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From STEM to STEAM: the Neuroscience Behind the Movement Towards Arts Integration in K-12 Curricula

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From STEM to STEAM:
The Neuroscience Behind the Movement Towards Arts Integration in K-12 Curricula

by

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Abstract

As a result of disparities in the educational system, numerous scholars and educators across disciplines currently support the STEAM (*Science, Technology, Engineering, Art, and Mathematics*) movement for arts integration. An educational approach to learning focusing on guiding student inquiry, dialogue, and critical thinking through interdisciplinary instruction, STEAM values proficiency, knowledge, and understanding. Despite extant literature urging for this integration, the trend has yet to significantly influence federal or state standards for K-12 education in the United States. This paper provides a brief and focused review of key theories and research from the fields of cognitive psychology and neuroscience outlining the benefits of arts integrative curricula in the classroom. Cognitive psychologists have found that the arts improve participant retention and recall through semantic elaboration, generation of information, enactment, oral production, effort after meaning, emotional arousal, and pictorial representation. Additionally, creativity is considered a higher-order cognitive skill and EEG results show novel brain patterns associated with creative thinking. Furthermore, cognitive neuroscientists have found that long-term artistic training can augment these patterns as well as lead to greater plasticity and neurogenesis in associated brain regions. Research suggests that artistic training increases retention and recall, generates new patterns of thinking, induces plasticity, and results in strengthened higher-order cognitive functions related to creativity. These benefits of arts integration, particularly as approached in the STEAM movement, are what develops students into adaptive experts that have the skills to then contribute to innovation in a variety of disciplines.

Keywords: STEAM, Arts Integration, Retention, HOCs, Plasticity

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I. Introduction

Within the last decade, *Science, Technology, Engineering, and Mathematics* (STEM) focused curricula have been pushed forward as the innovative frontier of education. In the United States, science is a widely credited source of both innovative discovery and major economic development (DeHaan, 2009). In 2005, prominent American business organizations came together to express concern of the United States ability to maintain its scientific and technological edge in the modern world. Together forming the Tapping America's Potential (TAP) coalition, this group of corporate leaders claimed that in order "to maintain our country's competitiveness in the twenty-first century, we must cultivate the skilled scientists and engineers needed to create tomorrow's innovations." (www.tap2015.org/about/TAP_report2.pdf). Likewise, in 2007 a panel of scientists, engineers, educators, and policymakers convened by the National Research Council (NRC) reported that the progress of the nation "is derived in large part from the productivity of well-trained people and the steady stream of scientific and technical innovations they produce" (NRC, 2007). The attitudes of the TAP coalition and NRC were major advocates for science and technology and supported the push towards STEM curricula in the United States. Yet with an aggrandized focus on STEM curriculum in schools over the past few decades, de-prioritization and budget cuts are slowly chipping away at arts education, leaving an imbalanced system of education. As a result of the disparities within the system, scholars and educators from multiple disciplines are currently arguing for a departure from this imbalanced educational system in favor of a holistic and heuristic integration of the arts back into the sciences, a movement popularly coined STEAM (*Science, Technology, Engineering, Art, and Mathematics*). STEAM is an educational approach to learning that focuses on guiding student inquiry, dialogue, and critical

thinking through interdisciplinary instruction that values both the proficiency of knowledge and understanding. Distinguishing between knowing and understanding content, the later involves the contextualization of deeper knowledge or knowing, requiring both learned skills and competency. Active participation is considered key for the assimilation, accommodation, and contextualization of learned information (Boy, 2013). The artistic activities not only naturally encourage, but require active engagement, creative problem solving, and creative thinking and thus present a potential avenue for greater student participation and learning in the classroom.

In addition to the importance of active participation in education, interdisciplinary education is crucial for development and innovative posterity in the United States. Boy (2013) posits that “interconnectivity, communication and interaction are major attributes of our evolving society” and as such, systems need to be investigated as complex wholes requiring a cross-disciplinary approach. As a consequence of this societal evolution, Boy states that “schools cannot continue to only teach isolated disciplines based on simple reductionism...STEM should also be integrated together with the Arts to promote creativity together with rationalization, and move (back) to STEAM”. This concept shift emphasizes the possibility of longer-term socio-technical futures instead of short-term financial predictions that currently lead to uncontrolled economies.

Furthermore, a group of interdisciplinary faculty members from The State University of New York at Potsdam presented a model for the education of interdisciplinary scientists and urged that the integration of the Arts back into STEM subject matter will encourage innovations in modern science and technology that are necessary to address the complex and intersectional problems facing human society today (Madden et al., 2013). Similar support for a STEAM educational approach has come from the fields of engineering and technology (Conner et al., 2015),

computer science (Park & Lee, 2014), medicine (Howell, et al., 2013; Pellico et al., 2009; Stuckey & Nobel, 2010), arts and science education (Acosta, A., 2015; Copley, 2001; Laursen et al., 2007), and many others (Hardiman et al., Harksen et al., 2014; 2012; Madden et al., 2013; Mishook and Mindy, 2006; Mote et al., 2014; Oner et al., 2016; Thurley, 2016; Radziwill et al., 2015).

In a report on the results of a small, preliminary classroom-based experiment that tested effects of arts integration on long-term retention of content, Hardiman et al. (2014) found that there were no differences between the common core classroom and the arts-integrative (AI) condition in initial learning, but significantly better retention of content in the AI condition. This experiment was based on research in cognitive neuroscience demonstrating that consolidation of long-term memory storage occurs through rehearsal of information (Kandel, 2006; Hardiman, 2003, 2010). Thus, Hardiman et al. (2014) posited and found that arts-integrative instruction improves retention by rehearsing content using various visual and performing arts activities, which may also have the benefit of enhancing student engagement (Mohr et al. 1998; Smithrim & Upi-tis, 2005). Hardiman et al. (2014) is a crucial study because it demonstrates the need to use research from cognitive and developmental neuroscience to inform educational policy and practice.

