HJSTEM
Hellenic Journal of STEM Education, 3(2), 21-27, 2024

www.hellenicstem.com
ISSN: 2832-840X

RESEARCH ARTICLE

From STEM to STE(A)M: STEM education through artistic pathways

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Abstract
STE(A)M Education is an evolving educational approach that aims to combine educational models, teaching methods and pedagogical practices in the disciplines of science, technology, engineering, arts and mathematics. The STE(A)M approach requires a combined application of standards from different scientific and artistic fields in a structure easily adaptable to all possible combinations. However, a necessary condition in order to design educational practices in which the various disciplines will function in tandem and complement each other, is the investigation of the educational relations between these educational subjects and the discovery of points of intersection between them. This article is a critical review of studies that reveal the ways in which Art functions during the learning process, the educational standards it applies and the possibilities of their application in teaching STEM subjects with the purpose of uncovering the bridge that exists between Visual Arts and STEM disciplines that are being taught in the Greek classroom.

Keywords
STE(A)M, visual arts, creativity, divergent thinking, innovation

• Received 21 August 2021 • Revised 2 May 2023 • Accepted 12 December 2023

Introduction
For several decades, and especially since the beginning of the digital revolution, we have been observing that reality is changing at a very different pace. The advent of the internet, information systems and digital media has significantly interfered with the way we perceive even basic concepts such as space, time, and sometimes even our own identity. It is a fact that the way we communicate, trade, consume and keep informed has changed radically. Amongst the logical consequences of this modern age phenomenon, we can find that the labor market has undergone and continues to undergo significant changes, seriously affecting almost all professions. Today's economy, and the various professional sectors, constantly require new skills to meet modern needs (Mehta & Shah, 1997). Reasonably, then, arduous questions arise such as how do we prepare young people for their smooth and successful integration into an ever-changing society? How should modern school curricula be structured and what should they offer in order to better serve the needs of contemporary society?

In such an unstable and ever-changing reality, the key word is adaptability (Andrew, 2012). The labor market is evolving at an accelerating pace and is now characterized by vital interconnections between sectors. Given that the career path of today's students may change direction several times during their lifetime, they will need to acquire the ability to adapt to constantly mutating professional environments as well as make connections between different disciplines. Specialization in a single scientific field has begun to prove inadequate and obsolete (Madden et al., 2013). One of the solutions educational planning is proposing to counter this modern phenomenon, is the development of educational approaches that gradually integrate the concepts of participatory and exploratory learning with an interdisciplinary approach to knowledge (Amory, 2014). Educational policy has begun to focus on initiatives that support the development of the so-called 21st century skills such as critical thinking, creativity, the ability to collaborate and communicate effectively, media literacy, adaptability as well as personal and group initiative, with the ultimate goal of promoting deeper learning (Rotherham & Willingham, 2009; Allina, 2018). One of the main aims is to encourage, as much as possible, self-action and personal initiative of the students during the learning process and consequently their awareness of the personal paths that they need to follow for the ultimate acquisition of knowledge. By developing knowledge on how each and every individual learns, the students will be able to apply appropriate thinking routines depending on the situations they encounter throughout their life, thus achieving the most ambitious goal of lifelong learning (Bertrand & Namukasa, 2020).

In recent years we have observed that the interest is gradually shifting towards the value of skill development and autonomous knowledge building and is leaving behind the dry provision of consolidated information and the learning of predetermined ways of solving problems (Collins & Halverson, 2009). The STE(A)M educational approach aims to highlight, and exploit, the inherent connections between the various disciplines by creating interdisciplinary learning spaces (Smith, 2013). Through STE(A)M education, the student is offered different scientific approaches to knowledge in a unified context, with the main purpose of developing an adaptive mind with the widest possible overview of things.

