Creative and Computational Thinking in the Context of New Literacies: Working with Teachers to Scaffold Complex Technology-Mediated Approaches to Teaching and Learning

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Abstract

For too long, creativity in schools has been almost solely associated with art, music, and writing classes. Now, creative thinking skills are increasingly emphasized across the disciplines. At the same time, technological progress has brought about calls for the integration of new literacies and computational thinking to prepare students as problem solvers and critical thinkers. However, in teaching and learning, all three perspectives most often manifest in isolation. We believe this is to the detriment of both educators and students alike.

In this paper, we develop an argument for the use of new literacies and computational thinking to promote creative thinking. First, we explore the various elements that comprise computational thinking, while demonstrating their overlap with the theoretical constructs of creative thinking. Second, we identify the design decisions that guided our plan for integrating all three perspectives in a sequence of educational technology courses designed for in-service teachers. Finally, we provide examples of the classroom activities that best facilitated creative thinking, and address how we achieved them.
Introduction

From Guilford’s 1950 address to the American Psychological Association on education and creative productiveness, to Ken Robinson’s renowned TED talks, creativity enjoys a robust history of scholarly and popular interest. A variety of insights about the creative process have emerged from psychological research (e.g., Amabile, 1996; Csikszentmihalyi, 1997; Sawyer, 2006; Sternberg, 1999). More recently, public intellectuals and otherwise inspirational materials (e.g., Gelb, 1998; Michalko, 2006; Pink, 2006) have emerged as a common point of reference on how to be creative in all aspects of modern life, from home to school to work.

At the same time, the pervasiveness of digital devices is quickly changing the K-12 landscape, where learners are moving from consumers to creators. Personal high-speed Web-enabled devices, data visualization applications, and 3D printing all promise to revolutionize the K-12 classrooms. Furthermore, social media (e.g., micro blogging sites including Twitter, Facebook) is providing avenues for discourse and interaction (e.g., Morgan, 2014). Given this explosion of technologies and the need to prepare students as innovative problem solvers (e.g., Bertram, 2014; Sheehy, 2013), this paper argues for the need to integrate creative thinking (Root-Bernstein & Root-Bernstein, 1999), new literacies (Coiro, Knobel, Lankshear, & Leu, 2008) and computational thinking (CT) (Wing, 2006; Grover & Pea, 2013; Yadav, Mayfield, Zhou, Hambrusch & Korb, 2014) in teaching and learning environments.

Unfortunately, schools largely consider these frameworks in isolation of each other. Professional development and school reform agenda all too often emphasize one perspective, which we argue is to the detriment of both educators and students alike.
Based on our experience, we have found that using new literacies and computational thinking to frame learning activities provides many foundational skills that naturally scaffold creative thinking. At the same time, both new literacies and computational thinking help to facilitate the organic and mutually beneficial relationship between creativity and modern digital technology (i.e., technology can enhance creativity, but technology can also require creativity).

Therefore, in this article we develop an argument for using new literacies and computational thinking to promote creative thinking. First, we define creativity in the context of an integrated master of arts in educational technology program. Second, we explore the various elements that comprise new literacies and computational thinking, while demonstrating their overlap with the theoretical constructs of creative thinking. And third, we identify the design decisions that guided our plan for integrating all three perspectives in a sequence of educational technology courses designed for in-service teachers. Based on these discussions, we then describe two examples of the activities that we felt best integrated creative thinking, computational thinking, and new literacies. Finally, based on these experiences, we outline recommendations for teacher education and/or teacher professional development.

What is Creativity?

For too long, creativity in schools has been almost solely associated with art, music, and writing classes. Now, creative thinking skills are increasingly emphasized across the disciplines (e.g., Hui & Lau, 2010; Craft, 2012; Lassig, 2009; Sawyer, 2011). However, in our efforts to promote both creative teaching and creative student outcomes with in-service teachers, we have found that teachers still commonly associate creativity with only artistic
and aesthetic endeavors. As such, teachers and learners who may not excel in these areas are all too quick to assert, “I’m not creative.” We propose that one way to ameliorate these misconceptions about creativity is to differentiate creativity from creative thinking. While many use the terms creativity and creative thinking interchangeably, we submit that the differentiation between creativity and creative thinking is an important one. Creativity tends to be defined in broader and somewhat imprecise ways. For instance, Sawyer (2012) provided an individualistic definition – “creativity is a new mental combination that is expressed in the world” – and a sociocultural definition – “creativity is the generation of a product that is judged to be novel and also to be appropriate, useful, or valuable by a suitably knowledgeable social group.” Where as, creative thinking, as we intend it, blurs theses rather open ended perspectives with traditional cognitive behavior, so that it might be integrated more easily in subject areas such as literacy, science, math, and social studies.

