# Evaluating the Impact of Collaborating Art and Design with Chemistry Teaching on Secondary Student Creativity and Engagement in Ugandan Schools

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**Abstract: Had every scientist embraced arts and design studies, the world would be more beautiful than it is now, and had all artists learned different sciences, there would have been more scientific innovation and creation. We would give our eyeteeth for an art-science Collaboration as the pedagogy of the 21st century. The incorporation of art and design into STEM education has led to the widespread use of the acronym (STEAM) in educational discussions. Therefore, this paper intends to evaluate the impact of collaborating art and design with Chemistry teaching on secondary student Creativity and engagement in Ugandan schools, demonstrating to educators, policymakers, Curriculum developers, and the public the benefits of Collaboration as a pedagogy to enrich the learners within the 21st century. A participatory demonstration with learners from Immaculate Heart Girls' School, Nyakibale, along with intentional analysis and observation, was carried out in the areas of recycling, ceramics, and metal casting. The results show a need for interdisciplinary pedagogical approaches.**

***Keywords:*** *Pedagogy, Interdisciplinary, Art-Chemistry, Collaboration, Sustainability, Systems Thinking, Epistemological Approach, Green Chemistry, Creativity and Innovation.*

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## I. INTRODUCTION

Had every scientist embraced arts and design studies, the world would be more beautiful than it is now, and had all artists learned different sciences, there would have been more scientific innovation and creation. For the past 10 years, concentration efforts to integrate STEM into the classroom have been underway (Francisco et al., 2017). According to Marín-Marín et al. (2021), methodologies integrating Science, technology, engineering, art, and math (STEAM) into education have emerged in recent years as a pedagogical alternative that offers a more holistic and engaging learning experience. The integration of the arts with STEM has recently gained momentum in a movement called STEAM in educational settings (Belbase et al., 2022). This union of subjects does not simply connote the classes in schools, but rather calls for the combination and integration of all five subject areas into one comprehensive area. The consequences of STEAM integration (Aguilera, D., & Ortiz-Revilla, J., 2021) are manifested in its impact on 21st-century learners. The STEAM initiative builds on established frameworks for interdisciplinary curricula; however, the amalgamation of art and design with STEM fields is particularly compelling (Smith, O., 2015). In Uganda, where a shift from theoretical to a more practical and competence - based curriculum in secondary schools at both levels has been realized, and more so on the emphasis given to the study of sciences, this needs further study to include art and design-science Collaboration pedagogy and to define the extent art can be a Science clearly. The 21st century needs 21st-century approaches to the formation of 21st-century learners, well equipped with 21st-century generic skills, including critical thinking and problem-solving, Creativity and innovation, Mathematical computation, and ICT proficiency, among others. According to Ruby & Arafa (2023), studies have revealed that the rapid development of the global economy in the 21st century has highlighted a significant gap between conventional education and the skills demanded by modern workplaces. The dynamic intersection of art and Science brings about Creativity and innovation. From a multidisciplinary perspective, artistic practices (e.g., technical skill-building) and scientific inquiry (experimental testing) complement each other, influence societal development, and drive technological and cultural advancements. Today, more than ever, we need to focus on developing our skills of creative and collaborative thinking. In his paper (Gardiner, P., 2020), which synthesizes research on creative Collaboration across a range of disciplines, outlines a framework to prepare a platform for collaborative thinking in educational contexts to help students generate creative responses to solve complex problems.

The study of axiology (from Greek *axios,* "worthy"; *logos*, "Science"), which is concerned with aesthetics, positions art to intersect with the Science that gives the world value and worth. Both art and Science share similar characteristics of observation, critical thinking, and empirical truth in education and academic research. The two disciplines deal with reality in a broader sense. Art, being a life subject, engages with all aspects of Science and technology. Actually, it is at the core of human life and existence. Sachdeva ( 2021 ) asks, "Is art a mere sensation or an effect or the artist's reflections on life presented through a sensational experience? Does the present situation alter its nature, function, scope of art, and its language?" 'Why do we need art? Why do we create art? What is its role in our society?' All these questions resonate with various debates in the domain of aesthetics. 21st-century concerns in art about an interdisciplinary approach. Across the globe, art reflects the above sciences, and so to what extent should it be integrated with them? More focus should then be placed on the Collaboration of these disciplines to produce 21st-century graduates who can fill the vacuum left by societal challenges that translate into unemployment.

