Elementary Education majors and one was a Middle Grade Education major. Blair and Ashley, both Early Childhood majors, worked together to plan and create a single Stop Motion Animation video. Anna, an Elementary Education major, teamed up with Jessica, an Early Childhood Education major. Both Jennifer, an Elementary Education major, and Rebecca, a Middle Grades Education major, opted to work alone.

Instructional Model

As stated earlier, in this exploratory study, our goal was to test the use of tablets and stop motion animation movies with a group of pre-service educators to better understand their perceptions about creativity, divergent thinking, and pedagogy. We utilized tablets (i.e., iPads) and a stop motion animation app to have participants create stop motion movies about the topic of "randomness." The instructional model was informed by tenets of design thinking and the use of storyboards to scaffold work process of participants.

The instructional model began with some basic instruction about the use and purpose of stop motion animation and the apps that can be used on tablets to create these movies. The instruction was provided by the instructor of record for the course (O'Byrne) and focused for ten minutes on how to create these movies. The tablets were then distributed through the classroom and participants were directed to play and see what they can create. The instructor distributed various materials (e.g., blocks, art supplies, math manipulatives) that participants could use in the creation of their stop motion movies. No other directions were provided for participants as they worked on their movies. The instructor rotated through the classroom to assist with any questions that may arise during the creation of movies.

During the next class session, the class was joined by O'Byrne, Hunter-Doniger, and Radakovic. The class was reminded of the work conducted to create stop motion animation in the previous class. Researcher Radakovic then instructed the participants to create a new stop motion animation, this time about the topic of "randomness." This work product may be used in their classroom of the future. Researcher Hunter-Doniger then provided some brief instruction about the use of storyboards to plan creation of the stop motion animation. Following these brief pieces of instruction, students were allowed to work individually or in groups. They then started working on their movies while the researchers rotated through the room to provide support and ask questions about the process. Participants then presented their final product and work process at the end of the of class while researchers asked questions about the work process and product. The class session and final presentations were video recorded to aid in data collection and analysis.

Data Collection and Analysis

As indicated earlier, data were collected and analyzed over two phases. Phase one included data collection over the course of one 13-week semester in which participants were expected to regularly post reflective accounts of materials presented during the course to websites they constructed in class. These reflective discussion responses were motivated by direct instruction, multimodal content, and online/offline discussions focused on integration of technology into education and development of project based learning units. Phase two focused on the use of tablets to create stop motion animation movies and a further investigation of intersections between creativity, divergent thinking, and pedagogy. The phases were structured so as to collect specific information from participants to help answer the research question.

Analysis Techniques

Qualitative data on participants were collected and analyzed to answer the research question. Critical to the process of qualitative data analysis in participatory action research is ensuring that data collection, management, and analysis operate in concert. Therefore, consistent with qualitative research guidelines, these three processes occurred simultaneously throughout the duration of the first phase of the study (Creswell, 2007; Merriam, 2009). This process insured the recursive nature of data collection and analysis necessary in naturalistic qualitative inquiry (Patton, 2002). Data analysis was conducted by a panel that consisted of the undergraduate research assistants under the supervision of the graduate research assistant and one of the primary investigators (Radakovic). The rationale for having the undergraduates work most closely with the data was to ensure that they were seeing themes directly from the data. This is a key tenet in participatory action research as insight is provided by individuals (i.e., the research assistants who share the experiences and perspectives of the participants under study (i.e., pre-service teachers). These undergraduate researchers are in the same program of study as the participants, and as a result have a much better understanding of the implications of this work on pre-service teacher's text, talk, and interactions (Silverman, 2006).

Analyses of patterns and themes in qualitative data allowed the dynamics of change to be more evident and permitted us to better understand how pre-service teacher's comprehension and instructional use of educational technologies, creativity, and divergent thinking changed over the course of the study. Data consisted of recordings of participant work sessions and presentations of their work, as well as completed work product, and researcher field notes. Data were analyzed in a multi-step process to recognize patterns (Patton, 2002) and to develop themes (Merriam, 2002). From the initial phase of data collection and analysis, we began to identify emerging patterns that enabled us to ask additional questions to promote greater exploration. We used these patterns as a guide to pursuing subsequent data collection (Denzin & Lincoln, 2005). During each pass through the data, the data analysis group (i.e., Kern, Parnell, and Radakovic) would agree upon the themes, categories, and codes in their analysis and present this to the full research team for review in order to check this work against the research question (Maxwell, 2012).

