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From STEM to STEAM: The Connections and Fostering of Creativity in STEAM

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Abstract: Aiming to understand the connections between STEM and STEAM education, and why using STEAM can be more creative for students, this review analyzes literature on STEM and STEAM especially as applied to mathematics and music education. The research questions are (a) why creativity in STEM is important; (b) How to relate STEM with arts (STEAM); and (c) Why STEAM is important in foresting students' creativity. STEM - Science, Mathematics, Engineering, and Technology - was launched as an initiative by the National Science Foundation (NSF) [7]. STEM education has attracted much attention in recent years, but how to teach STEM in a way which fosters creativity is unclear. However, STEAM (Science, Technology, Engineering, Art, and Math) education provides a potential way to foster students' creativity and innovation during teaching and learning STEM [9]. This study explores the literature on limitations of teaching creativity in STEM and why it is important to relate arts (STEAM) in STEM education. The findings of this study show that STEM can be more effective when related with arts, but the practical strategies as articulated in the extant literature are still limited.

Keywords: STEM education, STEAM education, creativity, mathematics, music

1. Introduction

In the literature of creativity, the definitions of creativity are always elusive. Young [19] describes creativity as the actualizing of people's potential; Torrance proposes that creativity is modifiable and can be learned [13]; [4] state that creative persons can see what others see and think what others have not thought. However, although these varied definitions of creativity are axiomatic in the areas of art and literature, the definitions of creativity in mathematics are vague [12]. In professional mathematics, it is certainly true that mathematical creativity implies mathematical giftedness [15] and creativity is a subset of mathematical giftedness[8]. [15] proposes that the ability of creativity at the K-12 level is "feasible for students to offer new insights into a math problem or a new interpretation or commentary on a literary or historical work." It means that mathematical creativity is the ability to produce unexpected original work and the ability to formulate new questions for other mathematicians [15]. In Sriraman's research, there have five overarching principles to maximize creativity for the K-12 classroom (*the Gestalt principle; the aesthetic principle; the free market principle; the scholarly principle; and the uncertainty principl*e). The five principles require K-12 teachers to provide open-ended problems, connect Arts and Science, encouraging risk taking and atypical thinking, challenging

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known paradigms, and tolerating ambiguity. Based on these definitions, creativity as human potential and ability can be fostered during the education processes. Especially at the school level, students should be cultivated and related creativity during learning processes.

However, [3] found that some studies do not consider mathematical learning as a social process. Creativity in mathematics is dynamic which should interact with cultural, linguistic, and academic aspects to create space and time [3]. Students may use images, illustrations, metaphors and so forth to revisit the past and then reinvent it to solve future problems. Dominguez et al.'s research closely relates mathematics with art by creating socially concerted movements which means the metaphors consisting of bodies, materials, improvisations, and images to visualize the mathematical problems. There is an example from Dominguez et al.'s research, "Sweeping Fourths into Fifths". Students required to use one spoonful of sugars (5 grams) to repartition fractions by themselves. By constructing their imagination using the familiar experience (move sugars), students can understand the concepts by creative strategies.

These definitions and demonstrations of creativity and the potential relationships between mathematical creativity and artistic creativity above show the need for a new perspective on STEM education. It is necessary to clarify the challenges in mathematical creativity, why it is important to relate STEM with art, and how to relate it. This paper proposes three questions which are 1) why is creativity in STEM important; 2) How to relate STEM with arts (STEAM); and 3) Why STEAM is important in foresting students' creativity. This literature review shows that STEAM-focused research is scarce especially in the areas of methods and practice.

2. Analysis

2.1. Why is creativity in STEM(mathematics) important?

Creativity is always defined in the arts and is axiomatic to our understanding of what is "art". However, it can be difficult to relate STEM activities with art, at least within our current understandings of the creative process within mathematical, technological, and scientific fields. However, Haylock explains the four steps of creativity in thinking within any field: 1) preparation; 2) incubation; 3) illumination; and 4) verification. Creativity in math has been defined as "problem-solving and or problem-posing", activities which are different than application of rote memorization strategies applied to problem solution [12]. [11] assert that exploring the collective mathematical understanding is an improvisational practice. According to these researches, creativity is an important element in the classroom setting for students to generate new ideas, whether in art or subjects such as mathematics.

[1] proposed that students have difficulty in solving calculus problems quickly by themselves because their creativity learning has not been developed yet. Bevan, Williams, and [2] also stated that to improve students' positive feelings in mathematics, teachers should incorporate creative activities to enhance their problem-solving skills. From the extant research, Bevan et al. [2] found that students who do not possess positive feelings toward mathematics will lose their interest in the subject. Incorporating instructional strategies can improve students' positive attitude in mathematics classrooms, like brainstorming; "thinking outside of the box"; providing students with questions and feedback; using games and teaching techniques; and using all the known strategies of improving motivation (e.g., small group, field trips, and technology). The outcome shows that by incorporating creativity activities, students can increase their interests and achievements in mathematics [2].