What is arts integration?

What exactly are Boy and Hardiman referring to when they talk about arts integrative curricula?

Are these models consistent in their approach and intent across multiple intellectual domains?

Simply put, no. In fact, these inconsistencies are one factor inhibiting a more widespread acceptance of arts integration. Even with the push for “arts integration” in schools, it remains a highly contested and convoluted term as arts educators have yet to agree on what integration would look

like, or even whether it is a goal of arts education specifically. As a convoluted concept, there are many meanings associated with arts integration. One is a community focused use of project-based learning to address community issues (Wolk 1994); another is the transfer of knowledge across artistic and non-artistic disciplines (Darby & Catterall 1994; Fiske 1999; Hamblen 1993); and another is simply the use of arts to enhance the study of academic disciplines (Catterall and Waldorf 1999; Fiske 1999).

There are multiple other definitions that further confuse the term, however, with regard to the STEAM movement there is one main approach. Efland (2002) argued for arts integration instead of a purely discipline-based art education, stating “the purpose of art education is not to induct individuals into the world of the professional art community. Rather its purpose is to enable individuals to find meaning in the world of art for life in the everyday world” (77). This view highlights the value of art learning as part of a comprehensive education in the liberal arts, while Davis (1999) put forward a similar concept of arts integration “arguing that in education there is currently a rigid disciplinarily that does not reflect the ill-structured problems of the workplace, and that integration is crucial in multidisciplinary fields such as design or engineering” (DeHaan, 2009). Thus expanding arts integration to the STEM fields, the current STEAM movement integrates both concepts to have the arts exist side-by-side with other academic disciplines in order to foster interdisciplinary and innovative thinking in students, preparing them for life beyond school.

However, some arts educators are wary of any movement integrating the arts into the non-arts subjects. Over the past twenty years, the arts education community has feared that the rise of the accountability movement and attendant testing will pressure schools into diverting

time and resources towards only tested areas of the curriculum, such as reading and math (Eisner 2000) and more recently, public concern that the arts are being undermined has risen. These fears are not unfounded as the current political administration has already proposed budget cuts for crucial organizations such as the National Endowment of the Arts (NEA).

The precarious position of arts education in schools and the fear that this integration will dangerously diffuse arts into the curriculum spurs wariness as many believe it will diminish the importance and unique approach of the arts (DeHaan, 2009). In 1992, The National Art Education Association (NAEA), the leading national advocate for arts education endorsed this aversion to arts integration, advocating for the integrity of the arts (NAEA, 1992). Although the NAEA attitude positively shifted in favor of the STEAM movement, this remains a concern as there is a substantial emphasis placed on subjects that can be assessed in standardized tests such as mathematics and English (Rossier et al., 2013). One large-scale study of arts education in the United States, Stake, Bresler, and Mabry (1992), found that schools advocating for arts integration typically used arts as “topical enhancements” and “motivators for learning basic skills objectives”. For example, singing the names of the U. S. presidents, designing murals depicting historical events, or acting out the biological processes of photosynthesis are effective artistic activity that some educators utilize to teach content. Stake, Bresler, and Mabry thus concluded that this form of integration was “of little value in learning authentic arts goals” and other large-scale studies of schools promoting arts integration came to similar conclusions (DeHaan, 2009). This sort of approach diminishes the integrity of the arts, transforming them into a simple tool to learn what are societally considered more important subjects. Therefore, when considering a transition from STEM to STEAM it is a crucial to ensure the arts do not simply become a tool to aid to other

disciplines, but are given equal attention and recognition for their importance in developing socially conscious, innovative, and transdisciplinary students.

A STEAM focus in K-12 curriculum.

Attention given to the STEAM movement is not limited to primary education, in fact, extensive literature from academia outlining models for arts integration at the university and graduate levels exist as well as numerous reviews on projects integrating engineering, biology, and mathematics college courses with art courses (Acosta, 2015; Connor, Karmokar, & Whittington, 2015; Pellico, Friedlaender, & Fennie, 2009; Thurley, 2016). Although recognized as beneficial in higher education, implementing a STEAM-focused curriculum as early as kindergarten and maintaining it throughout a student's journey through primary education would be more beneficial. "Education is one of the most important experiences in a child's life, and learning is often emphasized as the primary means by which one is able to excel or achieve success...art and thought are inter-connected, and consequently art may be a critical component of education" states Rossier et al. (2013). Emphasizing the importance of arts education for children, Rossier cites studies which found that the longer children were involved in visual art, the more complex their artwork became (Hanline & Milton, 2007) and another suggesting this "greater complexity of artwork reflects greater complexity of the underlying thought processes"(Cherney et al., 2006). Evidence supports that art programs facilitate the acquisition of critical thinking skills that are naturally shared across disciplines such as observation, envisioning, reflection, expression, and exploration (Young, 2005; Winner, 2007). Incorporating arts in early education is likely to have the most benefit for students as it is the period of greatest brain development and knowledge acquisition (Laursen, Liston, Thiry, & Graf, 2007). Adopting a STEAM program in child-

hood and continuing it over a prolonged period would have the greatest impact on developing students' intelligence and imagination.

Why has arts integration not become more widespread?