This nuanced approach is based on the framework provided by Root-Bernstein & Root-Bernstein (1999) in their book *Sparks of Genius*, and extensions of these ideas proposed by Mishra, Koehler, and Henriksen (2011). The skills that make up these frameworks include: observation, imaging, abstraction, pattern recognition, pattern formation, analogizing, body thinking, empathizing, dimensional thinking, modeling, playing, transforming, and synthesizing. Based on this work, we define creative thinking as cognitive activity comprised of various subsets of these component thinking skills that are mediated by the more aesthetic components of traditional creativity. Various combinations of these thereof facilitate creative thinking in different disciplines. For instance, Mendel modelled heredity through careful observation of patterns from a simple abstraction, the garden pea *Pisum* (Bickmore, 2010).
Unfortunately, creative thinking is too often conflated with its component skills. For instance, creative thinking is not critical thinking – but thinking critically is an important element of creative thinking; it is not just about having insights – but promoting insight is foundational to creative thinking. It is not just about seeing interconnections among disparate ideas – but seeing these relationships is a significant yet underemphasized skill, and, it is not just about divergent thinking – but the ability to repurpose ideas from their roots is indispensable. These examples showcase how creative thinking requires a multitude of thinking skills; however, by themselves alone, they do not comprise creative thinking. In this way, classroom initiatives designed to facilitate creative thinking must be clear about what exact skills they intend to impart. The thirteen thinking skills proposed by Root-Bernstein & Root-Bernstein (1999) and the seven transdisciplinary habits of mind derived from them by Mishra, Koehler, & Henriksen (2011) provide the proper frameworks from which to ensure this. These skills and mindsets include observing and imaging (or perceiving); abstracting; analogizing; recognizing and forming patterns; body thinking and empathizing (or embodied thinking); modeling; dimensional thinking; playing; transforming; and, synthesizing. Below, we outline how new literacies and computational thinking practices provide natural avenues to promote these creative thinking skills and mindsets in the classroom.

**New Literacies and Computational Thinking**

Literacies are “socially recognized ways in which people generate, communicate, and negotiate meanings, as members of discourses, through the medium of encoded texts” (Lankshear & Knobel, 2011, p. 33). They represent a social practice that is comprised of inter-related and dynamically connected symbol systems, technology (digital and not),
knowledge and skills, mutually evolving based on changing ideas about purpose, task, and context. This dynamic and mutable perspective allows “room for a degree of innovation and variation” (p. 35) within and across individual literacy practices.

Literacies generate meaning through encoded texts. These are texts that have been “frozen” or “captured” in a way that frees them from the context of production and make them “transportable” – sustaining meaning-making across distance and contexts. Kress (2003) argued this meaning making involves articulation and interpretation. Kereluik, Mishra, and Koehler (2011) extend this perspective based on Myers’ (1995) approach to literacy. That is, meaning making is not just articulation and interpretation of the texts (symbols), but also the ability to subvert these symbols so “one can control, even manipulate, how signs are used” (Myers, p. 582). The ability to subvert symbol systems is particularly relevant for teachers in a technology-mediated learning environment, given the need to repurpose tools and texts often not designed specifically for teaching and learning (Kereluik, et al., 2011). From this perspective, literacy emphasizes creative thinking from teachers. This is particularly important when considering “new” literacies given their deictic nature (Leu, et al., 2013), whereby “to be literate tomorrow will be defined by even newer technologies that have yet to appear and even newer discourses and social practices that will be created to meet future needs” (p. 1150). When new literacies are not just something that are “new today,” but “new every day of our lives,” their mastery and facilitation also requires a great deal of creative thinking.

While the notion of new literacies encapsulates the skills and strategies needed to negotiate, generate, and communicate meaning among myriad encoded digital forms of “text,” computational thinking represents a set of skills and strategies for problem solving
in data-mediated, technology-rich learning and work environments. Though there has long been interest in computer programming and the associated theories of computation (Papert, 1980), Wing (2006) is widely considered to have reignited the current interest in computational thinking for K-12 education, or “CT for all” (Grover & Pea, 2013). This movement is based on several “big ideas” about computing. First, computing is considered a creative human activity. Second, abstraction reduces information and detail in order to focus on concepts relevant to problem solving. Third, data and information facilitate the creation of knowledge. Finally, computing enables innovation in other fields. Given the role computing plays in students’ lives today, computational thinking is an important skill for the 21st century (Wing, 2006; Yadav, et. al, 2014).

