Pakistan Journal of Life and Social Sciences

www.pjlss.edu.pk

https://doi.org/10.57239/PJLSS-2025-23.2.001

RESEARCH ARTICLE

The Importance of Arts in STEAM Education: Contribution of Ceramics Art-Integrated Learning Skills to Enhance Innovative Learning

Dr. Badar Almamari [1], Prof, Ali Al-Shuaili[2]

[1,2] Sultan Qaboos University Muscat, Oman

ARTICLE INFO

Received: May 18, 2025

Accepted: Jul 2, 2025

Keywords

Arts, Education
Ceramics
STEAM

***Corresponding Author:**

bmamari@squ.edu.om

ABSTRACT

Since the arts entered the STEM educational system, the system has become broader by taking advantage of the applied nature of fine arts fields. Due to the special nature of teaching ceramics, which is considered the closest arts subject to science, this study analyzes the relationship between the skills required for ceramics in the art room and their parallel applications in the science classroom, especially in physics and chemistry. This study proposes models that link learning skills for ceramics with corresponding skills that can be easily acquired in science classes to achieve STEAM's educational goals.

INTRODUCTION

The transition from the old educational system of science, technology, engineering, and mathematics (STEM) to the new system of science, technology, engineering, arts, and mathematics (STEAM) reflects the importance of the visual arts. This branch of arts can be practiced in all science education subjects and is a reflection that there is an educational gap in STEM. Silverstein and Layne (2010) defined arts integration as "an approach to teaching in which students construct and demonstrate understanding through an arts form. Students engage in a creative process that connects an art form and another subject area and meets evolving objectives in both." According to Allina (2013), STEAM education emerged as a new pedagogy during the Americans for the Arts National Policy Roundtable discussion in 2007 in response to the need to increase student interest and artistic skills in STEM fields. Consequently, adding the arts to STEM and advocating for STEAM constitute the next step in establishing an agenda designed to campaign for and elevate the importance of arts subjects to support integrated learning (Bequette and Bequette, 2012; Liao, 2016; Riley, 2012; Sousa and Pilecki, 2013). For many researchers from STEM areas of education, STEAM offers contextual learning and develops subject overlap for greater understanding (Gettings, 2016).

However, this does not mean that the integration of the arts into STEM has been smooth or accepted by early-stage education staff. For example, arts integration is often misunderstood as referring only to the use of the arts to enhance teaching and learning; therefore, when it is unfortunately misunderstood in this way, art is often watered down in classroom practices (LaJevic, 2013). Moreover, although art and other subjects should be equally important in arts integration, as mentioned by Silverstein and Layne (2010), art is usually considered a vehicle for learning; consequently, sustaining the reliability of arts education is a concern for art teachers (Roucher and LovanoKerr, 1995; Sharapan, 2012; Ulbricht, 1998).

Perignat and Katz-Buonincontro (2019) pointed out that STEAM education is a relatively new area that does not have clarity; as such, it "is rife with ambiguity and various interpretations." They revealed that the abundance of interpretations and definitions of STEAM makes it difficult for practitioners to effectively integrate the "A" into STEM and to ensure the development of student creativity and other cognitive skills (Perignat and Katz-Buonincontro, 2019).

It seems that creativity has become of great importance in the modern educational process (especially during the first and second decades of the 21st century), which has necessitated the addition of the arts to the educational curriculum (STEAM) (Edwards, 2010; Trilling and Fadel, 2013). This has led to opportunities to apply arts educational skills in the classroom, such as improving student engagement, creativity, innovation, problem-solving, and other cognitive benefits (Hetland and Winner, 2004). In addition to these skills, the arts provide other skills that contribute to the achievement of learning outcomes, such as teamwork, communication, and adaptability (Colucci-Gray et al., 2017; Liao, 2016).