Despite extant literature urging for this integration, particularly during the early years of a child's education, the trend has yet to significantly influence federal standards for K-12 education in the United States (Boy, 2013; Conner et al., 2015; Hardiman et al., 2012; Madden et al., 2013; Mishook and Mindy, 2006; Mote et al., 2014; Park and Ko, 2012; Thurley, 2016; Radziwill et al., 2015). This unfortunate fact is partially due to the ambiguity and conflict surrounding the definition of arts integration and a lack of data on the efficacy of arts integration in the classroom. Additionally, despite public support, the arts are not often prioritized, causing them to be the first areas to receive budget cuts (Deforge, 2009). Perhaps this is the result of policies such as the "No Child Left Behind" law, which requires students to participate in the arts yet has no standardized exams for art education like those required for the maths and sciences. Despite the arts being publicly valued, this consequence suggests that art education is not emphasized in practice as having tangible or testable educational outcomes (Rossier et al., 2013). Encouraging federal and state policymakers to begin the arduous task of remaking a broken education system will require a solid foundation of scientific evidence as well as data collected from classroom assessment. Additionally, data from studies with a theoretical foundation in cognitive neuroscience and psychology are essential to supporting a fundamental shift in K-12 educational policies in the United States.

However, despite a paucity of necessary classroom assessment—like the valuable data collected in Hardiman et al. (2014)—researchers in the fields of cognitive neuroscience and psy-

chology have provided new understanding of human cognition, much of which supports integrative education. Approaching the discussion through this lens, Rinne, Gregory, Yarmolinskaya, and Hardiman (2011) argue that arts integration engages learners in thinking about information in new ways that improve retention. Improved retention through arts is also supported by the cognitive psychology of semantic elaboration, generation of information from a cue, enactment, oral production, “effort after meaning,” emotional arousal, and pictorial representation (Rinne et al., 2011) as well as the cognitive neuroscience of novel brain patterns and plasticity associated with the acquisition of higher-order cognitive skills.

II. Retention and Recall

Long-term memory storage is the fundamental process involved in what is typically considered successful mastery of content (Hardiman et al., 2012); repeated exposure to information is crucial to this process as it gives rise to the activation of memory-related genes (Dash et al., 1990; Bartsch et al., 1998). Activation of these genes, and thus the ability to consolidate memories in long-term storage, is related to both environmental and social contingencies (Kandel & Mack, 2003). Research has also shown that the persistence of long-term memory relies on the generation of new synaptic connections resulting from the activation of genes through learning (Bailey & Chen, 1983; Kandel, 2001). Based on the evidence that environmental contingencies (Bartsch et al., 1998, Kandel & Mack, 2003) along with repeated exposure (Kandel, 2006) are crucial to long-term storage, Hardiman et al. (2014), as aforementioned, developed a study based in cognitive research in order to establish the link between an arts integrative curriculum and improved retention of content. Results from posttests demonstrated that, although students learned

roughly the same volume of science content regardless of instruction method, students taught through the art integrative curriculum retained content significantly better than those taught using common core curriculum (Hardiman et al., 2014). This study provided evidence for the proposition that utilizing artistic activities as a facilitation for the acquisition of other content is a particularly effective means of enhancing retention because it leverages a number of factors whose positive influence on long-term memory have been established by cognitive psychologists. More specifically, Rinne et al. (2011) considered eight main effects influencing long-term memory consolidation and recall: (a) rehearsal, (b) elaboration, (c) generation arousal (d) enactment (e) oral production, (f) effort after meaning, (g) emotional arousal, and (h) pictorial representation. Here, these eight factors are summarized and their connection to artistic techniques explored.

Rehearsal.

Rehearsal of content is perhaps the most intuitive factor influencing the formation of long-term memory. We all likely remember the mundane repetition of flipping through vocabulary note cards before a test, regardless of subject matter. The theory behind the practice began with early work in cognitive psychology showing that spaced rehearsals of verbal information can improve recall. However, later research by Craik and Watkins in 1973 demonstrated that the effectiveness of rehearsal was not simply derived from the number of rehearsal periods, but rather, effective rehearsal required elaboration. Elaboration involves the convergence of pieces of information either to one another, to available information, or to pre-existing knowledge throughout the rehearsal process. In studies where “elaborative” rehearsal was dissociated from “maintenance” rehearsal, only the establishment of a more elaborate memory trace improved long-term retention (Rinne et al., 2011). Recently, nonverbal forms of rehearsal were also found

to improve recall for visual stimuli such as abstract symbols (Hourihan, Ozubko, & MacLeod, 2009), suggesting a more intuitive link to utilizing artistic techniques to improve retention. In the realm of cognitive neuroscience, research confirms the impact of elaborative rehearsal on long-term memory by identifying neural markers specific to rehearsal that would predict later recall of information (Davachi, Maril, & Wagner, 2001). Artistic activities provide an enjoyable and motivating form of naturally spaced and elaborative rehearsal. Take for instance a project requiring students to develop a song or jingle describing the biochemical process of respiration. Not only does the rhythm lend to greater recall due to increased attention, the process of developing a catchy tune is an elaborative process and once created, a song is easily rehearsed leading to greater recall.

Elaboration.

As discussed previously, elaborative rehearsal creates a more intricate memory trace, improving long-term retention. In addition, *semantic elaboration*, or elaboration that adds specific meaning, improves retention of information. “Depth of processing,” a common concept in cognitive psychology that essentially demonstrates increases in the quantity and quality of semantic elaborations, has been proved to increase retention of information (Rinne et al., 2001). For example, prompting participants to draw involved inferences while reading stories leads to faster response latencies for correct answers—retention is particularly strengthened when individuals elaborate on information by relating it to themselves. Various artistic activities naturally utilize semantic elaboration. For example, creative writing, poetry, and comics are art forms that frequently use metaphor and symbolism to connect and elucidate upon information. Thus, artistic activities are likely to improve both retention and recall of material since the process of creating

is based on a specific context and thus naturally establishes a more intricate memory trace (Rinne et al., 2011).