In this particular paper, emphasis is placed on the Art-Chemistry Collaboration. What correlation is there between the two disciplines? Pitz J. (2023) posits that Chemistry and art are often thought of as opposites. Whilst art is seen as creative, expressive, and fluid, chemistry is analytical, precise, and staid (Gamwell, L., 2020). However, there is, in fact, a significant crossover between the two subjects. Whilst visiting a museum or art gallery, we can easily forget that a lot of science lies behind the exhibits Macdonald, S., 2020). When it comes to cleaning, conserving, and restoring a piece of art, for example, science is invaluable (Baglioni, P., & Chelazzi, D., Eds.). (2013). By enthusing different audiences with the Science secrets behind art, we can help teachers, students, and the public appreciate the wider application of chemistry in the world. We have developed a wide selection of activities so that as many people as possible can get involved. Francisco, et al.,(2017) employ intriguing questions that can acertain collaboration and these are: 1) How can the work of art give us clues about scientific aspects? 2) How can chemistry help a painter to enhance his Creativity and, preserve the originality of his work? 3) Does an artist require any scientific knowledge to innovate? The other symbiotic fields between art and Science are: tattoos, as body art with physical and chemical consequences that require scientific innovations and new pigments

In an era when much of the literature emphasizes the importance of Collaboration between the arts and sciences, there is a prevailing knowledge-application gap regarding Art-Chemistry Collaboration within the Ugandan secondary school curriculum. Art-chemistry collaborations open diverse career pathways, ranging from conservation Science and materials development to medical illustration and cosmetic chemistry. These courses prepare professionals to bridge creativity with scientific rigor, making them valuable in industries such as museums, fashion, pharmaceuticals, and design.

➢ *Problem Statement:*

Even when Art and chemistry collaborations can proficiently open diverse career pathways, ranging from conservation Science and materials development to medical illustration and cosmetic chemistry with courses that prepare professionals to bridge Creativity with scientific rigor, making them valuable in industries like museums, fashion, pharmaceuticals, and design, knowledge application is still demanding in Ugandan Secondary schools. According to Spector, T. I., & Schummer, J. (2003), the neglect of chemistry by artists, curators, and art critics is quite surprising, because artists, like chemists, have always been personally engaged in combining, transforming, and experimenting with materials. The relation of art to chemistry is, in fact, the most overt among all the scientific disciplines (Schummer, J., 2003). Moreover, as new process-oriented art genres emerged in the second half of the twentieth century, chemical transformations became a central element of modern art. For instance, artists like Yves Klein and Janis Kounellis employed fire (the oxidation of combustible materials) either as artistic performances or as a means of artistic production. Crossing the boundary between painting and photography, Sigmar Polke and Achim Duchow mixed their own photo emulsions to perform photochemical reactions on canvas and other media. Spector, T. I., & Schummer, J. (2003). Students who show interest in studying a combination of the two subjects have their dreams shattered by educationists who, because of the bottom-up structure of education in Uganda, do not provide an appropriate space for these learners. However, Art-Chem studies at secondary school can lay a profound foundation for future careers and professions: ceramic engineers, architects, textile engineers, well-grounded mechanical and software engineers, applied and design technocrats, well-grounded doctors with proficiency, and the list is endless.