We started our analysis with open coding of the three videos. The codes are "tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study" (Miles & Huberman, 1994, p. 56). Stephanie and Reggie started with open coding and also employed axial coding (Strauss, 1987) which is an initial stage of the analysis of the transcribed data. In this stage, they identified the themes that emerged from reading the transcripts. There are two reasons why Reggie and Stephanie, the undergraduate researchers, were involved in coding. The first one is pedagogical. We wanted to give the students a chance to learn about qualitative educational research by being immersed in it. The second reason is that the three professors were involved in the data collection and in presenting the instructional model, we wanted to satisfy the criterion of credibility and confirmability of qualitative research (Guba, 1981) by involving the individuals who did not directly participate in the data collection. In addition, open coding was done separately in order to allow for multiple ways and potentially opposing ways of interpreting data which is consistent with Guba's (1981) credibility criterion.

Findings

As stated earlier, the analysis of data was conducted in two phases. This provided the research team with two stages of themes, categories, and codes from the data with informed our research question.

Stage One Themes

After the initial coding, the data analysis group (i.e., Kern, Parnell, Radakovic) met together to identify initial themes that emerged from the first iteration of coding. This debriefing session enabled us to compare our codes and themes and also to involve the peer scrutiny of the project (Guba, 1981). In this process, the group of three researchers came up with a set of 52 open codes. These codes and the resultant themes emerged from the analysis of video recorded observations and student work in the first stage of analysis. A series of three themes was developed (Patton, 2002; Merriam, 2002) from the original set of codes:

- **Technology & storyboards:** Participants utilized the tablets and storyboards for planning in a variety of ways that impacted how they profited from the experience.
- **Instruction:** Participants responded in a variety of ways to vague and incomplete directions about the assignment that was laced with humor and encouraging remarks from the instructors.
- **Content:** Participants expressed difficulty in the prompt of randomness and many offered a simplified definition of randomness in their final work product and reflections.

The original set of 52 open codes, as well as the three identified themes from stage one were presented to the full research team for review to ensure the identified content reflected the goals of the research question. The stage one analysis, while useful, provided an opportunity for the deeper, stage two analysis of data.

Stage Two Themes

In the second stage of the analysis, the data analysis group (i.e., Kern, Parnell, and Radakovic) went back to the coding keeping in mind the themes identified in the first stage of the analysis. The purpose of the second stage was to use axial coding (Strauss, 1987) to allow us to examine the connections between the existing themes organized in the first round of coding. Recursive, analytic inductive methods (Angrosino & Mays de Perez, 2000; Bogdan & Biklen, 2003) were used to make additional passes through recordings of student observations and presentations, student work products, and researcher notes. During the second stage of analysis, several themes and their associated dimensions emerged. These patterns were further distilled as successive passes were made to refine the initial structure. The process also involved reorganizing the data and reworking groupings so that the category structures and the way themes were defined adequately represented primary trends in the data. As we analyzed the data, we kept in mind the goals of the research question. Findings provide insight into pre-service teachers' considerations of divergent thinking, the role of culture in instruction, and participants' considerations of identity in the work process and product.

Pre-service teachers collaborated on ill-formed problems to explore divergent thinking through the use of tablets.

The purpose of this study was to encourage the exploration of creativity and divergent thinking through the production of stop motion animation on tablets. Participants that were able to profit from the experience did so through collaboration with their peers, and in response to ill-formed problems provided by the instructor. As a reminder, participants were not given directions as to whether they needed to work collaboratively or individually. Participants were also given the prompt of randomness to guide their work. This prompt was selected as an exploration of math concepts, but also as a challenge for participants do to the vague nature of the prompt. As directed by the design thinking process, instruction and guiding prompts were also limited during the workshop time.

Collaboration was viewed as a vital element in the design thinking process in a number of capacities. As participants refined their ideas, they designed prototypes which were documented by many in their storyboards or in some sort of product prior to the stop motion animation. Not all participants documented their thinking and changes over time. This process of creation of the prototype was not always clearly documented in the storyboards or other documentation of student work. Part of this may be due to the role of interpersonal connection and collaboration in the work process. For example, Anna and Jessica started with multiple storyboards, but then dismissed the idea, instead of creating their own diagram. As they began the development of prototypes, when asked by an instructor whether they had "other ideas before this one?", Anna responded

"Yes! Where's the other one (other planning sheet)? We have so many sheets." It seemed their learning and work process was documented on their storyboards, but it was also relayed through verbal and nonverbal communication between participants. Their prototype followed the creation of multiple storyboards but, according to Blair and Ashley, this emerged from associating randomness with irregularity and connecting it with an exercise of creating a picture from scribble. Thus, it does not seem that the emergent product came from selecting the most suitable idea, rather it originated from other ideas developed through divergent thinking during the process.