Computational thinking is rooted in a computer science perspective that relates to algorithmic thinking, problem solving, and computational methods (Barr & Stephenson, 2011). CT has its root in the 1950s and 1960s when it was known as “algorithmic thinking”, which means “a mental orientation to formulating problems as conversions of some input to an output and looking for algorithms to perform the conversions” (Denning & Freeman, 2009, p. 28). CT draws on the concepts fundamental to computer science, requiring “the thought process involved in formulating problems and their solutions so that the solutions are represented in a way that can effectively carried out by information-processing agents [i.e., computers]” in a variety of disciplines (Wing, 2011, para 2). Today, computational thinking has expanded to include several key features: (1) abstraction and pattern generalizations (including modeling and simulation); (2) logically organizing and analyzing data; (3) symbol systems and representation; (4) algorithmic flow of control; (5) structured problem decomposition: (6) iterative, recursive, and parallel thinking; (7)
conditional logic; (8) efficiency and performance constraints; and, (8) systematic error detection (Barr, Harrison, & Conery, 2011; Grover & Pea, 2013). Hence, computational thinking “represents a universally applicable attitude and skill set that everyone, not just computer scientists, would be eager to learn and use (Wing, 2006, p. 33)”.

In our courses, we focus on new literacies and computational thinking under the overarching umbrella of creative learning in a number of ways. First, we consider computing to be a creative human activity that allows learners to move from being consumers of technology to becoming producers that use technology to create artifacts (Mishra & Yadav, 2013). Second, we use abstraction to allow learners to reduce information and detail in order to focus on concepts relevant to problem solving. Finally, we utilize data and information to facilitate the creation of knowledge. Our courses draw upon the substantial overlap between creative thinking, new literacies, and computational thinking to change the traditional mindset “I am not creative”. We view these three perspectives as highly interdependent, mutually beneficial, and amenable to integration for teaching and learning. Below, we describe the process of designing a learning environment and activities that begin to do this.

**Design of the Experience**

The set of courses for which we have integrated creative thinking, new literacies, and computational thinking make up the third and final year of an immersive overseas summer masters program in educational technology. Over the course of four weeks, three courses are taught simultaneously – Learning Technology by Design, Creativity in Teaching and Learning, and a Proseminar in Educational Technology - from 8:30 to 4:00 every weekday.
In planning for this experience, one of the first things we do is establish an environment that is conducive to creative thinking. This starts from the very first minute of the class, when we eschew more typical introductions, syllabus reading, etc. for an introductory creative thinking and design activity. It is based on the Stanford Virtual Crash Course in design thinking, and sets the foundation for a learning experience that is typically unlike any the students have previously encountered, and puts them in charge of learning. The task requires that students break into pairs and attempt to re-create the gift giving experience with a limited inventory of crafting supplies, iterating over the Stanford design cycle - empathize, define, ideate, prototype, test. In particular we emphasize the freedom (and expectation) of failure. Thereafter we outline the expectations of the course. These include depth over breadth in the readings; time in the evenings to relax and refresh for creative and cognitively draining days; extensive team-based activities; several “design challenges” per week; student designed and lead activities to teach and practice the key creative cognitive tools emphasized through the course; and, daily time for reflection, reading, and incubation. More detail about the design of this learning environment can be found in DeSchryver, Leahey, Koehler, and Wolf (2013).

Many of these ideas are consistent with research that explores constructing creative climates in both workspaces and classrooms. For instance, we emphasize what Amabile, Fisher and Pillemer (2014), based on their research at design firm IDEO, call a “culture of helping.” Much like the IDEO leadership, we explicitly emphasize the need and opportunity for students to help each other with problems, which tend to be complex and ill structured. At the same time, we cast our own feedback (largely formative in nature) as help in the form of suggestions rather than categorical direction. In addition, we readily encourage use
of the Web as a cognitive “helper” in all activities and discussions. IDEO notes that “status is no barrier to being asked for help,” nor is it a barrier to asking for help. As faculty, we regularly ask students for help ourselves, from technical issues to decisions about project topics and timing. This environment establishes trust and accessibility early, which Amabile, Fisher, and Pillemer found mattered more at IDEO than competence when employees sought out helpers. One of the ways we do this is to ensure there is what IDEO calls “slack” in the daily schedules. This may include significant free work time, flexible timeframes for group activities (i.e., we often extend group activities beyond the planned time in order to accommodate positive student-student interactions), and limited expectations for individual work in the evenings. These freedoms facilitate unplanned interactions among students and faculty and support the accessibility that is so important to a helping culture. The latter in particular allows for casual interactions that may lead to helping each other, but also supports the notion that creative thinking requires down time to refresh and incubate.