However, other researchers have suggested that the motivation for integrating arts into the system comes from the demand for economic well-being due to the connection between arts and creative industries. Godin (2008) mentioned that the promise that STEM holds for the future is based on the idea that STEM fields drive critical innovation, and such innovation, in line with early- to mid-20th-century notions, is explicitly tied to economics. This places more attention on ignoring the thought that "one of the goals of STEAM is to involve the arts in order to increase the participation of students who are traditionally absent from STEM" (Quigley and Herro, 2016).

In the discourse on arts education, the arts are regularly described as having many instrumental benefits, including for other subjects, such as math and reading (Glass and Wilson, 2016). Due to the significant differences in the ways in which the arts are used in the STEAM system, this is evident in the multiplicity of the terms representative (transdisciplinary, interdisciplinary, multidisciplinary, and cross-disciplinary), as described by Perignat and Katz-Buonincontro (2019). However, it can be shown that teachers can create a transdisciplinary space in their own STEAM lessons by designing assignments that engage with multiple disciplines, thereby sustaining students' ability to transfer learning from multiple disciplines (Liao, 2016).

From the above, we can see the importance of arts in the study of science, whether it is based on the idea of using art as a secondary tool that achieves the goals of science teaching or of the arts as an original and pivotal subject in the educational process. This study reviews the strengths of using pottery (ceramics) lessons in science education based on experiments and applications of shaping, painting, and firing ceramic products, as well as the impact of these experiments on the study of natural sciences.

2. Ceramics in Art-Integrated Learning Skills

As a branch of fine arts, ceramics plays an important role in the development of students' creative skills at all stages of the educational process. This comes from the fact that ceramics, on the one hand, has the features of developing three-dimensional shape–forming skills and, on the other hand, employs flexible clay material in shaping, which is popular and attractive in learners' art classes. One of the most important differences distinguishing ceramics from the rest of the arts across different stages of education concerns the purely applied scientific aspects on which this artistic field is based. The connection between the study of ceramics and the natural sciences (e.g., mathematics, geography, and geology) in educational settings can be identified in the following three main aspects:

Forming Shapes for Ceramic Objects: The processes involved in students forming ceramic artworks using clay are clearly related to scientific processes and concepts related to the natural sciences and mathematics. For example, the process of forming ceramic pieces from clay slabs provides a real opportunity to teach the accuracy of measurements and measuring curves (Turner, 2004), while the visualization of the ceramic shape during the design processes on paper (sketching) provides an opportunity to learn skills in mathematical geometric spaces (Reijnders, 2021).

Glazing Ceramic Objects: In learning ceramic glazing, the process associated with forming ceramic glazes in the laboratory from mineral chemical materials (Daly, 2018), the accuracy of weighing using scales, the control of the flow rates of ceramic glazes (Williams, 2021), and the methods of applying glazes to fired ceramic objects all provide opportunities for learning that fully connect art with natural sciences (especially chemistry and mathematics).

Firing Ceramic Objects: When firing ceramic pieces in electric or gas kilns, the process of controlling temperature gradients down to the degrees at which the ceramic pieces are ready (usually 900–1300°C) is an educational opportunity that clearly links artistic and scientific skills (Muller and Zamek, 2011). In addition, calculating shrinkage rates in ceramic pieces before or after firing is considered an essential skill that serves science learners and is also an important basis for learning the art of ceramics (Lawrence, 1972).

Opportunities To Benefit From Ceramics In Science Education

From studying the possible educational benefits that students gain from studying ceramics, it has been found that several skills are effective in teaching the natural sciences. The followings are among a long list of the skills that can be learned from ceramics programs that are compatible with science subjects:

Negative Thermal Expansion: Negative thermal expansion is an unusual physicochemical process in which materials contract upon heating rather than expand, as most other materials do (Liu et al., 2011). Some materials, including ceramic clays after drying or having completed the firing cycle, shrink when heated at certain temperatures. According to Lakeside Pottery Studio, clay shrinks both when dried and when fired, but different clay bodies shrink at different rates, which can be as little as 4% or as much as 15%. The shrinkage ratio of ceramics, based on the shape and size of a product, is an important factor, with an uneven proportion in the distribution of shrinkage resulting in defects such as cracks (Chun-Ting et al., 2007).