Another factor that added to the theme of divergent thinking and the design thinking process was the presentation of ill-formed problems. Earlier we discussed the connections between creativity and divergent thinking, and the role of constraints these spaces. In this study, we provided the participants with very little instruction about stop motion animation, and the prompt of randomness was also meant to serve as a challenge, or impediment to the activity. It was hoped that participants could use strategy exchange and employ creativity and divergent thinking to accomplish their goals. As an example of this, one instructor (O'Byrne) asked Rebecca, a student working individually, "Why did we ask you to define random and randomness." Rebecca replied, "I don't.. I don't know (other students laugh) It was weird, I have no idea why you asked (students laugh louder)." O'Byrne continued his prompting, "Why would we ask for that? We could have asked for...I could have requested a video about peanut butter and jelly sandwiches. We could have asked for anything." Rebecca replied, "I don't ask for the reasoning of what you teach us (says as she smiles and laughs)." In Rebecca's final product, and the reflection that she shared, she indicated that she took it as a challenge to think through the problem. She even viewed it as more of a challenge to complete the work individually while still thinking deeply about the ill-formed problem she was presented.

Pre-service teachers utilized trust and interpersonal connections in the culture of the instructional environment to support work process and product.

In this study there were a number of variables that could impact the goals outlined in the research question. The use of tablets and stop motion animation apps presented some challenges for participants. The prompt of randomness and challenges provided by the ill-formed problem presented challenges for others. Still others were confronted by challenges with the design thinking process, or struggles with creativity or divergent thinking. Despite these potential challenges, most of the participants were able to profit from interpersonal connections, support, and trust between participants and instructors, as well as participants and themselves. Trust served as an important element in the culture of this learning environment. Trust was exhibited as interpersonal and intrapersonal verbal and nonverbal communications between all individuals in the room. Some of these communications and cues were shared between participants. In this section, we are choosing to highlight some of the discourse structures shared in discussions with participants.

The culture of trust was highlighted at the very beginning of the workshop time as instructors recognized the risk being taken in the work, while also noting the importance of this work. As he shared the prompt of randomness, Radakovic stated that he knew about how he was being "intentionally vague about the prompt," but highlighted the pedagogical importance of the assignment by asking "When you think about randomness, what do you think about, how does it connect to the curriculum?" The instructors also showed trust for the participants by allowing them to dictate the tools needed to complete this risky assignment. When a student (Blair) mentioned that she needed additional materials in order to complete her animation, the instructors were willing and eager to make these materials available even when it meant leaving the classroom to go locate said materials. Other materials were made available in the classroom but students were not forced to use any of them. Radakovic explained to the students, "I will give you some manipulatives. For example here we have, maybe you'll need it. We have dice. Maybe you're not going to need it" and continued stating, "I don't even know what you would use this for, but I have some unifix cubes for you."

The tone of the workshop was very important as instructors strived to cultivate an atmosphere of trust, and willingness to "fail fast" as they developed prototypes. As she was introducing the use of storyboards, Hunter-Doniger explained to the students, "I have plenty of these [storyboards], so don't worry if you start working and you go...aagh it's not working out" thereby reminding participants that it was okay to make mistakes or change their minds in the process. As participants asked for clarification on matters like if they were required to have a script for their project, Hunter-Doniger replied, "It's up to you how you're going to do it. This is your teaching tool." Furthermore, participants were encouraged to come up with their own ideas, as evidenced when Dr. Hunter-Doniger explained to the students, "It's up to you how you describe it." Edits and revisions during the process were valued, as long as they had necessary resources like a storyboard to use "as a worksheet that helps

you out along the way." Additionally, participants also quickly learned that they could revise their content in the process directly in the stop motion app on the tablet. In these activities, the goal of the instructors and participants was to ensure that all were fully aware that they should not worry about constraints or limitations to activating, and acting upon divergent thinking processes.

Pre-service teachers were constrained somewhat by considerations of identity and positionality as educators in their work process and product.

Participant identities as an "educator" played an important role in the study as the students in this study were given opportunity to describe "randomness" using stop motion animation. For many participants, the goal of their work product was to develop an instructional tool (or mini lesson) for teaching randomness to their students rather than to gain a deeper understanding of randomness. This resulted in a definition of randomness that did not go beyond the synonyms of irregularity, chaos, and unexpectedness. In other words, their identity as teachers was more salient than the identity as learners. This was interesting to the researchers that despite the huge amount of risk, trust, and uncertainty in the learning environment and activity, participants were more focused on their positionality in the learning process (Tisdell, 2001; Martin & Van Gunten, 2002). This means that personal epistemologies, bias, and perspectives as a pre-service teachers and future educators in a learning system shaped the work process and product.