Generation.

The *generation effect*—where generating information as a cued response increases retention more than reading that same information—has a well-known influence on memory and was most famously demonstrated by Slamecka and Graf in 1978. In their experiment, participants either generated words in response to stimuli or read words. Results showed that generated words were more promptly recalled than read words. Multiple explanations for the impact of generation on memory have been explored including a relationship to depth of processing and cognitive effort. However, McDaniel and Bugg (2008) more recently argued that generated information is more “unusual,” or is less common, than read information and it is this atypical aspect of generation that increases processing and long-term retention. Generating information utilizes past learned memory to create new meaning. Art involves a similar process referred to as the *Beholder’s Share*. A theory developed by psychoanalysts Ernst Kris and Ernst Gombrich in response to abstract art, *beholder’s share* posits that viewers respond to ambiguity in art in concordance with their personal experience and conflict, thus generating novel meaning and recapitulating the creative process experienced by the original artist. The *inverse optics problem*, the ambiguity between mapping sources of retinal stimulation and the retinal images produced, or the translation of three-dimensional objects to two-dimensions and back again, and the biology of the human visual pathway supports this theory of a viewer’s personal interpretation and involvement (Kandel, 2016). Thus, the critical analysis of art, and especially abstraction in art, re-

sults in interpretation and generation of meaning that would likely imbue students with greater memory of congruent content.

Enactment.

The *enactment effect* refers to the discovery that recall is greatly improved by physically acting out material instead of simply reading or hearing the same information. Originally, this effect was attributed to a convergence of motor and verbal encoding that occurred during enactment and improved recall (Mohr, Engelkamp, and Zimmer, 1989). However, McDaniel and Bugg (2008) suggest that the benefits of enactment are not based on retrieval of motoric memories, but that, similar to generation, enactment relies on the novelty it engenders and the subsequent increase in processing. This viewpoint is supported by evidence showing that additional processing essentially identical to that which occurs during “conceptual” encoding, but not motor encoding, occurs during enactment. However, despite some variation in theories describing the processing pathway of enactment, it remains a positive factor influencing long-term memory storage (Rinne et al., 2011). Enactment is a useful strategy readily encouraged through the performing arts, such as theater or interpretive dance, as are rehearsal, semantic elaboration, and generation. For instance, Rinne et al. (2011) references a meta-analysis of studies conducted by Podlozny (2000) that analyzes the use of drama in the classroom, noting that one of the greatest benefits for students was the ability to recall stories. Utilizing performance art techniques in non-art courses would help students not only better remember content, but to also gain deeper knowledge.

Oral production.

The *production effect*, a much more recently discovered factor (MacLeod, Gopie, Hourihan, Neary, & Ozubko, 2010), is when producing a word orally more cogently induces subsequent recall than does silent reading. In numerous experiments, MacLeod et al. (2010) observed the production effect when a subset of presented words spoken aloud were more readily recalled than subsets participants mouthed without vocalization. Ozubko and MacLeod (2010) attribute this positive influence on memory to relative distinctiveness, or the fact that oral production distinguishes pieces of information relative to surrounding non-verbal items. However, it seems that the production effect may confer with the explanation that unusualness, or novelty, leads to greater processing instead of relative distinctiveness and in turn augments long-term consolidation (Rinne et al., 2011). Despite the underlying reason, either the atypical nature or relative distinctiveness, artistic practices such as slam-poetry, singing, or acting could readily take advantage of the production effect to improve retention and recall of content.

Effort After Meaning.

Effort after meaning, a phrase coined by the famous British psychologist Frederic Bartlett in 1932, describes the required exertion of effort when understanding novel information. Also referred to as “effort toward comprehension,” Auble and Franks investigate the effect on subsequent recall of information in 1978 and found that recall of a sentence was best when presentation of a cue occurred after a short delay that allowed participants to puzzle or exert effort over the meaning. Initially, the influence of effort toward comprehension on memory was seen as distinct from, and more profound than, that of elaboration, and was additionally thought to derive from the production of an “aha!” reaction triggered by the delayed cue. However, Zaromb and

Roediger (2009) recently proposed that the positive impact on memory attributed to effort after meaning arises from the relatively atypical nature of exerting unique effort to understand specific content. Thus, this unusualness, as described by McDaniel and Bugg (2008) in a similar relation to generation, enactment, and potentially production, may lead to additional processing culminating in greater retention of information. Interestingly, Zaromb, Karpicke, and Roediger (2010) noted that participants had little to no metacognitive awareness of the benefits to retention, indicating that effort after meaning is unlikely to result from a conscious attempt to commit material to memory by students. This fact suggests that teachers aware of the benefits should use alternative effort after meaning approaches that do not involve explicit learning directives (Rinne et al., 2011). One compelling approach could be the naturally motivating character of artistic activities, since aesthetic enjoyment of art is dependent on the observer interpreting and comprehending the artwork in a way that gives it personal meaning. This human pursuit of aesthetic pleasure naturally endows the motivation necessary for exerting effort after meaning, making art a useful tool for teaching a wide range of educational content (Rinne et al., 2011).

Emotional arousal.