What proficiency skills can the Art-Chemistry Collaboration pedagogy offer a 21st-century learner in sustainability, problem-solving, critical thinking, innovation, and creative generic skills? Chemistry, which primarily covers the states of matter, structures and bonding, electrolysis, and mixtures, correlates with art in that art engages with chemistry. The Chemistry laboratory experience expresses this whole need for the pedagogical approach. Labby, K. J., & Braun, K. L. (2021) posit that, over the last thirty years, numerous initiatives have been made to improve chemistry education. These calls for reform often ask educators to adopt pedagogies that actively engage students in the learning process, promote student agency, and demonstrate chemistry's broad applicability while still conveying core chemical concepts. Williams, A., & Tkachenko, V. (2014). Policymakers, curriculum developers, and educators alike need to recognize the importance of integrating Science and art teaching at all levels and develop related courses that promote sustainability and societal problem-solving. For instance, a ceramic engineering student, through the ceramic process, needs knowledge and Understanding of complex chemistry concepts, including the states of matter, salts, and bases. The question here remains: to what extent will interdisciplinary approaches be defined? According to Rhoten et al. (2006) and Klein and Newell (1997), interdisciplinary education is understood as a mode of curriculum design and instruction in which teachers integrate information and theories from various disciplines to foster and improve students' capacity to create new solutions and approaches to existing problems Chen, M., Jeronen, E., Wang, A., & Wang, A. (2020). Chemistry learners who participate in hands-on ceramic projects (Onal, N. O., & Asmaz, A. C., 2026) will certainly gain a better Understanding of complex chemistry concepts and theories. The study engaged Chemistry and art students at Immaculate Heart Girls' School in activities such as glass recycling for glaze, firing ceramic products, recycling plastic for pavers, and recycling metal for casting. The experiences learners got were remarkable. There was a deeper Understanding of the complex concepts in Chemistry. The pedagogical Collaboration between chemistry and art (art-chemistry) is of great value to 21st-century learners. According to Dempster, M., Ganescu, S., Lau Ahier, C., & Bongers, A. (2025), the necessity of visuals in chemistry underscores the importance of representational competence in chemistry education, which The ability to interpret and generate visual representations is an essential skill. Arts Integration is an educational approach that connects knowledge across artistic disciplines with other subjects to enhance student learning outcomes, such as critical thinking, creativity, comprehension, and engagement. Clarifying how arts integration benefits diverse student learning styles can help educators see its broader impact and applicability in different classrooms. This method uses shared themes or concepts to bridge different disciplines, enabling students to explore connections between the arts and academic content. By integrating artistic processes, such as visual analysis and creative expression, with traditional subjects, Arts Integration fosters critical thinking, creativity, and a deeper understanding of content (Burnaford, 2007).

According to Dempster, M., Ganescu, S., Lau Ahier, C., and Bongers, A. (2025), the realistic portrayal of three-dimensional objects—such as that seen in still-life drawing activities—may appear incompatible with organic chemistry, primarily because molecular structures cannot be directly observed. However, organic molecules are often represented in three dimensions, as seen in Newman projections discussed earlier. In their study, the researchers designed an activity that practiced drawing techniques like contour drawing (the outline of objects) and negative space (the space within or between objects). This activity helps students create realistic representations of general objects and physical molecular models, illustrating how arts-based methods can deepen understanding of complex scientific concepts.

The activity lasts 45 minutes and involves a facilitator instructing a small group of participants on creating contour and negative-space drawings. After the instruction, the group is given time to work slowly on building a realistic portrayal of both a general object and a physical molecular model.

Occasionally, as an art teacher conducting my experiments in metal casting and ceramic glazing, I have received chemistry teachers and learners who come to gain practical experience. The question here is, what relevance is there between the two subjects? Is there any validation and relevance to teaching art-chemistry? Parents ask what use art is? Art, being practically oriented and driven by Creativity, is a doorway to the teaching and learning of the sciences, especially chemistry. In simple terms, art is a practical Science. In addition, Achiam, M. et al. (2026) posit that many Science centers, museums, art galleries, and mainstream festivals host exhibitions and programs that employ the arts to promote Science engagement. Learners in the 21st Century need this integration and Collaboration. When chemistry meets art (Art-Chemistry/Chemistry-Art), greater creativity and innovation, critical thinking, problem-solving, and environmental sustainability can be realized. According to Shrivastava, et al. (2020), sustainability Science must also engage with society and creatively employ all available sources of knowledge to create a sustainable Earth. This would be the correct response to the problems of the 21st Century, which need a 21st Century problem-solving agenda. Dr. Mae Jemison (2002) (a physicist and astronaut) stated that 'the arts and sciences are avatars of human Creativity'.

Therefore, the study seeks, firstly, to bridge the gap between Art-Chemistry Collaboration. Secondly, to inform policymakers, curriculum designers at both secondary and higher levels of learning, and stakeholders about the pedagogical intervention. Thirdly, to provide enlightenment to both learners and educationists of the 21st century for the need to rethink about generic skills of critical thinking and problem solving, Creativity and innovation, e.t.c, that can solve 21st century problems, where Art-Chemistry is optimal.