We also integrate several other philosophies that we think promote creative thinking in our classes that are consistent with research about workplace creativity. We ensure that students can see regular progress in what they are doing. This is consistent with Amabile and Kramer’s (2011) work that found employees “best days” as measured by overall mood, specific emotions, and motivation levels were most commonly associated with progress by the individual or related team. On these days, people were more intrinsically motivated—by interest in and enjoyment of the work itself. Both catalysts (actions that directly support work) and nourishers (shows or respect and encouragement) directly support progress. We integrate planned catalysts (e.g., the culture of help outlined
above) as a well as regular demonstrations of in-process work to the group that invariably provides constructive criticism that is heavy in nourishment from classmates. Progress includes both achieving long-term projects and major breakthroughs. However, Amabile and Kramer found that “small wins” or incremental progress can increase engagement in work and happiness during the workday.

Happiness that results from incremental progress, indeed happiness in any form, cannot be understated in a creative thinking environment. Analysis of 12,000 diary entries from employees indicated that they were far more likely to have new ideas on days they reported being happier (Amabile & Kramer, 2011). This is consistent with findings that positive affect leads to cognitive variation that leads to creativity (Clore, Schwarz, and Conway, 1994). Isen (1999) indicated this is due to three effects of positive affect: (1) more cognitive material is made available for processing; (2) this material represents a more diverse, extensive, and well-interconnected cognitive material set of ideas – a complex cognitive context; and, (3) increased cognitive flexibility which increased the probability that diverse elements among this material will be associated in new ways. As such, we promote happiness daily through activity structures that facilitate progress, but also by modeling the freedom to laugh, joke, and enjoy work and learning.

Our classroom demonstrates a variety of elements consistent with creative teaching and classrooms, too. In particular, our approach to teaching mirrors much of what Sawyer (2004) called “disciplined improvisation”. Characteristics of this approach include a somewhat unpredictable flow for the class that emerges from the actions of both teacher and students - “balancing structure and script with flexibility and improvisation” (p. 13). We regularly change the daily schedule based on how students react to the given activities.
For instance, in a recent class, a student led activity about observation and imaging led to a high level of creative energy in the class. This reflected what Sawyer termed the \textit{collaborative emergence} for teaching, an unpredictable and positive outcome determined not by one individual, but the all participants. As teachers, we knew that the planned discussion following these activities often provided a natural decrescendo when compared to the energy of the activity. On this particular day, we had a focused reading and writing time about how the Internet changes the way you think for which we wanted to corral the creative energy in the room. As such, we adapted the daily schedule to move the reading and writing right after the activity, and returned for the discussion later in the day. This is not uncommon in our classes. However, it is, as Sawyer indicated, a \textit{disciplined} improvisation in that we have clear plans and goals for each day, and adapt with those in mind.

We also emphasize the importance of taking chances and the freedom to fail in our courses. Starko (2014) noted how important it is to encourage risk taking, failure and continued efforts. Combined with a complete de-emphasis on traditional grades (all student are told on the first day of class a 4.0 is theirs to lose, and that only those that do not do the work diligently will be in danger of a lower grade), our students are free to fail in their analysis of difficult texts, in their exploration of new features within technology tools, and in their design choices. However, combined with extensive support from us, and equally accessible feedback from peers, we endeavor to promote “intelligent failure” (Sitkin, 1992). Intelligent failures (1) result from planned actions; (2) have uncertain outcomes; (3) are modest in scale; (4) are undertaken and evaluated with alacrity; and, (5) take place in are of reasonable knowledge so as to permit effective learning. In addition,
we believe that the nature of our co-faculty responsibilities in these courses also promotes a creative environment. Though research provides much to guide managers and teachers in ways to promote creativity in their employees and students, scant guidance is available about co-leading. While many co-faculty may choose to “split” their courses, we have chosen to fully embrace our positions as full time co-commitments. That is, for any given activity, project, or discussion, students have access to both of us for help, for feedback, for suggestions, and for the shows of respect and encouragement (nourishers) that are so important to motivation and affect. We also model a supportive and respectful demeanor between us. At the same time, students naturally gravitate toward one or the other of us for help in specific areas as the semester goes on and they begin to appreciate our own strengths and weaknesses.