Balancing the *Chemical Composition of* Substances: In schools, chemical composition can be described as the arrangement, ratio, and type of chemical substance, and the final chemical composition will vary when chemicals react under different conditions. However, while studying ceramics at educational institutions, students witness applied experiences in the ceramic coating laboratory by applying ceramic paints and achieving a perfect balance between components to ensure the quality of production and to avoid defects in the final product. The components of ceramic glaze are divided into four groups—**glass formers, fluxes, refractory or stiffening agents, and colorants** (see Table 1)—and the artist must weigh these chemicals with extreme precision using sensitive scales and ultrafine graduated cylinders. Before proceeding with the application of these recipes to ceramic bodies, students must prepare accurate equations, such as the model in Figure 1.

Table 1. Examples of chemical substances used in the ceramic glazing laboratory to create ceramic glazes and colors

Glass Formers	Fluxes	Stabilization Agents	Colorants
Silica	Borax frit	Alumina	Iron oxide
Quartz	Colemanite	Titanium oxide	Chrome oxide
Flint	Cornish stone*	Zirconium oxide	Cobalt oxide
	Dolomite		Copper oxide
	Feldspar (potash)		Manganese oxide
	Feldspar (soda)		
	Frits		
	Gerstley borate		

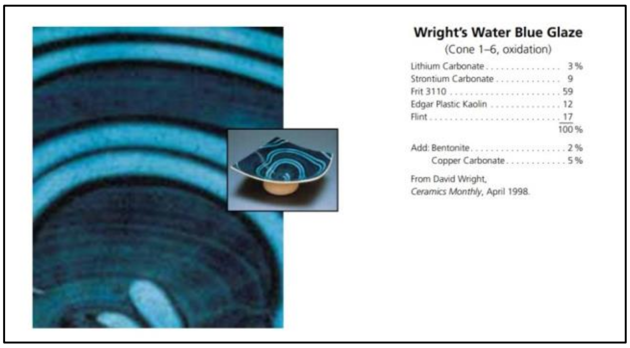

Figure 1. Glaze recipe including all four groups of ceramic glazing materials (glass formers, fluxes, refractories, and colorants) (source: Sierra Nevada College, www.ceramicartsdaily.org, 2013)

Viscosity of liquids

Viscosity is a type of mass property defined as a liquid's resistance to flow. Thus, when the intermolecular forces of attraction are strong within a liquid, there is greater viscosity (Petrucci et al., 2007). There is no doubt that studying viscosity in science classes, especially chemistry and physics, depends greatly on providing accessible models, such as presenting liquids (e.g., water, honey, and milk) with different rates of viscosity to students. However, the art room offers practical opportunities to measure viscosity by art students casting clay in gypsum molds. In ceramics, a certain degree of viscosity is considered more suitable for casting, and the Ford cup is used to measure the viscosity of liquid clay suitable for slip casting in gypsum molds (Figure 2). The difference between normally observing the degrees of viscosity of different liquids and experimentally adjusting viscosity ratios in practice by adding water and mixing clay until an appropriate degree of viscosity is reached in liquid clay lies in the fact that the practice in the art room is integrated with scientific concepts of fluid viscosity.

Figure 2. In the art room, a Ford cup is used to adjust and measure the viscosity of liquid slurry poured into a mold by calculating the time that the liquid passes through a hole in the bottom of the cup

Measuring Specific Gravity to Evaluate the Density of Liquids

Specific gravity is defined as the ratio of the density of a substance to the density of water at a specified temperature. Today, specialists use a scale (hydrometer) to measure fluid density (Figure 3), but this method may not be educational, especially in early non-university education.