According to Chen, M., Jeronen, E., & Wang, A. (2020), Sustainable development has been considered a major global goal since the launch of Agenda 21 in 1992. It has also been confirmed recently through the United Nations Conference on Environment & Development, Agenda 21, and the Sustainable Development Goals of Agenda 2030. Rio de Janeiro, Brazil, (3–14 June 1992). According to the report Our Common Future: The 2030 Agenda for Sustainable Development, sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

## II. REVIEWED LITERATURE

Recent initiatives in the USA, such as the Next Generation Science Standards and the Common Core State Standards for Mathematics (Hwang, J., Choi, K. M., & Hand, B., 2020). Focus on integrated STEM approaches. Similarly, the Department of Education of Western Australia states that STEM is a pedagogical approach that provides an access point to creativity, inquiry, dialogue, collaboration, and critical thinking. Recently, STEAM, with an A for arts, has been conceived as an alternative to STEM pedagogy to promote creativity, the habit of taking risks, engagement in collaborative, experiential learning, and perseverance in problem-solving to develop today's students as future leaders, innovators, scientists, engineers, educators, entrepreneurs, and learners of the twenty-first century. Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2022)

The STEAM approach is more than just an instructional strategy. It is an inspiration for innovation (Liao, 2019) and a transformative approach to school education and community development in different parts of the world, such as African regions (Digital Education Africa Network [DEAN], 2020; Kruger, 2019; Women Entrepreneurs for Africa, 2020) and Latin America (RICOH America Latina, 2020; SIEMENS-Stiftung, 2018). Likewise, European countries are promoting STEAM education at the school level through partnership and collaboration programs, such as the Euro STEAM project (Haesen & Van de Put, 2018). Therefore, STEAM is a new vision to promote student creativity, collaboration, and collective being through transdisciplinary consciousness and conscience All Education, Schools.com, 2019).

Arab nations, such as Egypt (Aziz, 2015) and the United Arab Emirates (Shaer et al., 2019), have emphasized integrated STEM/STEAM education as part of continuous reform in the school curriculum, aligned with national agendas and governments' visions to advance twenty-first-century skills. The schools are encouraged to promote STEM/STEAM education through certification and accreditation in Egypt (Aziz, 2015). The United Arab Emirates Ministry of Education, Abu Dhabi Department of Education, and Mohammad Bin Rashid School of Government in Dubai have emphasized promoting STEM/STEAM education through various programmes, for example, Advanced Science Agenda, Think Science, and National Agenda and the UAE Vision to be one of the top twenty high performing nations in PISA and the top 15 high performing nations in TIMSS Shaer et al., (2019).

### *A. Theoretical Reviews:*

#### ➢ *Systems Thinking Approach*

According to Amissah, M., Gannon, T., & Monat, J. (2020), systems thinking is an approach to reasoning and treatment of real-world problems based on the fundamental notion of 'system.' The term' system' here refers to a purposeful assembly of components. Thus, systems thinking is aimed at understanding the relationships among components, their overall impact on system outcomes (i.e., intended and unintended), and how a system of interest fits within its broader environment. Torsetnes, G. (2021). (Meadows, D. H., & Wright, D., 2009) define a system as an interconnected set of elements that is coherently organized in a way that achieves something.

Systems thinking is an epistemological approach that focuses on the identification, modeling, and prediction of complex systems as entities rather than on isolated phenomena (Sommer & Lücken, 2010; von Bertalanffy, 1973). A systems thinking approach is essential for various actors, both at the global level (such as policy-makers, governments, researchers, and companies) and at the individual level (Jacobson & Wilensky, 2006). This becomes especially apparent in the context of present and future complex social and environmental challenges, as set out, for example, in the United Nations Agenda for Sustainable Development (United Nations, 2015). Recognizing this importance can inspire students and educators to see their role in shaping a sustainable future, fostering a sense of purpose and empowerment. Consensus across conceptualizations, however, can be observed, particularly regarding three central skills of systems thinking (Mehren, R., Rempfler, A., Buchholz, J., Hartig, J., & Ulrich-Riedhammer, E. M., 2018). (a) *identifying system organization*, (b) *analyzing system behavior*, and (c) *system modeling.*

These cognitive skills not only appear in various fields of systems thinking research but also describe systems thinking across fields (Ben-Zvi Assaraf & Orion, 2010; Tripto et al., 2017).