Within this environment, we structure the course around the thirteen creative thinking skills (Root-Bernstein & Root-Bernstein, 1999) compiled into transdisciplinary creative thinking tools (Mishra, Koehler, & Henriksen, 2011). These include perceiving, patterning, abstracting, embodied thinking, modeling, deep play, and synthesizing. All work in the courses revolves around two of these during each of the first three weeks, concluded by synthesis during the final week. Then, as we fashion projects that deepen understanding of these ideas through practice and reflection, we begin to match elements from new literacies and CT in assignments. Some of this is explicit (e.g. we read about CT during week two just prior to multiple activities that scaffold CT and creative thinking). At other times, the integration is less direct, as it is when Twitter is used to facilitate engagement and deep reading of the course texts. In the latter case, it is a design decision to make the integration of new literacies transparent to reduce the meta-cognitive load of
the activities we engage in. That is, though we use it daily during the class, we do not explicitly study the implications of microblogging for educational purposes.

**Classroom Examples**

Several of the projects we include in the summer experience incorporate the elements of creative thinking, new literacies, and computational thinking. Among them is an educational cinemagraph. Based on the work of Beck & Burg (2011), our interpretation of the cinemagraph blends the technical affordances of digital still images and digital video in a product that represents a hybrid of still art and animation to evoke and reinforce big ideas in education. In these projects, short video clips are edited in ways to “freeze” much of the video, but for the essential movement toward which students intend to draw the viewer. This genre may prove to have significant educational value, providing a compromise between still images that may require too much inference on the part of the student, and video, which can lead to passive consumption. Each student creates two artifacts, both intended to: (1) have a strong, provocative idea at its core; (2) awaken feelings and imagination; (3) move the audience to a new way of seeing and re-seeing; (4) change the viewer emotionally and intellectually, both during and subsequent to viewing; and (5) highlight difference essences of the same complex educational subject matter.

This project is designed to awaken the creative thinking skills related to perceiving – observation and imaging (Root-Bernstein & Root-Bernstein, 1999). At the same time, students practice abstraction, another of the key early skills we introduce for creative thinking, but also a central concept from computational thinking (Wing, 2006). Additional computational thinking skills are practiced in this project, including parallelism, iteration, and debugging. Finally, the entire project is undertaken in the genre of digital
photography, digital video, and multi-media construction, all core new literacy skills (Walsh, 2009).

For instance, one student (Janet, a pseudonym) focused her cinemagraph project on buoyancy. She created an image of a nitrogen infused beverage with bubbles moving repeatedly in a downward motion and another image of a rowing skull frozen in time on a river, with the water moving underneath it. She detailed the intended effect and thought process for these projects in her reflective commentary:

Initially I wanted to work with the concept of density, which plays a critical role in the principles of buoyancy. I found that the design ideas I had formulated in my head were more specifically about buoyancy than density, buoyancy being a natural application of density. So the idea evolved from a general to a more specific expression of density. The idea also evolved from dealing strictly with liquids to contrasting the behavior of a gas in a liquid in one iCinemagraph with a solid in a liquid in the second, thus providing two different essences of buoyancy. We don’t intuitively consider liquid pressure in thinking about buoyancy, nor do we really consider buoyancy as it relates to gases and liquids. We expect through experience that gasses will rise, and we tend to restrict examples for buoyancy to solid objects. So, the intended experience is that viewer will be engaged by the...surprising downward motion of the gas bubbles. This downward flow of bubbles should contradict previous experiences with how gases behave in fluids. With the sculling iCinemagraph, I had initially intended for the boat to be in motion, with the water standing still, giving the impression of a very light craft hovering over the water without disturbing the surface. This is a technically challenging effect to achieve, however, I went to great lengths to capture the footage, and felt committed and determined to use these two ideas, and so therefore settled for a difference perspective in using the sculling iCinemagraph. I believe the subtle movement of the water contrasting the motionless rowing skull still gives the impression of a hovering craft. The intended correlation between the two iCinemagraphs is more to perturb understanding than to provide a harmonious assimilation of the two artifacts. The viewer should perceive the light gaseous substances sinking, and the heavier solid object floating effortlessly creating some dissonance with their previous experiences, leading to a more thoughtful consideration of the forces at work.