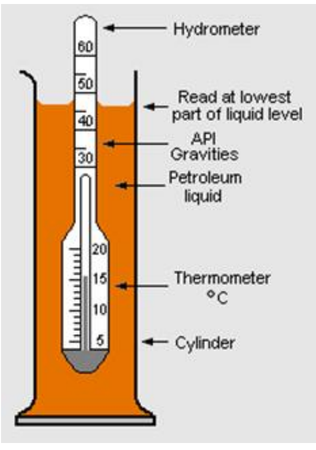

Figure 3. Schematic drawing of an API hydrometer combined with a thermometer (source: Milton Beychok, CCO)

To understand and explain fluid density in the early stages of education, the educational process should bypass the idea of obtaining results and focus on how to get the results. Thus, art classes and ceramics teaching contribute to teaching fluid density measurement skills by showing how to measure the density of ceramic glazes using sensitive scales and a graduated cylinder. In fact, calculating the specific gravity of a glaze is important for ceramic artists to obtain consistent paint for pots. A typical method uses a 100 mL graduated cylinder to measure and weigh the same volumes of glaze and water. The specific gravity is the weight in grams divided by 100. Normally, the weight of the glaze in the cylinder would be between 145 and 50 g (Almamari, 2020). For example, when filling a graduated cylinder to a level of 100 mL with ceramic glaze, the apparent weight is divided by the weight of water at the same level. The result is the density of the glaze liquid (specific gravity).

Figure 4. Measuring the specific gravity of an ACTP clay slip (SQU Ceramics Lab) (source: Badar Almamari, JSBAR, 2020)

Understanding Centripetal Acceleration Using a Potter's Wheel

Physics teachers may find it difficult to teach centripetal acceleration because of the abstract diagrams in textbooks. However, they can take advantage of the information available on practical applications in which the mathematical rules of centripetal acceleration theories are applied, such as in rollercoasters, porch swings, cream separators, and washing machines. However, these examples, which are outside the boundaries of the classroom, are insufficient for explaining the physical law of centripetal acceleration; therefore, it is possible to use a potter's wheel for this purpose, which is available in the art rooms of many educational institutions, with high efficiency.

To understand centripetal acceleration, it is necessary to comprehend Newton's three laws. Newton's first law (law of gravity) states that if a body is relaxed or moves in a straight path at a steady velocity, it will remain at rest or move in a straight line at a constant speed until it is acted upon by force. Newton's second law states that power is equivalent to the adjustment of energy (motion of a moving body) per change in schedule, which is a measurable description of the effects that a force can have on a body's mobility. Finally, Newton's third law shows that when two bodies come into contact, they apply forces to each other that are comparable in magnitude and opposite in direction.

These three laws can be observed directly and clearly in the classroom using a potter's wheel. However, a potter's wheel can additionally provide practical lessons in using Newton's laws to understand more complex topics, such as centripetal acceleration. Unlike the classic examples that always feature in textbooks to explain centripetal acceleration, the most famous being rollercoasters, porch swings, cream separators, washing machines, etc., by using a potter's wheel to produce ceramics, science students have a great opportunity to gain knowledge not from the level of viewing but from the level of direct practical application. The weight and size of the clay lumps, when placed on a moving potter's wheel with measurable rotational speeds, can provide applied knowledge that is easier to access and absorb by students in the art room than theoretical knowledge in science classes.