Art inherently constitutes a field of inquiry, experimentation and observation that requires creativity, personal as well as group initiative and provokes critical thinking (Lampert, 2006b). These facts are being consistently reflected in the current curricula of artistic disciplines throughout primary and secondary education. Art curricula are already largely structured by having these objectives in focus. Creativity, sensitive response, careful observation and a critical approach, of both the works that are being analyzed and studied, and of the works that students create during the learning process, represent an integral part of the general purpose of teaching

https://doi.org/10.51724/hjstemed.v3i2.19

in the Visual Arts field (Ministry of Education, 2003). Students in the classroom, are encouraged in conducting research, experimenting with various media, developing new ideas and expressing emotions. They learn the properties and special characteristics of artistic mediums, techniques and materials, so that they are able to make targeted choices depending on the result they want to achieve. They learn the visual language, which is eminently symbolic, and manage to interpret formal elements and visual images, through this form of expression (Lampert, 2006a). Students are being trained in the oral and written presentation of their works of art and in the justification of their choices. During Visual Arts education, students learn to communicate and collaborate successfully in the creation of group art works. They receive training in original expression and additionally, get the chance to experientially realize the pluralism of society. They, therefore, learn to respect the opinion of others by observing, in real life situations, that when dealing with the same issue, each person brings a different result. They, also, gain an understanding of the environmental parameters that affect the work of art and realize the social, historical and ideological implications that it represents. Students, through visual arts education, develop visual and perceptual skills in regard to fundamental concepts such as space, time, volume, depth, rhythm, movement, and learn to apply the principles of perspective, composition, balance, and organization, all concepts that find applications in many scientific fields (Ministry of Education, 2003).

Moreover, students are trained to ask the appropriate questions, to explore an issue from different perspectives, to formulate, present, justify and support their views in the plenary of the classroom. Housen's body of work on aesthetic and critical inquiry techniques with K-12 education students shows that the production and analysis of works of art activates critical thinking, encourages attentive observation and offers opportunities for the application of the Socratic teaching method, the dialectical method and free argumentation during the visual arts courses (Housen, 2001-2002; Housen & Yenawine, 2001). In this creative discussion framework, students realize that their opinion has intrinsic value, and their active participation promotes the learning process. In the context of active creative learning and under the teachers' guidance, students learn to challenge and evaluate information, control their sources and are being naturally encouraged into further investigation (Ritchhart et al., 2006). The most important contribution of the aforementioned exercises is the familiarization and finally the training of students in deep thinking, creativity, critical thinking, effective communication and successful cooperation. In simple terms, students through art, are subconsciously cultivating skills that prove to be critical in the 21st century (Larson & Northern Miller, 2011).

Visual Arts have been employed, frequently and with relative success, as a gateway for teaching various school subjects, by making use of their inherent characteristic of problem posing, capturing interest and easily focusing the viewer's attention on a specific matter. Common educational practices that include the involvement of visual arts, are the display of works of art, intended as visual stimuli related to the subject of teaching, as well as the encouragement of students in artistic creation centered on a specific didactic goal (Ministry of Education, 2003). On the other hand, it is a fact that when there is a lack of specialization, by the part of the tutor, on the basic principles of art and its' didactic models, only a superficial use of the arts can be achieved. Whenever art is being employed as a mere medium by non-trained personnel in this field, the principles of artistic creation and the critical analysis of the structural elements of artistic creations are largely being ignored, resulting in the inability to exploit in depth the mental functions performed during the creative process or even worse the spread of misinformation.

STE(A)M educational practices should not be confused with the simple act of integrating artistic activities into the teachings of other disciplines (Huser et al., 2020). In respect of the principle of specialization, which is considered a prerequisite for a thorough and successful educational approach, STE(A)M programs are based on the interdisciplinary collaboration between sectors (Liao, 2016; Bequette & Bullitt, 2012). STE(A)M training requires the parallel application of educational standards of different scientific fields in a structure easily adaptable to all possible combinations of academic subjects. Through the combination of educational standards, teaching methods and practices of the STEM field and the Visual Arts field, STE(A)M education aims at building integrated teaching proposals with a holistic approach to the educational process (Yakman, 2008). STEAM education promotes learning experiences that encourage students to explore, question, research, discover, and exercise their creative skills and their potential for innovation (DeJarnette, 2018). However, a necessary initial condition, in order to achieve a substantial synergy at the level of methods and standards that will allow us to design educational practices in which the various fields of knowledge can function in tandem by complementing each other, is to explore the educational similarities between these fields and individuate their points of intersection. This commentary presents a critical review of numerous studies that reveal the ways in which Art functions during the learning process, the educational standards it applies and the possibilities of their application in teaching STEM subjects. The ultimate purpose of highlighting the existing convergences between Visual Arts and STEM disciplines is to explain how those can be utilized in order to design successful educational practices through their synergy and osmosis.