From this commentary, several of the key creative thinking skills listed above are
evident. First, she demonstrated imaging (Root-Bernstein & Root-Bernstein, 1999) in the design stages of the project – e.g., visualizing the boat in motion over still water. She also designed two works intended to scaffold the skill of observation – seeing and seeing again – for the audience. That is, the downward motion of the bubbles perturbing the viewer was intended to compel them to look closer at the image to clarify or further disrupt their interpretation. Finally, the project required her to practice her own ability to abstract meaning from the complex concept of buoyancy, first “seeing” the less obvious properties of buoyancy in her mind, and then emphasizing each in its own cinemagraph.

Once these essences have been isolated, the cinemagraph project requires that students determine how to created a cinemagraph that best represents them. We do this in Photoshop, in lieu of simpler cinemagraph software or apps, promoting a layer-by-layer and frame-by-frame understanding of the artifact. Using layer masks, students “reduce information and detail” (Grover & Pea, 2013, p. 39) in the images they select, at the same time using the mask refine options to “focus on concepts relevant to understanding” and solving their problem. Without knowing it, students created a variable (the part of each image that changes from frame to frame) and often integrated multiple layers of abstraction in the final image.

An important distinction between abstraction as is commonly associated with creative thinking and abstraction as is commonly associated with computational thinking emerges here. That is, creatively, an abstraction is widely considered to be the essence of an individual entity that does not generalize to other similar entities. For instance, the abstraction Picasso created in The Bull is only meaningful in that specific context. Understanding Picasso’s specific abstraction of a bull will not necessarily help viewers
understand Klee’s *Fatherhood*. Whereas abstraction for computational purposes is intended to generalize. That is, the abstraction process for an animated gif in Photoshop is similar across all platforms. Once one understands it, the process of application to other animated gifs is similar. However, in this project, the two interpretations of abstraction combine to achieve the individual student’s interpretation and require a high level of both creative *and* computational abstraction on their part.

Students also begin to appreciate the importance of parallelism in multi-media. The relationship among a group of layers, still images, and the frames in which they are all assigned is a complex process. Understanding of this concept emerges through discussion of what layers can be used for the still image sections, whether multiple images might make up the still sections, and how multiple points of motion might also be accommodated. Given that these conversations take place around the creative abstractions students have selected, the practice of parallelism in this project is indicative of how computational thinking skills and creative thinking skills often support each other, rarely manifesting in isolation of one another.

Iterative thinking is another skill that pertains to both creative and computational thinking. Resnick (2007) noted that iteration is at the heart of the creative process. It is also foundational to all computation thinking (Grover & Pea, 2013). The cinemagraph project emphasizes both, in different aspects. The process of designing follows the path of “constantly critiquing, adjusting, modifying, and revising” (p. 5) that Resnick encouraged. As noted above, Janet followed this process individually with her interpretation of the sculling image. In addition, as faculty we provided formative feedback several times during project development, leading to further modification and refinement to the technical and
aesthetic decisions for this project. Computationally, iteration is inherent to a successful cinemagraph, given that it is a constant loop of individual digital still images. Students must learn how to sequence, time, and alter these images in a way that results in the desired experience. For instance, in several cases, continuous forward iteration of the images did not achieve the desired smoothness of presentation, so students and faculty together designed a process by which the still images were reversed, replayed, and then iterated to achieve the desired effect. In doing so, a concerted process of debugging was critical to finding the best solution. At the same time, this “programming” and “reprogramming” of the frames was in the context of aesthetic creativity (i.e., the computational thinking in this case directly supported the goal of making the experience of the cinemagraph visually pleasing).

From a literacy perspective, the cinemagraph project meets many of the characteristics of a “new” literacy as outlined above. It is a new “medium through which meanings are generated, communicated, exchanged, and negotiated,” and “allows for a degree of innovation and variation.” While many students of our students have experienced animated GIFS previously, approaching the project from a more artistic perspective as that emphasized by Beck & Burg (2011) provided a new genre from which to apply the technology. At the same time, repurposing the cinemagraph for educational purposes reflected the sort of subversion of symbol systems that is consistent with literacy, and new literacies in particular.