Recently, there have been calls to integrate systems-thinking approaches into chemistry education to strengthen students' conceptual understanding, build their problem-solving capabilities, (York, S., & Orgill, M. 2020) and prepare them to make informed, ethical decisions about globally relevant issues, such as sustainability. Unfortunately, implementing systems-thinking approaches in chemistry classrooms currently poses challenges. According to Mehren et al., (2018), though research on systems thinking is derived from a variety of fields, common system principles can be identified for complex systems in general: (a) systems are models of complex realities, (b) they show structural and behavioral complexity, revealing linear and non-linear interactions as well as emergent effects, (c) they are open and interact with their environment, and (d) their patterns are self-organized, meaning that system patterns occur without explicitly striving for a target state. Exemplar systems thinking materials with a STEM focus are limited, particularly at the tertiary level. Moreover, the Science education community has yet to agree on a definition of systems thinking or develop a comprehensive list of systems thinking skills that students should develop. Thus, a current priority for the advancement of systems thinking in chemistry education is the development of resources for instructors and students alike (York, S., & Orgill, M., 2020). Crucially, systems thinking in sustainability entails bridging scientific and social perspectives (Onat, N. C., Kucukvar, M., Halog, A., & Cloutier, S. 2017). Researchers note that students must learn to see natural and social phenomena as interconnected Wong, S. L., Hodson, D., Kwan, J., & Yung, B. H. W. (2008). (Schuler et al. 2018) observe that systems thinking helps students grasp "the complexity and dynamics of natural, social and economic systems" (p. 192).

#### ➢ *Bloom's Taxonomy Theory*

Darwazeh, A. (2017) based on psychology, current learning theories, and research studies conducted over time, it can be said with confidence that a human being's mind applies different mental processes while she or he manipulates, interprets, stores, and retrieves information

(Gagne, 1977; Guilford, 1959; Lindsay & Norman, 1977; Piaget, 1952; Rothkoph, 1966; Rumel hart, 1980; Wittrock, 1974a, 1974b). Accordingly, several instructional psychologists have utilized the results Darwazeh, A. (2017). of cognitive research and applied their principles into fields of education (Bloom, Engel hart, Furst, Hill, & Krathwohl, 1956; Guilford, 1959; Gagne, 1977; Gagne, Briggs, & Wager, 1992; Gagne & Driscoll, 1988; Merrill, 1983; West, Farmer, & Wolff, 1991). Instructional psychologists have aimed to help teachers, trainers, and curriculum developers design instruction that helps students store, retrieve, and use the intended material effectively (Darwazeh, A., 2017). The aforementioned educators believed that presenting knowledge in a sequence consistent with how human memory functions will help students store, retrieve, recall, and use information effectively; otherwise, the entire learning process will be hindered. Bloom et al. (1964) and Darwazeh (2017) classified forms and levels of learning based on the cognitive processes learners engage in during knowledge construction. These forms and levels are: 1. Knowledge: Exhibits memory of previously learned materials by recalling facts, terms, basic concepts, abstractions, generalities, and so forth. 2. Comprehension: Demonstrates understanding of facts and ideas by giving the meaning, translating, interpreting, explaining, and describing the main ideas, and so forth. 3. Application: Uses acquired knowledge in new or novel situations to solve problems. 4. Analysis: Examines and breaks information and materials into parts to see the details and relationships. (see Fig. 2)

- *Green Chemistry Theory:*

Green chemistry refers to the design and application of practices that prevent pollution and promote environmental sustainability. Anastas, P. T., & Warner, J. C. (2000). A set of 12 principles forms the core of the green chemistry philosophy and has provided the basis for the development of education for sustainable development programs. (The twelve principles of green chemistry are designed to promote environmentally friendly practices in chemical processes. They include:Prevention: Minimize waste, Atom Economy: Maximize the incorporation of all materials used in the process into the final product, Less Hazardous Chemical Synthesis: Use and generate substances that possess little or no toxicity to human health and the environment, Designing Safer Chemicals: Design chemical products to preserve efficacy while reducing toxicity, Safer Solvents and Auxiliaries: Minimize the use of auxiliary substances, Energy Efficiency: Minimize energy requirements and use renewable energy sources, Renewable Feedstocks: Use renewable raw materials whenever possible, Reduce Derivatives: Minimize the use of blocking or protecting groups, Catalysis: Use catalytic reagents to improve efficiency, Design for Degradation: Design chemical products to break down into innocuous degradation products, Real-time Analysis for Pollution Prevention: Develop analytical methodologies to allow for real-time monitoring and control, Inherently Safer Chemistry for Accident Prevention: Design chemicals and their forms to minimize the potential for chemical accidents. Since their emergence, these principles have been widely implemented in tertiary chemical education. As an interdisciplinary science, Clark, J., Jones, L., & Summerton, L. (2015), green chemistry aims to secure a sustainable future, Matlack, A. (1999), and to promote Collaboration between life scientists and social scientists to develop and implement practical solutions, Anastas, P. T., & Zimmerman, J. B. (2018). This has led to the development of a multitude of teaching materials aimed at promoting students' competence in systems thinking and societal decision-making within the framework of sustainability (Koulougliotis, D., Paschalidou, K., & Salta, K., 2024).