Theoretical Background

To understand the internal structure, methodologies and intentions of the STE(A)M educational approach we will need to refer to progressive learning theories, the origins of which can be traced in the research of Dewey, Piaget, Vygotsky and Bruner and which continue to concern educational researchers to date. According to Dewey, progressive education with an emphasis on learning related to authentic experience is based on the integration of new knowledge into the personal structure already created through the student's previous authentic experiences. The construction of the material under study must be done in a way that facilitates this integrative

process. The role of the teacher lies in the effective organization of students' learning experiences in order to allow the assimilation of new material in a context that is understood and becomes useful to them (Dewey, 1963).

The constructivist theory of learning argues that every human being acquires knowledge through a constant interaction with the physical and social environment, which leads them to personal paths of discovery and capability of rendering meaning to mental constructs. Constructive learning is an active, collaborative process in which the individual perceives objects, concepts and ideas in their own personal way. According to Piaget, the construction of knowledge, although performed in collaboration and interaction with the environment, is a subjective, internal process (Piaget, 1955). To reinforce this, Fosnot and Perry (1996) define constructivist learning as a self-regulating, interpretive, and non-linear process of knowledge construction achieved through active interaction with the physical and social environment.

By summarizing previous research, Yilmaz (2008) states that learning is essentially a process of understanding the world. All knowledge is a social construct and social interaction plays an important role during the learning process. Learning is an adaptive activity inextricably linked to the context in which it occurs. Also, experience and previous knowledge play a prominent role in the learning process. This means that knowledge involves to some extent a personal element. In any case, knowledge is not innate and is difficult to absorb passively on the contrary it is constructed through the student's active interaction with the world (Yilmaz, 2008).

In simpler terms, we conclude that although students are taught the same subjects and skills, they each learn and develop differently. Ontologically and epistemologically, we could say that although there is an objective reality, human beings fail to understand it objectively. Based on the characteristics of constructivist learning defined as personal knowledge construction, we can reasonably consider that the learning process is a continuous process of creating something new. Constructivism views the process of learning as a subjective, creative process with characteristics of originality. In this light, we could say that the construction of knowledge has common elements with the process of artistic creation (Topolovčan, 2016).

Constructivist learning methods are applied both in mathematics (especially in the field of mathematical proof making), in physics and chemistry through experimentation, and in architecture and art through the creation of alternative and original solutions (Pritchard & Woollard, 2010). These approaches serve well the different ways in which people are being taught and learn. The constructivist theory treats the student as a creative individual. Based on existing knowledge, which students acquire through their interaction with the natural or social environment, they add new elements, make new correlations or apply it in different ways thus creating new knowledge (Topolovčan, 2016). Active teaching methods, based on constructive learning, aim to encourage students to develop their own views and concerns, while the teacher ceases to be considered the unchallenged source of knowledge and assumes the role of guide in paths of reflection, dialogue, communication and creativity (Herro et al., 2019; Topolovčan, 2016). It is also considered necessary to apply multiple methods for the transversal understanding of the applications of knowledge in different scientific fields. This requires a structure within the educational system that allows the allocation of space and time dedicated to interdisciplinary teaching and study, in order to promote the transfer of knowledge while maintaining the dominance of individual disciplines in their own fields. Exactly such a structure is proposed by the educational approach of STE(A)M education (Yakman, 2008).