**Example 2: Infographic Project**

While we agree with Root-Bernstein and Root-Bernstein (1999) that recognizing patterns is an important thinking tool that enhances creative thinking, we also agree that
the use of computing enables people to create digitally and translate intentions to digital artifacts (College Board, 2012) by enhancing traditional forms of human expression and experience. Mishra and Yadav (2013) argued that creativity is not determined either by only the individual or the technology, but rather through a “partnership” between the two. We supported this perspective using two examples that showcase how technology can enhance human creativity by automating problem solving process.

Within this context of creativity and computational thinking, we utilized an infographic project to emphasize pattern recognition and allow teachers to process data to gain insight and find pattern patterns. The Root-Bernstein’s argued that recognizing and forming patterns are important tools for creative thinking and imagination especially since humans are inclined to use these tools. Furthermore, this project focused on one of the big ideas of computational thinking: Data and information facilitate the creation of knowledge (College Board, 2012). Specifically, we wanted to highlight two computational thinking constructs: (1) logically organizing and analyzing data; (2) symbol systems and representation. We wanted the teachers to be able to recognize patterns that allowed them to make sense of the information and what they should “look for among the clutter of detail” (Root-Bernstein & Root-Bernstein, 1999, p. 89).

The process of creating infographics was not only about patterns, it also included visualizing how to represent the information by using technology tools that enhanced students’ use of problem solving skills. Instead of using commonly available tools (info.gram, visual.ly, etc…) that allow teachers to easily create infographics, we made a decision to use Adobe Illustrator. We believed that using Illustrator as a tool to form patterns would help students combine and juxtapose multiple structural elements in a way
that yielded an infographic that was different than the individual parts (Root-Bernstein & Root-Bernstein, 1999). The different layers students utilized to lay out various elements in Illustrator also served as a good metaphor for layers of knowledge/information that teachers needed to juxtapose different pieces of information within the infographic.
This project was designed to allow students to recognize and form patterns as well as abstract the complex information to showcase the underlying simplicity (Root-Bernstein & Root-Bernstein, 1999). The students’ infographic mainly fell under three main types: statistical-based, timeline-based, and process-based infographic. Statistical-based infographic included graphs, charts, and figures that represented complex information and were designed to convey that information quickly. For example, one student (Robert, all students names are pseudonyms), who taught history at the high school level developed an infographic to showcase a data driven cultural, social, and economical relationship between United State of America and China. This infographic included several layers of information that compared the USA and China on a number of factors, including population, unemployment, renewable energy, and military assets. Finally, Robert demonstrated how, in spite of their differences, the economies of both countries are intricately tied through trade. Another student (Olivia) utilized timeline in her infographic to help her students’ understanding of time. Specifically, she created a circular timeline (See Figure 1) within her infographic to depict the scaling of time from 1300s to 2000s showcasing major events that happened across the centuries.
Finally, Asha utilized a process layer within her infographic to showcase how parents could utilize the reading approach to engage their children in literacy practices. These examples clearly demonstrate that the infographic project allowed students to use multiple creative thinking tools from pattern recognition and formation to dimensional thinking skills of scaling while also using their imaging skills on how to visualize data. In summary, this project allowed students to recognize and form patterns across apparent randomness of the information/data available, fostering creative thinking as they did so.

**Recommendations for Teacher Education or Professional Development**

This article outlines how we have integrated both computational thinking and new literacy skills in our courses in efforts to increase creative thinking among practicing teachers. This sets the stage for them to begin doing the same with their own students. Here, we provide the primary recommendations we share with these teachers as they return to their own schools and begin exploring how this might be done. These ideas, and those discussed above, provide a framework for working with pre-service and in-service teachers, either in teacher education courses or professional development setting.

First, we encourage them to consider differentiating creativity from creative thinking. As noted above, we think this helps chart a path for teachers and students alike who do not consider themselves creative in the traditional sense (e.g., aesthetically or musically) to begin to envision themselves as creative thinkers. This is not to say that a line should be drawn between creativity and creative thinking. As reinforced by Root-Bernstein and Root-Bernstein (1999) practicing creative activities such as those in visual and performing arts provides an excellent foundation for creative thinking across the core
subject areas. At the same time, the creative thinking in these subject areas should be practiced as “in-disciplinary” (Mishra, Henriksen & The Deep Play Research Group, 2012) creative thinking that happens in a discipline or context while also cutting across disciplinary limits.