Findings suggest that participants approached the assignment with a deep sense of their own identity as an educator and that they made design decisions based on their perceived audience. For example, when asked about her interpretation of randomness, Jennifer, who is in the elementary education program and expressed her interest in teaching the second grade, stated: "And I picked a kind of really simple definition. Because I wanted to say an unexpected event but I felt like unexpected was a bigger word than random and if this is something that I'm showing to younger kids they would understand crazy and odd." Similarly, replying to Radakovic asking if her definition of randomness was "without pattern", Ashley, an early childhood education major, replied that "yeah, I don't want to make it too difficult they can't understand."

It should be noted that in researcher notes, the instructors made attempts to not identify a particular purpose, or intended audience of this work. However, in the analysis of data, the data analysis group (i.e., Kern, Parnell, and Radakovic) identified that discussions about educator identity were salient in this phase as participants were making decisions on how their tablet constructed video would be used in their practice. In other words, they were doing some proto-lesson planning during the project. For example, while presenting their final work product, Blair and Ashley were asked about the decision to use the stop motion animation as an assessment for an elementary classroom. O'Byrne asked them: "You decided you were going to stop your stop motion movie in the middle and use it as a discussion question for students. We didn't even talk about that. We indicated that you should make a stop motion demonstration...and your group decided you wanted to make it a teaching and almost an assessment tool." Ashley responded "Okay so in terms of like early education, we're going to simplify it for our future students." She continued responding by writing on the whiteboard to explain their thinking. "We could first of all like have randomness and like spell it (continues explaining her ideas)...okay so I'll show you (starts drawing on board)." Future iterations of this study need to examine the roles of the learner and the instructor and the connections made through the use of a the tablet as a teaching tool. For example, did the participants modify their work process and product based on the positionality of the instructor and themselves? Furthermore, would this work change if the instructor was unknown to the participants, or introduced themselves as a scientist, engineer, or layperson? Would positionality of work process and product change if this were not class in an education program and instead were an elementary art lesson, or perhaps a high school biology lab?

Discussion

This exploratory study tested the development and implementation of an instructional tested the use of an instructional model that provided minimal instruction in the use of tablets to create stop motion animation movies. Results from this study provide opportunities to expand the integration of creativity and divergent thinking into teaching and learning. The study identifies potential opportunities for interdisciplinary research and education using educational technologies (e.g., tablets, hybrid spaces) while using design thinking as the common discourse. The results also suggest new opportunities for the use of tablets, and stop motion movie production to expand on the process and product of learning. We were excited for the opportunities that exist

through the use of stop motion animation as a digital text to allow educators to teach, and learners to document thinking over time.

Potential limitations of this study need to be acknowledged in any interpretation of the results. One significant limitation of the study was the convenience sample from one small higher education classroom for a short period of time. Little is known about the prior educational history, or experiences of these students before involvement in the study. We do not know about prior coursework on aspects that would relate to creativity, divergent thinking, or educational technology usage as it relates to the work conducted in this study. Finally, there is no meaningful way to account for the dispositions and pedagogical history of the three lead instructors in the study and the teaching philosophies they espouse in their classes. We had data analysis conducted by the undergraduate researchers as a way to distance the primary researchers from findings drawn from the data. Even still, there is a need to examine the epistemologies of the participants, instructors, and researchers to determine the habits, attitudes, and aptitudes they normally bring into instruction to see if this affects creativity, divergent thinking, or use of educational technologies.

Considering this is an exploratory examination of our instructional model, we engaged in discussions as a research team to help understand what happened in this study, but also consider future work. Three areas of further discussion motivated our thinking as we collected data and analyzed our findings. These three areas help us provide some context for our work, while also help identify possible next steps for research and instruction in the field.

Participants were able to successfully utilize tablets for the purposes of creating and sharing stop motion animation movies to explain conceptual information.

In this study, the researchers made attempts to challenge the thinking of pre-service educators and their use of educational technologies. Most of the participants had little to no expertise in creating videos or movies for instructional or personal use. Stop motion animation can cause challenges and by its very nature creates disruption in the content creation process. That is to say that an individual cannot just push record and capture a video. There is a certain amount of planning, revision, and iteration required in the process of creating a stop motion animation. That being said, the participants were skillful in their use of the tablet to produce this type of video content. There are many possible reasons for this aptitude in their use of tablets and video production. Most of the students were not afraid to take risks and create something that did not work the first time. Students also learned from others and shared strategies that would help them be successful in the creation of their work. Future research should identify opportunities to use tablets and the production of stop motion animation for teaching and learning.

Participants were able to self-select and collaborate, or work individually to complete the goals of the study with varying degrees of success.