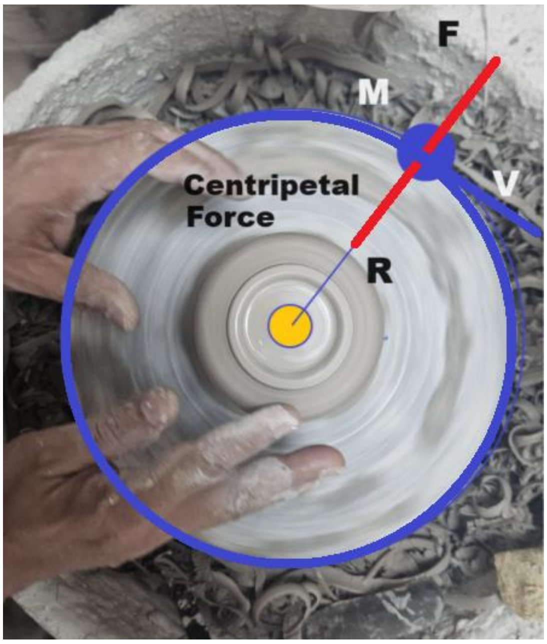

Figure 5. A visualization of a potter's wheel used to teach centripetal acceleration (source: the author, Sultan Qaboos University)

Study Outcomes: Ceramic Learning Skills and Related Chemistry and Physics Lesson Topics

From this review, the field of ceramics appears as a dividing zone between the natural sciences and the arts in which the potter deals directly with obvious practical physical and chemical laws. The fire processes in ceramic furnaces (kilns), calculations of the expansion and contraction of ceramic pieces, students dealing with the chemical composition of ceramic glazing in laboratories, the mechanisms of clay formation in the moisture phase, the laws of absorption governing the use of gypsum in the formation of plaster molds, and other applied models are examples of the connection between teaching ceramics and natural sciences, especially chemistry and physics.

Table 2 provides a list of wider artistic applications carried out in the art room for ceramics skills learning that correlate with skills learning in the fields of chemistry and physics in particular.

Table 2. Ceramics learning skills and related chemistry and physics lesson topics

Ceramic Skills Learning	Examples of Related Lesson Topics in Science Subjects
Preparing Clay Skills	
Collecting clay from nature	Collecting soil/clay from around school and making observations. This activity outside the classroom trains students to use their senses to compare their soil/clay samples with those collected by their classmates.
Treating clay collected from nature (grinding, sieving, monitoring water immersion)	With different clay samples available in the art room, science students can perform exercises related to both clay and soil (observing the composition and particles that make up soil to determine soil types by soil texture tests; examining organisms that live in the soil and learning about their roles in the ecosystem).
Mixing different clays together	Training students to mix soil/clay samples found earlier on campus and create usable batches of clay for many forming activities. Mixing and wedging clay are educational skills suitable for early grades (grades 1–3) to develop muscular abilities for writing, with wedging clay considered the most suitable for achieving this goal.
Mixing clay slips and colored powders (for mold slip casting)	**Mixing colors with clay** helps in learning about primary and complimentary colors through easy color-mixing art activities that include some science, art, and problem solving.
Forming Techniques	