The challenges that teachers face in mathematics classrooms are to meet heterogeneous learning requirements and to be aware of the diverse learning approaches of their students to identify the creativity in students' multiple solutions [8]. Researchers define the term "creativity" as "the work of mathematicians and their novel discoveries", which is related to school mathematics as "problem-

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solving or problem-posing"[12]. However, the traditional way to understand STEM education is isolating elements of the individual disciplines within their own standards and practices, while the newer understanding of STEM education is integrating the teaching and learning practices of individual disciplines [17]. [17] propose that it was difficult to consider the influence of art disciplines on teaching and learning of the disciplines of STEM. However, researchers also state that the combination of art disciplines can expand the influences between each of the main subjects including science, technology, engineering, and mathematics [17]. Based on STEM, STEAM-style education is a new framework to engage more students' success in better understanding the systems and connections[18]. In order to create a more enjoyable environment for students to engage in deep learning, STEAM education provides a new educational theory for educators.

2.2. How to relate STEM with art (STEAM)?

The arts are commonly understood to include language arts, physical arts, liberal arts (social), and fine arts [17]. Based on the understanding of the definitions of art,[17] found the development and connections of each subject, which creates a STEAM framework for the educators to teach STEM subjects in an interactive way (see Figure 1).

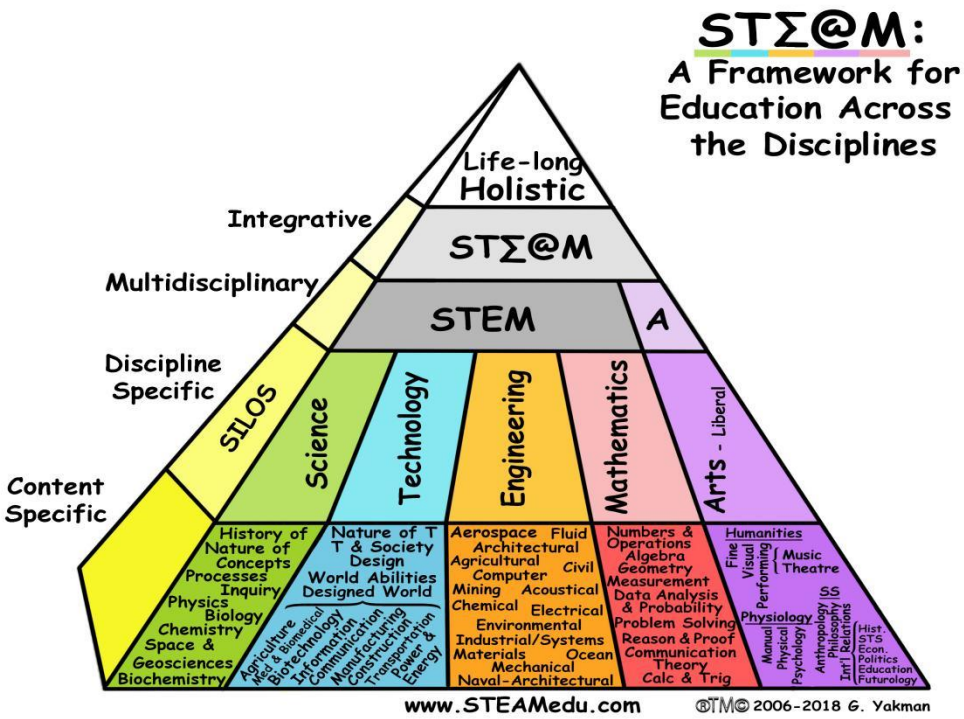

Figure 1. STEAM: A framework for teaching across the disciplines[18].

The new definition of the framework became: STEAM = Science & Technology, interpreted through Engineering & the Arts, all based on mathematical elements [18]. Yakman shows that a common thread for each primary division is to promote a need for students to develop proficiency in the subject. This need can promote students' basic development to continue to adapt and learn. She proposes that the arts contain all of the divisions that interact with the pure possibilities of the other fields to shape the direction of development. The goal of STEAM education is to help students obtain the ability to apply higher-order thinking and transfer knowledge between disciplines. For STEAM pedagogy to evolve so that it can be adopted in classrooms and studied, key concepts of STEAM

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education must be established along with effective approaches for developing creativity through the arts [14].