In the design thinking process, instructors gave the participants latitude to decide how they would complete the work detailed in this study. Participants were given a minimal amount of direct instruction, and expected to identify the path that would help them complete the goals of this project. They could work individually, or with partners. As detailed by the design thinking process, much of the learning and prototyping in the work was to occur as participants watched and learned from each other. Because of this, some participants chose to work with people that they were friends with. Still others chose to work individually. This ultimately affected how participants profited from the experience as groups tended to have more discussion, reflection, and experimentation in the work process. Individuals were still able to complete their work, however some of the learning and creation wasn't as deep or complex as that completed by collaborating members of a group. In future iterations of this model, attention needs to be paid to how participants enter into groups for the purposes of creating the videos. This is also a concern that relates to assessment of work product as well as decisions made in visual aesthetics as it relates to video production.

Participants were able to trust instructors as they took risks in learning and employing new strategies to complete work product.

In this exploratory study, pre-service educators worked on complex assignments in a class with instructors they had previous experiences with. That is to say, that they knew the expectations and dispositions of the instructor

before, during, and after the completion of the study. Several times in the findings we shared insight into the humor used in instruction, or the role of fun or failure in pedagogy as provided by the course instructors and lead researchers. This familiarity may have played a role in the willingness for participants to engage in the work of the study, as well as take risks to complete work on ill-defined problems. Put simply, we asked participants to take their nascent understanding of tablets and stop motion animation and make a movie about "randomness." We specifically took a concept that was, by its very nature "random" and used it to challenge the epistemologies and ontologies of these budding educators. Several times in our research and analysis we wondered if our participants would have pushed back against, or laughed at other faculty members if they made these specific requests. We believe that future research needs to examine the culture of the learning environment, interactions between students and each other, and relationships between learners and instructor to fully understand how fertile the ground may be for design thinking.

Conclusion

This study explored the use of tablets and stop motion animation as a means to develop creativity, divergent thinking, and connections with pedagogy. Use of the digital devices and visual mediums has the potential to allow learners to explore and problematize their work process and product. The challenge that exists as we engage with these digital texts and tools is that the social and interpersonal acts between co-learners and instructors are still very important as we use, create, and share with these texts and tools. Perhaps with the informed use of tablets and other new technologies and texts, we can design opportunities for educators and students to imagine and develop new, original futures. Perhaps Bill Gates did not quite have it correct when he stated, "Technology is just a tool. In terms of getting the kids working together and motivating them, the teacher is the most important." We must also take into account the role of the colleague and trust involved in the learning process.

Recommendations

We believe tremendous potential exists in providing opportunities for educators and their students to use stop motion animation as a means to express information. The nature and affordances of stop motion animation create a space that fosters creativity while at the same time providing constraints in the process. It is in these intersections we believe potential exists to more effectively integrate creativity (Hunter-Doniger, 2016) and divergent thinking (Benson & Dresdow, 2014) into teaching and learning. The use of tablets in this endeavor also provides opportunities for interdisciplinary research and education using educational technologies across hybrid spaces linked by a common discourse of design thinking (Dym, Agognino, Eris, Frey, Leifer, 2005). It is the strategies involved in design thinking that allow for a focus on process and product as students work individually and collaboratively. Finally, we should also note that the classroom instructor, culture of the learning environment, learners in the environment, and relationships between all of these factors play a large role in the success of this endeavor. A culture of trust, and a focus on growth after reframing failure is necessary as learners collaborate to express themselves in these new mediums.

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References

Batanero, C., & Sanchez, E. (2005). What is the Nature of High School Students' Conceptions and Misconceptions About Probability?. In *Exploring probability in school* (pp. 241-266). Springer US.

Batanero, C., Arteaga, P., Ruiz, B., & Roa, R. (2010, July). Assessing pre-service teachers conceptions of randomness through project work. In *Proceedings of the 8th International Conference on Teaching Statistics. Lubjana: International Association for Statistical Education*.

Beckman, S. L., & Barry, M. (2007). Innovation as a learning process: Embedding design thinking. *California management review*, *50*(1), 25-56.

Beltrami, E. (1999). *What is random?: chance and order in mathematics and life*. Springer Science & Business Media.

Benson, J., & Dresdow, S. (2014). Design thinking: A fresh approach for transformative assessment practice. *Journal of Management Education*, *38*(3), 436-461.

Beschorner, B. & Hutchison, A. (2013). iPads as a literacy teaching tool in early childhood. *International Journal of Education in Mathematics, Science and Technology, 1*(1), 16-24.

Blicblau, A. S., & Steiner, J. M. (1998). Fostering creativity through engineering projects. *European Journal of Engineering Education, 23*(1), 55-65.

Boaler, J. (2015). *Mathematical mindsets: Unleashing students' potential through creative math, inspiring messages and innovative teaching*. San Francisco, CA: Jossey-Bass.

Bonk, C. J., & Reynolds, T. H. (1997). Learner-centered Web instruction for higher-order thinking, teamwork, and apprenticeship. *Web-based instruction*, *8*(11), 167-78.