It is a highly recognized fact, not only in cognitive psychology, but in the greater cultural and societal collective knowledge, that high levels of emotional arousal impact memory. The famous description of “flashbulb memories” by Brown and Kulik (1977) is a well known anecdote relating to the near-perfect recall of the environment surrounding an individual during a traumatic experience (Rinne et al., 2011). For example, most of us likely recall with striking clarity what we were doing, and where we were doing it, when we first heard the news on September 11th, 2001. However, outside of these high intensity moments, research has also shown that in more

subtle and common ways both positive and negative emotions influence long-term declarative memory (Kensinger & Schacter, 2008). There are multiple factors that converge to influence the emotional enhancement of long-term memory. However, the amygdala, a part of the mesolimbic system highly involved in emotional regulation, is widely accepted as a crucial player in the consolidation of memory. Research has shown that activation levels in the amygdala during memory encoding are strongly related to the recall of emotionally arousing information (Rinne et al., 2011). Evidence also supports that attentional focus during encoding may be modulated through emotional response, indirectly affecting memory to increase the likelihood of long-term retention (Rinne et al., 2011). Considering that art is an emotive process, it follows that utilizing artistic activities in a classroom setting could amplify recall abilities by means of emotional arousal.

Pictorial presentation.

The final factor influencing retention and recall addressed here, is commonly termed the *picture superiority effect*. Popularly summarized by the term “a picture is worth a thousand words,” numerous studies have found that the pictorial presentation of information leads to better retention than when the same information is presented in written form. A widespread theory exploring this effect is Paivio’s “dual-code” theory. The “dual-code” theory argues that pictures dually encode both visual and verbal information leading to superior memory. However, more recent theories suggest that transfer-appropriate processing better explains the picture superiority effect (Rinne et al., 2011). Transfer-appropriate processing is a type of state-dependent memory that specifically relates memory performance to not only the depth of processing, but also the relationship between the initial method of encoding and the later method of retrieval. For example, McBride and Doshier (2002) argue that encoding memory from pictures requires more con-

ceptual processing, such as free recall or semantic categorization, relative to words. This indicates that more conceptual processing associated with viewing images makes pictorial information more readily recalled than the same information presented in writing. However, it is important to note that the effects of pictorial presentation are more cogent when paired with matching formats (studying pictures when required to actually complete a picture) and that pictorial presentation does not show the same impact on children younger than seven years old, suggesting it develops as we age and depends on a capacity for recollection (Rinne et al., 2011). Although the relative benefits of pictorial presentation may depend on context and type of content, it is a factor that positively influences memory. When considering how these eight factors converge within various artistic techniques, it is plausible to conclude that models of integrative art education such as STEAM would better take advantage of these influence than the current STEM model and assist in improving retention and recall of content from multiple disciplines.

III. Novelty and Focus

Another facet of cognitive research is the use of novelty as a tool to enhance attention by engaging the brain's alerting and orienting systems (Posner & Rothbart, 2007; Smith et al. 1978). Exploratory activities, empathetic responses, and novel approaches are intrinsic in artistic creation. According to Lin et al. (2013), "artistic training is a complex learning that requires the meticulous orchestration of sophisticated polysensory, motor, cognitive, and emotional elements of mental capacity to harvest an aesthetic creation," and as such, represents a method of teaching that fosters ingenuity and innovation. Likewise, Rinne et al. (2011), although admitting that rehearsal and thus retention of content can be prompted through numerous strategies, argues that

artistic activities are particularly beneficial as they introduce novelty and thus increase student's motivation to learn, having a unique ability to prompt sustained attention naturally.

In addition to naturally increases student engagement and motivation, artistic activities increase observational skills by encouraging fresh ways of assessing visual cues in art. For example, a quasi-experimental study titled "Looking Not Seeing," examined the experience of an art museum on the observational and diagnostic skills of nurses and found that students who engaged in a 90-minute experience with an artwork made significantly more written observations and noted a higher number of possible objective clinical findings than those who did not participate in the museum program (Pellico, Friedlaender, & Fennie, 2009). Furthermore, students who previously engaged with artistic critique suggested more alternative diagnoses based on their observations. The findings from this study suggest that observational skills can be enhanced through the practice, common in art curriculum, of critically viewing and critiquing original artwork.

Additionally, the concept of novelty is implied throughout the assessment of the eight factors influencing long-term memory in Rinne (2011), as it suggests they all are somehow related to McDaniel and Bugg's (2008) theory that "unusualness," rather than the previously proposed dual-coding or relative distinctiveness theories, leads to greater processing and thus better retention and recall. This unusualness is really the phenomenon of novel experiences that are linked to improved memory. Pairing educational content with unfamiliar art techniques and/or artworks may provide students with the atypical experience that McDaniel and Bugg (2008) associate with higher-level processing.

IV. Empathy and Synchrony

Connected to improved memory due to oral production and pictorial presentation, research in the fields of cognitive neuroscience and psychology has determined a link between synchrony and memory. For example, Cohen & Parra (2016) found that memorable audiovisual narratives effectively synchronize sensory and supramodal neural responses, increasing recall abilities. In some regards, the primary role of the brain is as the ultimate multisensory integrator of vital information from our surroundings. As such, multisensory representation of the world, such as synchronized audio and visual information, help to facilitate encoding of long-term memories by providing a myriad of cues regarding the salience of lived experiences (Cohen & Parra, 2016). Additionally, evidence indicates that the development of synchrony in dyads is related to empathy.

Generally defined as the capability to experience and understand the feelings of others, empathy is also a powerful tool for enhancing memory encoding as well as increasing depth of understanding. Using the Interpersonal Reactivity Index (IRI), an established empathy scale, Beadle et al. (2013) found that amnesic patients demonstrated reduced empathy on all scales, with a most pronounced reduction in cognitive empathy, or the conscious drive to understand another's emotional state also referred to as perspective taking. Additionally, amnesic patients had attenuated responses to empathy induction when compared to healthy patients, suggesting a link between empathy and memory (Beadle et al., 2013). Investigating these findings further, Wagner et al. (2015) assessed the relationship between dispositional empathy, or the tendency for people to imagine and experience the feelings and experiences of others, and the encoding of new information in memory in healthy students. Results established a positive relationship be-

tween cognitive empathy and general memory performance, augmenting the clinical findings reporting reduced empathy in patients with primary memory impairments (Beadle et al., 2013; Wagner et al., 2015). These data suggest a link positively correlating the cognitive functions of memory and empathy. In relation to emotional arousal as discussed earlier, art creation is an emotive process that augments long-term memory consolidation. Furthermore, critically engaging in art as a viewer generates empathic responses as established by the *beholder's share*. Thus, through associating empathy with memory, the results from Beadle et al. (2013) and Wagner et al. (2015) connect arts integration to learning and memory even further.