Any kind of creation constitutes learning, especially in the way it is defined, perceived and researched by the constructivist learning theories. Artistic creation is a form of learning which is mainly expressed as a human constructivist activity. This is what constructivist educators argue when they refer to art in general, but also whenever they treat art as a path to knowledge acquisition (Topolovčan, 2016). The basis of the STE(A)M educational approach, by building on progressive learning theories of the past, is found in teaching and learning strategies such as research, collaboration, discovery, autonomous problem solving and educational gaming (Gross & Gross, 2016; Huser et al., 2020). During STE(A)M training, the provision of sterile consolidated knowledge for memorization or prefabricated problem-solving instructions is avoided, on the contrary, students are encouraged to independently process the problems presented to them through a combination of methods and standards of different scientific fields. Students are motivated, through the interdisciplinary STEAM approach to solve real-life problems, to identify innovative solutions, learn from their mistakes, to synthesize original ideas and come up with alternative propositions. Through the context of discovery and exploratory learning, they experience the real-life correlations between the various cognitive objects and realize that it is not only the content of the information that matters, but also the ways someone chooses to apply it, the possible correlations someone will be able to make and the new research questions that will arise from that (Roberts & Schnepp, 2020).

While the demand for well-trained professionals in STEM science fields is constantly increasing and this phenomenon is now being recognized, by international unanimity, both at an academic as well as a governmental level, various challenges are being encountered in regard to planning the education of young people in these fields in effective and sustainable ways in order to encourage innovation. Some of these challenges are being addressed by educational policy by introducing creativity, through the arts, into the education and training of future STEM scientists (Segarra et al., 2018).

The Concept of Creativity

Creativity, divergent thinking and innovation are among the key skills of the 21st century (Quigley & Herro, 2016) and in addition to being fundamental elements of artistic education, they are also some of the primary goals of STE(A)M education. Although various psychologists have shown

interest in the phenomenon of creativity in the past, the intensification of research on this subject began after the speech with which J. P. Guilford accepted the presidency of the American Psychological Association in 1950. In this speech, Guilford highlighted the need for a systematic investigation of this phenomenon and urged his colleagues to study it as a distinct human characteristic. Creativity is defined as a deliberate mental function that each individual is capable of performing to some extent. It unfolds through a recognizable process and is verified through the uniqueness and usefulness of the result. For the most part, researchers agree that creativity can be improved through education (Ford & Harris, 1992). Although public opinion and creativity theorists often assume that creativity depends primarily on talent, there is significant evidence that intense effort and strong motivation, which of course can be supported or undermined by the social environment, also play a central role in developing and enhancing creativity (Amabile, 2001).

Through the evolution of research in recent decades, creativity has acquired very different dimensions. The original exclusive connection of the concept of creativity with the world of artistic creation has been reconsidered and research interest in that regard has gradually shifted to other fields, such as science, mathematics, engineering and architecture (Cropley, 1999). Meanwhile, we have also added creativity to the measurable factors of success in areas such as education, business and the general social context of everyday life. In business planning, it is related to the practices that lead to the predominance of a company over the competition, the constructive management of human and material resources and the ways a company employs in order to increase labor productivity (Woodman et al., 1993). In the field of education, creativity is expressed mainly through creative learning strategies (Seechaliao, 2017), while at the level of everyday life it is understood as the ability to adapt to and effectively manage the various social and work situations.

Scientific investigation of the concept of creativity often includes the distinction between divergent and convergent thinking. Convergent thinking follows a process to reach a solution to a problem, while divergent thinking involves the search for many possible solutions to a problem. Curricula designed to promote creativity often focus on teaching strategies for practicing divergent thinking. Studies have also demonstrated that students who participate in educational programs aimed at practicing creativity show more advanced thinking skills, better stress management, greater self-awareness and better social skills such as communication, successful group work, self-confidence, autonomy (Madden et al., 2013).

To summarize, although creativity is still a cloudy concept, it is generally defined as the ability to generate original ideas or useful solutions and, undoubtedly, still finds itself at the heart of research. Regardless of the academic field, scientific research rewards the creative approach to issues in order to produce innovation. The identification of new issues worthy of reflection and solution, the explanation of mysterious phenomena, the production of new interpretations of important cultural or historical events and the development of new methods of study of the world are the subject of those who wish to promote evolution in any scientific field (Ulibarri et al., 2019). Although some important questions about the nature of creativity remain unanswered, psychologists have largely managed to shed light upon the ways in which individuals achieve this particular and most important form of optimal human functioning that holds a prominent seat in all areas of human activity (Simonton, 2000).