Chuang, H. H. (2013). A case study of e-tutors' teaching practice: Does technology drive pedagogy?. *International Journal of Education in Mathematics, Science and Technology*, *1*(2).

Cooperrider, B. (2008). The importance of divergent thinking in engineering design. In *Proceedings of the 2008 American Society for Engineering Education Pacific Southwest Annual Conference* (pp. 27-28).

Cortese, A. D. (2003). The critical role of higher education in creating a sustainable future. *Planning for higher education*, *31*(3), 15-22.

Csikszentmihalyi, M. (1996). *Flow and the psychology of discovery and invention*. New York: Harper Collins.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of research in science teaching*, *37*(6), 582-601.

DuFour, R., & Eaker, R. (2009). *Professional Learning Communities at Work: Best Practices for Enhancing Students Achievement*. Solution Tree Press.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, *94*(1), 103-120.

El-Murad, J., & West, D. C. (2004). The definition and measurement of creativity: What do we know?. *Journal Of Advertising Research*, *44*(2), 188-201.

Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of research on Technology in Education*, *42*(3), 255-284.

Furini, M., Geraci, F., Montangero, M., & Pellegrini, M. (2010). STIMO: STIll and Moving video storyboard for the web scenario. *Multimedia Tools and Applications*, *46*(1), 47.

Glăveanu, V. P. (2011). How are we creative together? Comparing sociocognitive and sociocultural answers. *Theory & psychology*, *21*(4), 473-492.

Greer, A., & Mott, V. W. (2010). Learner-centered teaching and the use of technology. *Dynamic Advancements in Teaching and Learning Based Technologies: New Concepts: New Concepts*, 248.

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Technology Research and Development*, *29*(2), 75-91.

Guilford (1967). *The nature of human intelligence*. New York: McGraw-Hill.

Gutstein, E., & Peterson, B. (Eds.). (2005). *Rethinking mathematics: Teaching social justice by the numbers*. Rethinking Schools.

Haught-Tromp, C. (2017). The green eggs and ham hypothesis: How constraints facilitate creativity. *Psychology Of Aesthetics, Creativity, And The Arts*, *11*(1), 10-17. doi:10.1037/aca0000061

Henriksen, D., Mishra, P., & Fisser, P. (2016). Infusing Creativity and Technology in 21st Century Education: A Systemic View for Change. *Educational Technology & Society, 19* (3), 27–37.

Herring, A., & Hunter-Doniger, T. (2018). The Title I Narrative: Connecting cultural and critical awareness through the arts. *International Journal of Education Through Art.* (forthcoming).

Herro, D. & Quigley, C. (2016). Innovating with STEAM in middle school classrooms: Remixing education. *On The Horizon*, *24*(3), 190-204. doi:10.1108/OTH-03-2016-0008

Hoban, G. F. (2005). From claymation to slowmation: A teaching procedure to develop students' science understandings. *Teaching Science: The Journal Of The Australian Science Teachers Association*, *51*(2), 26-30.