V. Creativity and Higher-Order Cognitive Skills

Although useful and convincing evidence for integrative education, the aforementioned research focuses on the benefits of utilizing art in the classroom as a tool to achieve greater understanding of non-art subject matter, and thus, reflects some of the aforementioned fears expressed originally by the NAEA and art educators. However, arts integration as defined in the context of the STEAM movement would benefit students beyond the superficial improvement of long-term memory by not only facilitating creativity but by also teaching new ways of thinking.

Creativity is often regarded as a unique human trait that, for a long time, was considered an intrinsic quality of talented individuals. However, modern research has demystified creativity and demonstrated that like critical thinking, it is a skill that can be learned, fostered, and strengthened through various educational approaches. But in order to address creativity, we must first define it. The definition of creativity, similar to that of arts integration, is often a point of argument and ambiguity. Inventiveness or creativity in any field is often thought of as a special

giftedness associated with geniuses such as Da Vinci or Einstein. However, this sort of “genius” is what Kaufman and Beghetto (2008) call big-C creativity. “Big-C” creativity describes the ability “to generate new ideas that contribute substantially to an intellectual domain”. Howard Gardner defined this type of creativity as that which leads to solutions to problems, invention of products, or generation of novel questions in such a way that engenders revelation in a domain that ultimately influences the forward movement of society and culture (DeHaan, 2009). “Big-C” creativity is the idealistic and seductive ideation of genius; however, various authors identify another level of inventiveness coined “little-c” (Craft, 2000) or “mini-c” (Kaufman and Beghetto, 2008) creativity, which is considered to be a characteristic human trait. An example of such creativity as described in the workplace is when a coworker comes up with novel ideas for new marketing strategies or organizational approaches to improve sales or efficiency. Based on the concept of “possibility thinking,” when insight or a new visualization helps accomplish a task in an improved manner, “little-c” creativity can be represented as the “aha” moment when two seemingly disparate concepts merge to form new connections. This sensation is something that everyone has likely experienced at some point and was identified by Arthur Koestler in 1964 as bisociation, or the perception of a phenomenon in two “habitually incompatible” yet “associative contexts” (DeHaan, 2009).

However these distinctions in creativity likely describe the same cognitive function, with the difference of intensity only determined by the potentiation and augmentation of specific cognitive skills. Similarly, DeHaan claims “creative thinking is a multicomponent process, mediated through social interactions, that can be explained by reference to increasingly well-understood mental abilities such as cognitive flexibility and cognitive control that are widely distributed in

the population” (DeHaan, 2009). Creativity is an essential factor in effective problem solving and of critical thinking. Applications of creativity such as inventiveness and ingenuity are considered among the Higher-Order Cognitive Skills (HOCs) as defined in Bloom’s taxonomy (Crowe et al., 2008). And not surprisingly, creativity itself is considered an element of the HOCs that can be effectively taught through inquiry-based and constructivist instruction (DeHaan, 2009). Beyond cognitive theory, modern research supports that creativity is dependent on teachable mental abilities, and like other HOCs, may be enhanced through targeted educational approaches.

HOCs, including creativity, are vital cognitive functions that enhance content mastery. However, creative thinking is often erroneously associated with natural intelligence or special giftedness and is considered disparate from STEM fields. A growing body of research posits that creative thinking can be taught (DeHaan, 2009; Dugosh, 2000) and that applying learned content through creative activities requires both critical thinking and real-world problem-solving that increases proficiency and mastery of knowledge, regardless of subject matter (Hardiman, 2012). Science educators recognize that for students to become successful innovators in STEM fields, they must not only develop deep conceptual understanding of foundational theories, but also, the ability to apply this knowledge in a myriad of contexts and visualize their relevance to real-world situations. Innovators are those not only capable of perceiving novel connections and opportunities, but also able to realize them better than their peers and thus depend on instruction that enhances their capacity for creative thinking. Studies on nontraditional science courses based on constructivist principles have found that HOCs teaching strategies enhance mastery of content and dexterity in thinking. Thus DeHaan suggests that these approaches will promote both “cre-

ativity and cognitive flexibility if students are explicitly guided to learn these skills” (DeHaan, 2009).

For students confronted with unfamiliar content, solutions to many types of problems presented in both their courses or daily lives may be found through the application of newly learned theories or procedures (DeHaan, 2009). With practice, this applied problem solving becomes routine and represents mastery of a subject, producing what Sternberg refers to as “pseudo-experts” (Sternberg, 2003). But beyond the routine use of content, curriculum should strive to facilitate development of the HOCs necessary to apply, analyze, synthesize, and evaluate learned knowledge (Crowe et al., 2008). The aim is to establish students with adaptive expertise, or the ability to identify meaningful patterns, retrieve relevant knowledge, and apply that knowledge effectively in novel ways (DeHaan, 2009). Instead of simply applying learned procedures as “pseudo-experts,” adaptive experts utilize their mastery of content to invent or adopt unique approaches to a new problem within their field. Ideally, adaptive experts should have an interdisciplinary approach and are readily able to apply conceptual frameworks from one intellectual domain to another (Schwartz et al., 2005). This dexterity and inventive application of knowledge results in creative problem solving, and thus stems from what may be considered the cognitive skill of creativity itself.