[17] state that "scholars of teaching and learning can address field-specific issues if they are going to be heard in their own disciplines, and they must speak in a language that their colleagues understand (p.1075)." Mathematics as a universal base language and language arts have the common thread to help students have deeper and broader understandings that could support transference of knowledge between subjects.

Creating a trans-disciplinary environment can promote creative spaces for students [6]. With the questions about what creativity is and how teachers can foster creativity in their students, their study included pedagogical practices used by teachers in their classrooms and interviews with teachers. [6] explored pedagogical practices for schools' administrators and teachers which were intended to enhance creativity within their learning environments. According to the authors, through practices including dialogic scaffolding, interdisciplinarity, creative environments, and school practices, teachers can promote secondary school students to learning and thinking in a creative perspective. From the part of providing creative environment for students through interdisciplinarity, one teacher shared that students can bring their thoughts and connections in other domains to the discussion that the group might not consider. Some students might be good at maths or music, and they can share their different experiences in such domains and perspectives. Through a subject like music, students can learn mathematics, structures, science, and symbolic language. Making multi-disciplinary connections can enhance divergent thinking and enrich classroom discussions, promote students to express their thoughts, and deepen the personal connections with the topic [6]. In Harris and De Bruin's research, the outcomes for fostering creativity in secondary school showed that the vital elements were collaboration and collectivity, environments, cross-disciplinary focus, real-world relevance, and the role leadership can play in asserting creative pedagogies, spaces, and practices in schools. Based on the results, cross-disciplinary practice, which is consistent with STEAM education, is one of the strategies that can promote creative activities in classroom settings.

2.3. Why STEAM is important in fostering students' creativity?

[11] assert that students learn mathematical knowledge and concepts by memorization and solve similar problems by memorizing procedures. However, using this teaching strategy, students cannot really understand the underlying mathematical ideas. To improve mathematical understanding, students should use "the lens of improvisation", which means to interplay the ideas of multiple individuals and not in a way that is located only in the mind of one individual. Researchers describe the similarities between collective mathematical understanding and improvisation in jazz; both are dynamic and inherently creative. As a result, incorporating arts education with STEM education is important in fostering students' creativity by sharing and exchanging ideas in the group, in a guided yet flexible manner.

In one specific example of the relations between mathematics and music, Geoghegan and [5] contend that music experiences have a positive influence on mathematical achievement. Research shows that traditional mathematical education has been taught in isolation, is irrelevant to daily life, and is devoid of creativity or aesthetics. Pursuing changes in traditional mathematics class is all educators' direction. These authors state that music can offer a new dimension for teachers to educate and integrate. In their study, Geoghegan and Mitchelmore compared mathematical concepts understanding among preschool children who either had or did not have specific elements of musical training. Those receiving musical training were exposed to content including the concepts of pitch, dynamics, and duration. After 10 months of training, the two groups were tested on mathematical achievement by the Test of Early Mathematics Ability-2. The results showed that the score of children who received the music training was higher than the children who had a limited music background.

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This research provides a valuable initial experiment about how musical experiences can influence preschool children to develop mathematical thinking, but it is still limited in the curriculum connections between two subjects.

3. Conclusions and Limitations

Establishing the curriculum for fostering students' creativity is the main goal for every educator and researcher in the world. In contemporary research, epistemologists and theorists consider that cross-disciplinary approaches could be more effective for learning and advanced discoveries in STEM. Interweaving arts education with STEM could become a key approach for educators to practice. This study provides the concepts of relationship between STEM and STEAM, the limitations of teaching STEM traditionally, and the importance of integrating arts to foster students' creativity. Contemporary educators should focus more on educational possibilities than on just learning facts. Integrating the arts to reform education strategies rather than imparting knowledge into students' minds is the key to transforming education.

However, within the research and theory I reviewed, the actual practices and experiments were quite limited. The definitions of creativity in mathematics are scarce, and the connections to creativity in the arts are not yet clear. [16] discussed that many STEM educators and professionals argue that STEM fields cannot lose their uniqueness. Still, it is time to reflect on commonalities and consider the influence of cross-disciplinary education in the collective sense. Accordingly, STEAM-style education provides a new perspective on which to concentrate. At the same time, it is necessary to find ways that can benefit cross-disciplinary approaches that will not limit the autonomy of each field [16]. Because of the scarcity in the literature, the research of STEAM education still needs scholars to pay more attention to specific structures, methods, standards, and evaluation instruments. STEAM education offers a new perspective for future education directions. For future research, researchers should provide the methods of education reform, the feasibility of new education strategies, and specific age levels of students (K-12 or adolescents, university students or adults), and types of schools (private or public school) to perfect the doctrine and to improve the strategies of education.

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