Hunter-Doniger, T. (2016). Snapdragons and math. *YC: Young Children*, *71*(3), 30-35.
Kivunja, C. (2013). Embedding digital pedagogy in pre-service higher education to better prepare teachers for the digital generation. *International Journal of Higher Education*, *2*(4), 131-142.
Korthagen, F. A. (2004). In search of the essence of a good teacher: Towards a more holistic approach in teacher education. *Teaching and teacher education*, *20*(1), 77-97.
Kwon, O. N., Park, J. S., & Park, J. H. (2006). Cultivating divergent thinking in mathematics through an open-ended approach. *Asia Pacific Education Review, 7*(1), 51-61.
Ladson-Billings, G. (1994). The dreamkeepers: Successful teachers of Black children. John Wiley & Sons.
Land, G., & Jarman, B. (1993). *Breakpoint and beyond: Mastering the future--today*. HarperCollins.
Leclerc, R. (2017). Play, Think, Design: Play as a Means to Acquire and Enhance Design Thinking Skills. In *Design Education for Fostering Creativity and Innovation in China* (pp. 179-211). IGI Global.
Kamp, B. L., & Deaton, C. C. (2013). Move, stop, learn: Illustrating mitosis through stop-motion animation. *Science Activities: Classroom Projects and Curriculum Ideas*, *50*(4), 146-153.
Karwowski, M., Jankowska, D.M., & Szwajkowski, W. (2017). Creativity, imagination and early mathematics education. In Leikin, R. & Sriraman, B. (Eds.), *Creativity and Giftedness: Advances in Mathematics Education* (7-22). Switzerland: Springer International Publishing. doi:10.1007/978-3-319-38849-3_2
Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The Four C Model of Creativity. *Review of General Psychology*, *13*, 1-12.
Kemmis, S., McTaggart, R., & Nixon, R. (2013). *The action research planner: Doing critical participatory action research*. Springer Science & Business Media.
Kim, Y., & Park, N. (2012). The effect of STEAM education on elementary school student's creativity improvement. *Computer Applications For Security, Control & System Engineering*, 115-121. doi:10.1007/978-3-642-35264-5_16
Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H. Y. (2015). Design thinking and education. In *Design Thinking for Education* (pp. 1-15). Singapore: Springer.
Kröper, M., Fay, D., Lindberg, T., & Meinel, C. (2010). Interrelations between motivation, creativity and emotions in design thinking processes - An Empirical study based on regulatory focus theory. In Proceedings of the 1st International Conference on Design Creativity ICDC 2010, Kobe, Japan, November 2010.
Levin, T., & Wadmany, R. (2006). Listening to students' voices on learning with information technologies in a rich technology-based classroom. *Journal of Educational Computing Research*, *34*(3), 281-317.
Madden, M. E., Baxter, M., Beauchamp, H., Bouchard, K., Habermas, D., Huff, M., Ladd, B., Pearon, & Plague, G. (2013). Rethinking STEM education: An interdisciplinary STEAM curriculum. *Procedia Computer Science*, *20*, 541-546.
Maguire, C., Kang, E. J., Hogan, T., & McCarthy, M. J. (2016). Robots, Bookmarks, and Guitars, Oh My!. *Science and Children*, *54*(4), 70.
Martin, R. J., & Van Gunten, D. M. (2002). Reflected identities: Applying positionality and multicultural social reconstructionism in teacher education. *Journal of Teacher Education*, *53*(1), 44-54.
Maxwell, J. A. (2012). *Qualitative research design: An interactive approach* (Vol. 41). Sage publications.
McAuliffe, M. (2016). The potential benefits of divergent thinking and metacognitive skills in STEAM learning: A discussion paper. *International Journal of Innovation, Creativity and Change*, *2*(3), 71-82.
Moore, J. (2012). A challenge for social studies educators: Increasing civility in schools and society by modeling civic virtues. *The Social Studies*, *103*(4), 140-148.
Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers college record*, *108*(6), 1017.
Mishra, P., & Koehler, M. J. (2008, March). *Introducing technological pedagogical content knowledge*. Paper presented at the Annual meeting of the American Educational Research Association, New York City.
Newell, A., & Simon, H.A. (1972). *Human problem solving.* Englewood Cliffs: Prentice Hall.
Ni, M., Yang, L., Chen, J., Chen, H., & Li, X. (2014). How to improve divergent thinking capability by information technology and extenics. *Procedia Computer Science*, *31*, 158-164.
Orr, K. L., Golas, K. C., & Yao, K. (1994). Storyboard development for interactive multimedia training. *Journal of Interactive Instruction Development*, *6*(3), 18-31.
Paletz, S. B., & Schunn, C. D. (2010). A social-cognitive framework of multidisciplinary team innovation. *Topics in Cognitive Science*, *2*(1), 73-95.
Patten, B., Sánchez, I. A., & Tangney, B. (2006). Designing collaborative, constructionist and contextual applications for handheld devices. *Computers & education*, *46*(3), 294-308.
Philip, T., & Garcia, A. (2013). The importance of still teaching the iGeneration: New technologies and the centrality of pedagogy. *Harvard Educational Review*, *83*(2), 300-319.
Prieto, J. C. S., Migueláñez, S. O., & García-Peñalvo, F. J. (2013). Understanding mobile learning: devices, pedagogical implications and research lines. *Education in the Knowledge Society*, *15*(1), 20.

Puryear, J. S., Kettler, T., & Rinn, A. N. (2017). Relationships of personality to differential conceptions of creativity: a systematic review. *Psychology of Aesthetics, Creativity, and the Arts*, *11*(1), 59-68.

Reason, P. & Bradbury, H. (2008). Introduction. In Peter Reason & Hilary Bradbury (Eds.), T*he Sage handbook of action research. Participative inquiry and practice* (2nd ed., pp.1-10). London: Sage.

Rhoten, D., O'Connor, E., & Hackett, E. J. (2009). The act of collaborative creation and the art of integrative creativity: originality, disciplinarity and interdisciplinarity. *Thesis Eleven*, *96*(1), 83-108.

Robinson, K., & Aronica, L. (2015). Creative schools: The grassroots revolution that's transforming education. New York: Penguin Books.

Runco, M. A., & Jaeger, G. J. (2012). The Standard Definition of Creativity. *Creativity Research Journal*, *24*(1), 92-96. doi:10.1080/10400419.2012.650092

Schoenfeld, A. (2009). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. *Colección Digital Eudoxus*, (7).