Second, we encourage teachers to establish a healthy balance of “effortless” and “design dependent” technology tools. We believe that choosing Photoshop and Illustrator in lieu of effortless apps that could produce instant cinemagraphs and infographs facilitated computational thinking with our students. Similar choices apply in K-12 classrooms. Some of these occur within individual programs. For instance, iMovie supports both limited editing for “trailer” projects (templated movies) while full movie projects allow students to start from scratch and make more design decisions. At the same time, we understand that time constraints sometimes necessitate less focus on underlying technical elements and use of one-click options. In these cases, use of effortless solutions should be paired with brief discussions of their constraints, both in terms of technical ability and knowledge representation. That is, infographs made from effortless solutions may not be as capable of demonstration complex and sophisticated layers and relationships of data as those constructed in illustrator.

Third, given the complexities of creative thinking, especially when paired with computational thinking and new literacies, we encourage regular and integrated time for reflection. All of our larger projects require a “commentary” version of the artifact where students use screen recording software to discuss the design process and decisions. These include specific scaffolding of the reflection to ensure that students reflection on specific thinking skills. We also specifically emphasize the importance of considering “audience” in
these reflections. Given that we endeavor to provide projects that will have real world application, considering audience during the process through empathy and feedback helps to establish the social context often associated with creative thinking (e.g., Csikszentmihalyi, 1997). To ensure this is a meaningful activity, we also provide students time during the project, often during class, to take notes about their creative and technical insights. We also encourage them to write about how they feel - whether frustrated, excited, or cognitively spent. In this reflective process, students can begin to understand their own patterns and creative thinking flow.

Fourth, in order to promote creative teaching across grades and subject areas, we agree with Root-Bernstein and Root-Bernstein’s (1999) assertion that there is a need for a common language within schools. As such, we encourage teachers to team up with colleagues so they can identify the words and phrases they would like to use to describe and evaluate creative and computational thinking and skills. These should be developmentally and contextually adapted. For instance, algorithmic thinking is not appropriate for early elementary environments, but using recipes to solve problems may be. This is important both to establish the scope and sequence of creative thinking that is targeted, but also helps students begin to appreciate these thinking skills as applicable across subject areas and not isolated to one or two.

Finally, teachers who endeavor to promote and support creative thinking in their students should consider the importance of living more creatively and practicing creative thinking themselves. Csikszentmihalyi (1997) provided an excellent primer for those interested in enhancing their personal creativity that we use in our courses. Among others, he suggested that we trying to be surprised by something every day, trying to surprise
someone else every day, setting specific goals for each day, explicitly shaping schedule and space, and always aiming for complexity are simple ways that anyone can begin to live more creatively on a daily basis. There are many other popular books available to explore similar ideas, including *Zig Zag: The Surprising Path to Greater Creativity* (Sawyer, 2013), one of few to explicitly base their recommendations on creativity research. Establishing a minimal foundation of creative living is vital for teachers who want to facilitate creative thinking in their classrooms. Together with various components of computational thinking and in the context of new literacies, these teachers can begin to educate the next generation of students prepared for the complex and interconnected world that awaits them.

**Recommendations for Future Research**

In this paper, we have outlined the interplay of new literacies and computational thinking and how together they may undergird learning experiences in which teachers also engage in creative thinking. Our embedded creative thinking approach provides an abundance of potential research opportunities. For example, future research could examine how teachers can support the development of creative thinking among elementary students. Specifically, researchers have argued that this begins with imagination during early years (Torrance, 1962); hence, it would be worthwhile to explore how young children's imagination plays a role in the development of creative thinking, particularly in technology-mediated environments. Prior research on teacher perceptions of creativity suggested that teachers believe that providing challenging activities and freedom in the classroom promotes student creativity (de Souza Fleith, 2000). Based on our experiences, it may be useful to further examine the impact of an interconnected technology-mediated approach to creative thinking on teachers’ perceptions of how they might foster their own
students’ creative thinking. There is also limited research on the development of computational thinking among students. Future research should address how children’s computational thinking concepts and practices (such as, iteration, debugging, abstraction, and parallelism) develop across the grade levels in the context of creative thinking. Brennan and Resnick (2012) provide a framework of assessing computational concepts and practices within the context of using Scratch programming environment, itself predisposed to supporting creative thinking in a variety of subject areas. In summary, we believe that this is an important area of research that could guide educational policy in the United State of America for teachers to incorporate activities that cultivate creative thinking among students.
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