The Building of Knowledge through Art

As Arnheim (1974) very aptly states, one of the privileges of the artist is the ability to capture the nature and meaning of an experience in terms of an artistic medium, and thus to make it tangible. During the creative process, the artist engages in mental processes similar to those of a scientist or a child when they try to understand the world through the course of their activities. The creation of a work of art by an artist, like the constant experimentation of a researcher or the effort a child makes in understanding reality through lived experience and experimentation, can all be characterized as adaptive and evolving processes that continue until a temporary state of equilibrium is reached. This process is complete when, after repeated tests, the objects or materials are properly adapted to an idea (Mandelbrojt & Mounoud, 1971).

By deepening on the subject of artistic creation, Piaget's theory of cognitive development connects children's sketches with the evolving human ability to perceive the permanent existence of objects and the development of their mental representations. A necessary condition for children to be able to recall the past and predict the future, is for them to realize that objects have a permanent existence. Children must develop the ability to relate an image-symbol to these objects, through which they will be able to view the object in their mind. The role of the image-symbol is to replace what is not in front of them at a particular the moment. This mental process is the beginning of abstract thinking, the last and most advanced stage of the cognitive development of an individual. The representation of these images-symbols through the children's drawing, is the means by which people organize their everyday life experiences so that they can understand them further (Piaget, 1955). Symbolization and mental representation, in addition to being basic elements of the neurobiological function of the human brain, are also expressive tools for the artist (Gombrich, 1960/2000).

Visual art is a language. It represents an alternative system for the communication of concepts, ideas, thoughts and emotions. As mentioned above, the production of works of art requires students to define a concept, recall an experience, an emotion or even just an object that they do not have in front of them at a particular moment. The brain during this creative endeavor is forced into mental processes that refer to abstract thinking (De Pisapia et al., 2016). Students are then asked to select the appropriate symbols and rendering techniques in order to be able to express visually what they want, thus unconsciously being forced to make correlations of concepts. The result of this process is the counterpart of figurative speech and the use of

analogies during language exercises. The creative process is an extremely symbolic activity that develops abstract thinking which in turn is related to logic, the ability to solve problems and to draw conclusions through the correlation of concepts or elements. Abstract thinking is one of the most important cognitive functions of the human brain and allows complex reasoning, the elaboration of abstract concepts and spatial perception, all mental functions and consequent skills that are required and developed in tandem throughout the STEM fields of research and pedagogy (National Research Council, 2006).

Moreover, the theory of perception, argues that young children, draw only what they can see or perceive. According to Arnheim, young students do not see objects as the sum of the observed parts, but as whole images structured by the brain. According to Arnheim, perception is a skill learned through training in visual discrimination (Arnheim, 1974). A regular teaching process during art courses, is the enhancement of student's visual perception through careful observation of their environment which results in the detailed breaking down of everyday objects into the individual shapes and geometric solids of which they are composed (basic principles of artistic drawing) (Karystinos & Stefos, 1998; Antonopoulou et al., 1999). This process is based on the dialectical relationship between visual arts and the principles of geometry, planimetry and stereometry. In addition, the practice of analyzing works of art in terms of their compositional elements, structure, balances, weights, rhythm, color, shapes and morphological elements, as well as the very process of deciphering and interpreting the message they carry, inherently requires the mental processes of reflection, analysis, correlation and discovery. It is a fact that art is an intimate expression of the society that births it. Therefore, it is structured in very similar ways and is inherent in all human interventions.

The Role of Art in STE(A)M Education

By exploring the relationship between STEM and visual arts, we automatically realize that the ability to draw and visualize is already included in the prerequisite skills of professionals in these fields. The most obvious and widespread form of use of the symbolic language of visual arts, in these scientific fields, is visual representation. STEM disciplines are, by definition, functionally dependent on visual ways of communicating and problem solving. This includes schematic representations, symbolic logic, scientific illustration, and photography (Quillin & Thomas, 2015). It is a fact that every STEM theorist, researcher, teacher or professional learns how to decipher and produce graphs, cell diagrams, architectural plans of buildings, drawings of electronic and hydraulic systems or visual representations of natural phenomena depending on the field to which they belong.