VI. Plasticity and Neurogenesis

Since creativity is a higher-order cognitive skill prevalent among populations and may be strengthened through targeted education, the STEAM model of arts integration singularly demonstrates exceptional promise for the development of such adaptive experts. In fact, expand-

ing on the literature of cognitive psychology, neuroscientists have used these theories to explore the impact of arts education on brain-cognition and patterns of neuronal activity. According to Perkins (2002), creative thinking depends upon “break-through” or “out-of-the box” processing. DeHaan (2009) suggests that when an individual experiences an “aha” or “out-of-the-box” moment, although often characterized as a singular breakthrough by the individual, it is actually the result of a multicomponent process influenced by group interactions and social context. This is the underlying process of creativity and is theorized to include at least three diverse, yet identifiable, aspects. First, divergent thinking, which relies on ideational fluency or cognitive flexibility allowing for the visualization and incorporation of many relational ideas. Secondly, convergent thinking, or the cognitive function of inhibitory control that allows one to mentally focus and evaluate ideas. And lastly, analogical thinking, which is the ability to understand a novel idea in terms of one that is already familiar, for example using a personal anecdote to better comprehend a new experience. These are the cognitive elements believed to underlie creativity. Additionally, it is now generally accepted that memories operate along multiple systems with the ability to run independently and/or parallel to each other. Not surprisingly, creative thought, often referred to as “insight” or a “Eureka” moment (Jung-Beeman et al., 2004), was found to involve brain patterns that are variable from ordinary problem-solving. Research using electroencephalography (EEG) from Fink et al. (2007) found that tasks requiring subjects to generate creative, original responses rather than conventional ones demonstrated different patterns of brain activity. Similar findings were reported in Jung-Beeman et al. (2004), suggesting that this kind of “insight” thinking is related to particular physiological differences in the brain, and that these patterns of activity may be strengthened through artistic training.

As indicated previously, memory is a distributed cognitive function that involves multiple systems. However, within the domain of neuroscience, it is commonly accepted that learning in terms of memory formation occurs by “changes in the patterns of connectivity between neurons—or ‘synaptic plasticity’” (Howard-Jones, P., 2008). Learning not only produces changes in connectivity at a cellular level, but it is also linked to larger structural changes in the brain that can occur over relatively short periods of time. Lin et al. (2013) reported that long-term artistic training can “macroscopically imprint a neural network system of spontaneous activity in which the related brain regions become functionally and topologically modularized in both domain-general and domain-specific manners.” Essentially, discovering an attenuated modularity that indicates that long-term artistic experience nurtures resilient plasticity in the brain (Elbert et al., 1995; Lin et al., 2013; Münte et al., 2002; Schlegel et al., 2015). Thus relating the generation of new synaptic connections to the activation of genes that occurs during repeated learning experiences (Bailey & Chen, 1983; Kandel, 2001).

In addition to augmented connectivity, animal studies have shown that cognitive effort associated with learning impacts the rate of neurogenesis in the hippocampus, a crucial brain region in learning and memory. Furthermore, animals that learned a behavior best had more new neurons formation after training than those who did not learn as efficiently. Thus, learning and memory are correlated with increased brain plasticity and structural modifications. Additionally, the results of Lin et al. (2013) relate to a previous discovery linking exploratory and spatially orienting activities to neurogenesis (Woollett et al., 2011), where initially inexperienced taxi drivers learning the complex street system of London demonstrated increase brain density in the hippocampus. When considering that cognitive effort leads to neurogenesis which subsequently

influences memory, long-term artistic training, like that experienced by participants in the Lin et al. (2013) study, may also influence hippocampal neurogenesis.

So how can these theories from cognitive physiology and the evidence supporting cognitive flexibility through greater plasticity and neurogenesis be applied to education? One group of techniques, suggested by McFadzean (2002), called “paradigm-stretching” can encourage creative ideas. An example of one such technique, called heuristic ideation, encourages students to discover innovative connections by forcing together two seemingly unrelated concepts; essentially, representing a more modern version of what Koestler’s previously termed “bisociation” (DeHaan, 2009). Although these “paradigm-stretching” techniques may be useful and widely applicable cognitive tools, evidence from Lin et al. (2013) and Jung-Beeman et al. (2004) demonstrates that long-term artistic training is also a poignant, and potentially more natural and motivating, technique for developing cognitive flexibility and creativity.

VII. Conclusion

Although these studies, and numerous others, addressing the neurocognitive benefits of long-term art-based training, as well as articles addressing the success of integrative art teaching methods in K-12 schools, have been published, there exists a disconnect between these discourse communities. This disconnect could be attributed to numerous issues: the convulsion surrounding the seemingly simple term “arts integration,” the de-prioritization of arts education and resultant budget cuts, the lack of quantitative studies and standardized assessment models for the arts, as well as the disconnect between the education sector and the domains of cognitive psychology and neuroscience. With these considerations, literature outlining the current research in cognitive

and developmental neuroscience in a way that is accessible to education policymakers is necessary to demonstrate the evidential foundation supporting the STEAM movement. It is crucial to put shared knowledge and neuroscientific research into practice (Howard-Jones, 2008); as Nobel laureate and neuroscientist, Eric R. Kandel, a strong advocate for arts integration in the sciences, stated:

An enriched understanding of the brain is needed to guide public policy. Particularly promising areas are the cognitive and emotional development of infants, the improvement of teaching methods, and the evaluation of decisions. But perhaps the greatest consequence for public policy is the impact that brain science and its engagement with other disciplines is likely to have on the structure of the social universe as we know it. (Kandel et al., 2013, pp. 559-560)