Forming using pinching and coiling techniques	Ceramic techniques can be used to teach students how to build educational models in the fields of physics, and chemistry. The construction of educational models with complex organic shapes is easily achieved using clay (e.g., globe models, chemical bond models, DNA, human body systems, landform models, plate tectonics, and cells).
Joining techniques (scoring and adding slips to glue clay)	Unlike the gluing techniques learned by school students, which are based on combining different materials (e.g., glue and cardboard, nails and wood), ceramic forming activities provide educational skills based on changing the position of the same material (clay) from its solid state to its liquid state (slip) so that clay slabs are glued together using the same material without extraneous materials being used. This activity can contribute in an applied way to the study of the solid, liquid, and gaseous states of matter and their impact on scientific applications.
Forming using wheel-throwing techniques	A potter's wheel, which is available in the art rooms of many educational institutions, is used with high efficiency to study the physical laws of motion, such as the laws regarding centripetal acceleration and others related to rotation, in physics classes.
Forming using slabbing techniques	The process of building ceramic pieces using the slabbing technique and gluing them to form three-dimensional geometric shapes is considered one of the best educational techniques related to teaching geometric shapes in mathematics, and clay surpasses other materials by being the least expensive and the most flexible in the hands of early-age students (grades 1–4). It avoids the necessity of using sharp cutting tools to build slides.
Forming using slip-casting techniques	Producing ceramic pieces using plaster molds (slip casting) is based on osmotic laws, whereby gypsum absorbs liquid clay and produces a clay wall that forms the ceramic piece. The practice of liquid clay casting with gypsum molds provides a great opportunity to study everything related to the laws and applications of osmosis, both in aspects related to the study of liquids (physics and chemistry lessons) and in applications related to osmotic pressure in living organisms (biology lessons).
Forming using 3D printing techniques	Despite their high cost and rarity, three-dimensional clay printers associated with artificial intelligence provide opportunities for many applications within the classroom, especially for grades 6–10. However, the most important consideration here is that 3D clay printers differ from similar printers that use plastic films (e.g., PLA, TPU, or ABS) in that they provide an educational opportunity to adjust the level of fluidity of the clay material as a skill from which students' creativity develops at this educational stage, which is not available when using ready-made plastic films.
Glazing and Coloring Skills	
Glazing raw materials	Students learn to distinguish between natural materials extracted from the earth and chemical compounds, as well as the effects of these groups on their mixing, to form ceramic glazing emulsions.
Measuring raw materials	Students learn fine composition skills using sensitive scales and learn the differences between wet and dry mixing.
Applying glazes on ceramic fired objects	Students learn creative design skills and express themselves through freedom of choice. They also learn the physical rules governing the absorption of liquids by bodies.
Firing Techniques	

Using skills for different types of kilns (electric, gas, wood)	Studying ceramics provides an opportunity to identify the sources of heat and fire by using various types of ceramic kilns or by visiting workshops and factories that use such equipment.
Learning to choose the appropriate temperature for clay	Ceramics learning contributes to the development of science students' skills in terms of choosing the appropriate temperatures for burning ceramic clays with different burning rates. These skills will have a positive impact on students' abilities in applying the effect of heat on the natural materials represented in clay.
Adjusting electric kilns' control devices	Despite their complexity, controlling the devices associated with ceramic kilns provides an opportunity for science students to develop their experience in dealing with laboratory devices and controlling the conditions of laboratory experiments.

CONCLUSION

This study aimed to trace the contributions of ceramics teaching in supporting the teaching of educational topics in all fields of science. This research demonstrated that ceramics, as a branch of fine art, plays an important role in the development of students' creative skills at different stages of the educational process, especially in chemistry and physics. This study provides a comprehensive list of the skills that students gain by studying ceramics and their impact on learning in pure scientific fields through applied and interactive teaching methods. Therefore, the researchers recommend making use of educational processes in the art room at all stages of education to provide a learning environment through which the STEAM system is realized in a serious and practical way.

REFERENCES

Allina, B, 2013. 'The Evolution of a Game-Changing Acronym: Why Government Recognition of STEAM is Critical', *ARCADE*, Vol. 31, No. 2. http://arcadenw. org/article/the-evolution-of-a-game-changing-acronym

Almamari, B. 2020. 'Examining the Quality of Local Omani Clays for Ceramic Slip Casting in Art Schools: Testing Deflocculant, Specific Gravity, and Viscosity', *International Journal of Sciences Basic and Applied Research (IJSBAR)*, Vol. 52, No. 2, pp. 183-190.

Bequette, J. W. and Bequette, M. B, 2012. 'A Place for Art and Design Education in the STEM Conversation', *Art Education*, Vol. 65, No. 2, pp. 40-47.

Colucci-Gray, L., Burnard, P., Cooke, C., Davies, R., Gray, D. and Trowsdale, J, 1970. 'The Open University', *Open Research Online*. https://oro.open.ac.uk/62156/

Daly, G, 2018. *Developing Glazes*. Bloomsbury Visual Arts.

Edwards, L. C, 2010. *The Creative Arts: A Process Approach for Teachers and Children*, 5th edition, Upper Saddle River, NJ: Merrill Publishing.