Schrag, F. (2016). *Thinking in school and society*. Routledge.

Shin, M., Kim, B. S., & Park, J. (2005, October). AR storyboard: an augmented reality based interactive storyboard authoring tool. In *Mixed and Augmented Reality, 2005.Proceedings. Fourth IEEE and ACM International Symposium on* (pp. 198-199). IEEE.

Silverman, D. (2006). *Interpreting qualitative data: Methods for analyzing talk, text and interaction*. Sage.

Staker, H. (2011). The Rise of K-12 Blended Learning: Profiles of Emerging Models. *Innosight Institute*.

Thomas, D., & Brown, J. S. (2011). A new culture of learning. *Issue Eleven| September 2014*, *10*.

Thomasian, J. (2011). Building a Science, Technology, Engineering, and Math Education Agenda: An Update of State Actions. *NGA Center for Best Practices*.

Tisdell, E. J. (2001). The politics of positionality: Teaching for social change in higher education. *Power in practice: Adult education and the struggle for knowledge and power in society*, 145-163.

Turner, E. E., Gutiérrez, M. V., Simic-Muller, K., & Díez-Palomar, J. (2009). "Everything is math in the whole world": Integrating critical and community knowledge in authentic mathematical investigations with elementary Latina/o students. *Mathematical Thinking and Learning*, *11*(3), 136-157.

Unal, H., & Demir, İ. (2009). Divergent thinking and mathematics achievement in Turkey: Findings from the programme for international student achievement (PISA-2003). *Procedia-Social and Behavioral Sciences*, *1*(1), 1767-1770.

Vos, P. (2011). What is 'Authentic' in the Teaching and Learning of Mathematical Modelling? In G. Kaiser, W. Blum, R. Borromeo Ferri & G. Stillman (Eds.), *Trends in teaching and learning of mathematical modeling* (pp. 113-122). New York: Springer.

Vu, P., McIntyre, J., & Cepero, J. (2014). Teachers' use of the iPad in classrooms and their attitudes toward using it. *Journal of Global Literacies, Technologies, and Emerging Pedagogies*, *2*(2), 58-74.

Wagner, P. A., Johnson, D., Fair, F., & Fasko Jr, D. (2016). *Thinking Beyond the Test: Strategies for Re-Introducing Higher-Level Thinking Skills*. Rowman & Littlefield.

Wallace, C. E., & Russ, S. W. (2015). Pretend play, divergent thinking, and math achievement in girls: A longitudinal study. *Psychology of Aesthetics, Creativity, and the Arts*, *9*(3), 296.

Watson, A., & Geest, E. D. (2005). Principled teaching for deep progress: Improving mathematical learning beyond methods and materials. *Educational Studies in Mathematics*, *58*(2), 209-234.

Watters, J. J., & Ginns, I. S. (2000). Developing motivation to teach elementary science: Effect of collaborative and authentic learning practices in preservice education. *Journal of Science Teacher Education*, *11*(4), 301-321.

Westwood, R., & Low, D. R. (2003). The multicultural muse: Culture, creativity and innovation. *International Journal of Cross Cultural Management*, *3*(2), 235-259.

Wheeler, S., Waite, S. J., & Bromfield, C. (2002). Promoting creative thinking through the use of ICT. *Journal of Computer Assisted Learning*, *18*(3), 367-378.

Whyte, W. F. E. (1991). *Participatory action research*. Sage Publications, Inc.

Williams, S. D. (2004). Personality, attitude, and leader influences on divergent thinking and creativity in organizations. *European Journal Of Innovation Management*, (3), 187-204. doi:10.1108/14601060410549883.

Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: An analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of educational research*, *72*(2), 131-175.

Vieira, I., Lopes, A. P., & Soares, F. (2014). The potential benefits of using videos in higher education. In *Proceedings of EDULEARN14 Conference* (pp. 0750-0756). IATED Publications.

O'Neil, J. M., & Egan, J. (1992). Men's and women's gender role journeys: A metaphor for healing, transition, and transformation. In B. R. Wainrib (Ed.), *Gender issues across the life cycle* (pp. 107-123). New York, NY: Springer.

Plath, S. (2000). *The unabridged journals.* K. V. Kukil (Ed.). New York, NY: Anchor.

Schnase, J. L., & Cunnius, E. L. (Eds.). (1995). Proceedings from CSCL '95: *The First International Conference on Computer Support for Collaborative Learning*. Mahwah, NJ: Erlbaum.

Schultz, S. (2005, December 28). Calls made to strengthen state energy policies. *The Country Today,* pp. 1A, 2A.

Scruton, R. (1996). The eclipse of listening. *The New Criterion, 15*(30), 5-13.

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