Scientific imaging is a familiar platform for STE(A)M, although it is not considered the only model of productive collaborations between science and art. The visual, spatial and graphic arts have the potential to reveal scientific concepts through alternative paths that complement the traditional ways of exploring and assimilating (Segarra et al., 2018). Today's visual arts initiatives in STE(A)M environments incorporate clear standards of aesthetics, visual literacy and communication. The addition of art to STEM education offers a more creative platform that allows for deeper understanding and consolidation of scientific concepts, the reinforcement of technical skills that are inexorably required by the scientific fields, and the enhancement of students' skills in creative, original, innovative design and interdisciplinary collaboration. (Bequette & Bullitt, 2012). Additionally, the active integration of visual arts in STEM educational programs encourages the participation of students in scientific research and, subsequently, facilitates students' reflection on their scientific experience through the creation of STE(A)M artwork (Segarra et al., 2018).

The integration of artistic activities in scientific research and learning, makes the whole activity authentic, experiential and creative, which is also the main goal of the STE(A)M educational approach. Moreover, Land (2013) states that introducing the component of visual patterns into STEM activities brings both cognitive and creative benefits, since it helps to understand the natural world as well as abstract concepts. Engaging in drawing enhances careful observation, helps to create correlations between form and function, and can serve as a model of application in solving authentic problems (Quillin & Thomas, 2015). It is also interesting to note that practical applications of visual and plastic arts such as drawing, modeling, photography and origami have been proposed as effective interdisciplinary approaches for the development of spatial intelligence, which constitutes a critical feature of successful STEM professionals (Newcombe, 2010). In addition, there is evidence that integrating visual arts activities into STEM education makes the learning process more natural, by helping students to effortlessly gain deeper understanding of complex scientific subjects (Burton et al., 2000). STE(A)M learning environments identify and exploit the thinking routines and skills that are being cultivated in art courses and encourage students to apply them when solving authentic problems that belong to the STEM fields.

Conclusions

Visual arts are inherently intertwined with society. Hence, we can reasonably deduct that they share linguistic elements with most areas of human activity. Visual arts introduce unique learning routines in education by revealing deeper levels of interpreting natural and social phenomena. They lead students onto paths of self-discovery and, at the same time, push them effortlessly into mental exercises of logical correlation as well as the production and solution of authentic problems. They provide an alternative language of expression and different ways of exploring and capturing the environment through the use of a richer, more creative, vocabulary for their communication with the world.

STE(A)M education is an attempt to re-create the ways the world functions, within the scholastic environment. It offers the student an educational context that works in ways that simulate real world experiences. It aims to equip students with the flexibility of mind that is considered

necessary to deal with the increasingly complex issues that arise in the rapidly changing reality we are already experiencing. At first glance, one might say that sciences belonging to STEM and visual arts, are two independent fields governed by completely different principles. Indeed, in the field of arts, great importance is ascribed to subjectivity, intuition, emotions and the uniqueness of the product, while sciences that belong to STEM education are governed by objectivity, repetition, logic and analysis. With a closer look, however, we realize that the coupling points of these two sectors are multiple. Analysis, synthesis, careful observation, originality and innovation are building blocks of both STEM and Art education. Abstract thinking, deep thinking and creativity are characteristics that are required and cultivated both in the creative world of the arts and in the fields of science.

The STE(A)M educational approach is based on the fact that, although arts and science are two distinct, and autonomously important, subjects of general education, they complement each other effortlessly by cultivating the same skills in different ways. Divergent thinking, in-depth observation, critical thinking, spatial intelligence, originality, the ability to visually represent concepts as well as creativity, innovation and effective collaboration are at the core of both sectors. What remains to be done by educational planning, is to turn these two parallel learning paths into intersecting ones, by integrating more artistic activities in STEM education and thus offering to students a more holistic view of the world through creative and wholly enjoyable experiences.

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