Eisner, E. W. and Michael, D, 2004. *Handbook of Research and Policy in Art Education*. Lawrence Erlbaum Associates.

Gettings, M, 2016. 'Putting it all Together: STEAM, PBL, Scientific Method, and the Studio Habits of Mind', *Art Education*, Vol. 69, No. 4, pp. 10-11.

Godin, B, 2008. *Innovation: The History of a Category*. Institut national de la recherche scientifique, Centre Urbanisation Culture Société.

Hsu, C.-T., Chou,C.-J., Huang, T.-S., Hung, P.-M. and Chen, C.-N, 2017. 'The Effect of Firing Shrinkage Ratio of Ceramics on Thickness', *Journal of Interdisciplinary Mathematics*, Vol. 20, No. 3, pp. 937-950. https://doi.org/10.1080/09720502.2017.1358892

LaJevic, L, 2013. 'Arts Integration: What Is Really Happening in the Elementary Classroom?', *Journal for Learning Through the Arts*, Vol. 9, No. 1, 1-28.

Lawrence, W. G, 1972. *Ceramic science for the potter*. Chilton Book Co.

Liao, C, 2016. 'From Interdisciplinary to Transdisciplinary: An Arts-Integrated Approach to Steam Education', *Art Education*, Vol. 69, No. 6, pp. 44-49. https://doi.org/10.1080/00043125.2016.1224873

Liu, Z.-K., Wang, Y. and Shang, S.-L, 2011. 'Origin of Negative Thermal Expansion Phenomenon in Solids', *Scripta Materialia*, Vol. 65, No. 8, pp. 664-667. https://doi.org/10.1016/j.scriptamat.2011.07.001

Müller, K. and Zamek, J, 2011. *The Potter's Complete Studio Handbook: The Essential, Start-to-Finish Guide for Ceramic Artists*. Quarry Books.

Perignat, E. and Katz-Buonincontro, J, 2019. 'Steam in Practice and Research: An Integrative Literature Review', *Thinking Skills and Creativity*, Vol. 31, pp. 31-43. https://doi.org/10.1016/j.tsc.2018.10.002

Petrucci, R. H., Harwood, W. S., Herring, F. G. and Madura, J. D, 2007. *General Chemistry: Principles & Modern Applications*. Pearson Education, Inc.

Quigley, C. F. and Herro, D, 2016. '"Finding the Joy in the Unknown": Implementation of STEAM Teaching Practices in Middle School Science and Math Classrooms', *Journal of Science Education and Technology*, Vol. 25, No. 3, pp. 410-426.

Reijnders, A, 2021. *The Ceramic Process: A Manual and Source of Inspiration for Ceramic Art and Design*. Bloomsbury Visual Arts.

Riley, S, 2012. *STEAM Point: A Guide to Integrating Science, Technology, Engineering, the Arts, and Mathematics through the Common Core*. Westminster, MD: Education Closet.

Roucher, N. and LovanoKerr, J, 1995. 'Can the Arts Maintain Integrity in Interdisciplinary Learning?', *Arts Education Policy Review*, Vol. 96, No. 4, pp. 20-25.

Silverstein, L. B. and Layne, S, 2010. *What is arts integration?* The John F. Kennedy Center for the Performing Arts.

Sousa, D. A. and Pilecki, T, 2013. *From STEM to STEAM: Using Brain-Compatible Strategies to Integrate the Arts*. Thousand Oaks, CA: Corwin.

Trilling, B. and Fadel, C, 2013. *21st Century skills: Learning for Life in our Times*. Jossey-Bass.

Turner, A, 2004. *Pottery Making Techniques: A Pottery Making Illustrated Handbook*. American Ceramic Society.

Williams, J, 2021. *Ceramic Glazes: A Beginner's Guide to Understanding Ceramic Glazing and Firing Techniques*.