Identifying these challenges facing researchers at the interface between neuroscience and education, Howard-Jones et al. (2008) suggests a “levels of action” model for approaching educational policy that is informed not only by developmental cognitive neuroscience, but also by evidence from the social sciences assessing the importance of social and cultural factors in learning. This approach is essentially an updated brain-mind model with bi-directional permeable boundaries that emphasize the influence of educational social environment on cognitive development. Although yet to widely influence educational policies on state and federal levels, the STEAM movement developed from a considerable enthusiasm for interdisciplinary educational approaches, specifically regarding arts integration. And the “levels of action” model suggested by Howard-Jones et al. (2008) indicates that, despite the philosophical and logistical challenges facing the movement, research in the realms of the social sciences and cognitive sciences can bidi-

rectionally inform theory and, when combined, augment the potential for improved systems of education. Additionally, when specifically approaching arts integration, it is crucial that the arts are not diminished or perceived as only a useful tool for teaching prioritized content. Although evidence summarized in Hardiman et al. (2014) and Rinne et al. (2011) confirms that artistic activities increase retention and recall, cognitive neuroscience research suggests that artistic training generates new patterns of thinking, induces neurogenesis and plasticity in the brain, and results in strengthened higher-order cognitive functions related to creativity. These benefits of arts integration, particularly as approached in the STEAM movement, are what develops students into adaptive experts that have the skills to then contribute to innovation in a variety of fields. As one of the greatest innovators of the 20th century, Albert Einstein, noted “the mere formulation of a problem is far more essential than its solution, which may be merely a matter of mathematical or experimental skills. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advances in science.”

Further considerations for arts integration.

A further consideration concerning arts integration is the challenge of developing methods of assessment that are detached from standardized tests, which often prioritize content areas such as mathematics and the sciences at the expense of the arts. Beyond integrative arts education, neuroscientific research could help address the problem of assessing suggested models in the classroom without leaning on standardized tests. Although not a primary focus of this paper, research of current knowledge in the cognitive sciences uncovered alternative techniques of classroom assessment that may be preferential for integrative systems of education. According to Hardiman et al. (2012), “evaluation is not just a way to assign grades, [but] is a valuable tool for

enhancing learning and memory” and Pashler et al. (2005) found that recall of material improved by 494% when students learned the correct answer following an incorrect response. Additionally, Finn & Metcalfe (2010) demonstrated that *scaffolding feedback*—providing incremental hints while allowing students to arrive at the correct answer themselves—improves memory. Based on this research, Hardiman suggests that “creative thinking can be enhanced through the use of alternative assessments such as work portfolios and projects that infuse technology and the arts”. Thus, research from cognitive neuroscience and psychology may have the potential to inform not only curriculum development, but also assessment strategies to enhance critical thinking in K-12 students (Hardiman et al., 2012).

VIII. Annotated Bibliography

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- The author, Guy A. Boy, is a University Professor & Dean of the School of Human-Centered Design, Innovation and Art at the Florida Institute of Technology and leader in the STEAM movement. In this article he argues against reductionism in education and advocates for a concept shift towards Human-Centered Design (HCD) and the integration of Science, Technology, Engineering, and Mathematics (STEM) with the Arts to promote creativity, rationalization, and critical, innovative thinking. The author has an M.S in psychology and a Phd in Automation and System Design and has written numerous books on Cognitive function Analysis, Interactive Systems, and Human-Centered Design. The article targets professionals and scholars in the education system and those that develop regulations and standards of curriculum in schools. This article represents an important and tangible approach and model for how education systems could organize the integration of the Arts back into the STEM subject matter. The pulling away from reductionism and towards intersectional and trans-disciplinary system is common in the STEAM discourse community and is central to the movement’s support.
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This study is a report on the results of a small, preliminary classroom-based experiment that tested effects of arts integration on long-term retention of content, which found that there were no differences between the common core classroom and the arts-integrative (AI) condition in initial

learning, but significantly better retention in the AI condition. This experiment was based on research in cognitive neuroscience demonstrating that consolidation of long-term memory storage occurs through rehearsal of information and the authors posited and found that arts-integrative instruction improves retention by rehearsing content using various visual and performing arts activities, which may also have the benefit of enhance student engagement.

Mariale Hardiman is interim dean of John Hopkins University, and is a co-founder and director of the School of Education's Neuro-Education Initiative (NEI). The NEI is an innovative cross-disciplinary program, bringing to educators relevant research from the learning sciences to inform teaching and learning. Her research focus using techniques that foster innovation and creative problem-solving to enhance educational practices . Her current research includes a randomized trial investigating the effects of arts integration on long-term retention of content and student engagement, as well as, how knowledge of neuro- and cognitive science influences teacher practice and efficacy. This study is a crucial because it demonstrates the need to use research from cognitive and developmental neuroscience to inform policy and practice

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This study investigates the resting-state functional connectivity networks from professional painters, dancers and pianist using a graph-based network analysis. Focusing on art-related changes of modular organization they reported that long-term artistic training can “macroscopically imprint a neural network system of spontaneous activity in which the related brain regions become functionally and topologically modularized in both domain-general and domain-specific manners”. This attuned modularity indicates that the long-term artistic experience nurtures resilient plasticity in the brain. This study provide neuroscientific data that supports previous studies’ findings that long-term artistic training increases brain plasticity and alters brain morphology, especially when started at a young age.

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model for the education of interdisciplinary scientists with hopes of encouraging innovations in modern science and technology that are necessary to address the complex and intersectional problems facing human society. This article represents an important and tangible program for how a specific university that could be used as a model for the integration of the Arts back into the STEM subject matter.

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