A main objective of green chemistry education (GCE) is to foster and improve scientific literacy in sustainability and to develop the corresponding skills among present and future generations (Cann, M. C., 2009). However, 25 years after the interdisciplinary emergence, green chemistry practices are possibly more incremental than transformative if the XII Principles [Anastas, P. T., & Warner, J. C. (2000)] are not considered to be a uniform system establishing the "hows" and "whys" of these practices Marcelino, L., Sjöström, J., & Marques, C. A. (2019). According to Anastas, sustainability has been little incorporated into the curricula and education of green chemists and engineers (Anastas, P. T., 2009). In addition to reducing waste and hazards, GCE could also address the wider societal impact of responsible technology innovation (Von Schomberg, R., 2013). This calls for the active search for different solutions to societal challenges Stilgoe, J., Owen, R., & Macnaghten, P. (2013) and incorporation of additional humanistic principles such as a fair and equitable distribution of benefits based on at least one of the Sustainable Development Goals (SDGs), Asveld, L. (2019) to ensure sustainability in the broadest sense.

- *Interdisciplinary Education Theory*

According to Rhoten et al. (2006) and Newell Klein, J. T., and Newell, W. H. (1997), interdisciplinary education is understood as a mode of curriculum design and instruction in which teachers integrate information and theories from various disciplines to foster and improve students' capacity to create new solutions and approaches to existing problems. Unfortunately, to date, little attention has been paid to integrative teaching methods promoting sustainability education (SE) in higher education ((Coops, N. C., Marcus, J., Construt, I., Frank, E., Kellett, R., Mazzi, E., ... & Sipos, Y. (2015)., Bourn, D., Hunt, F., & Bamber, P. (2017)).

Science and technology alone cannot solve our food, energy, environmental, and health problems. Meeting goals in these areas requires interdisciplinary Science. Tripp and Shortlidge (2019) define the concept 'interdisciplinary Science' as the collaborative process of integrating knowledge/expertise from trained individuals across two or more disciplines, leveraging various perspectives, approaches, and research methods to advance beyond the scope of any one discipline. The term "interdisciplinary" first surfaced in the early 20th century, when the Social Science Research Council used it as bureaucratic shorthand for promoting research that involves more than one discipline (Frank, 1988). Around the same time, increased interest in the meaning of *integration* at the postsecondary level surfaced, with an emphasis on developing the "whole" person through the general education movement (Klein, 2005). Through the publication of a book called *Integration: Its Meaning and Application* (Hopkins, 1937), ideas of unity emerged but were quickly stifled, as participants in a meeting held by the National Education Association concluded that complete unity was impossible (Klein, 2005), clarifying that deeper knowledge in the disciplines was more important. This advocacy for disciplines dates back to Aristotle's influence in 387 BCE, when the classical division of knowledge was enacted based on a hierarchy of disciplines, with philosophy at the top, physical and natural sciences following, and all other disciplines ranked by importance in a stepwise manner toward the bottom (Moran, 2002).

The pursuit of a sustainable society and civilization is a challenge recognized by our generation and will, by definition, need to be met by all generations into the future. These challenges are at the center of the UN Sustainable Development Goals. According to Brundtland, G. H., & Khalid, M. (1987), "Environment" is where we all live, and "development" is what we all do in attempting to improve our lot within that abode. The two are inseparable.… Humanity can make development sustainable: to ensure that it meets the needs of the present without (Brundtland, G. H., & Khalid, M. (1987)) compromising the ability of future generations to meet their own needs. It is difficult, if not impossible, to imagine a scenario where the goal of sustainability can be attained unless the fundamental chemistry that comprises the material and energy basis of our society and economy is transformed to be healthful rather than toxic, renewable rather than depleting, and restoring rather than degrading Anastas, P. T. (2003).

Green Chemistry has, from the outset, been known as "the chemistry of sustainability" (Beach, E. S., Cui, Z., & Anastas, P. T., 2009; Cann, M. C., 2009). However, it is equally true that green chemistry alone, no matter how fundamental and broad in its reach and impact, is not sufficient to achieve a sustainable civilization. There is a need for an interdisciplinary approach, and in this case, an Art-Chemistry Collaboration is ideal. Going one step further, Boix Mansilla (2000) elaborates interdisciplinary Understanding as "the capacity to integrate knowledge and modes of thinking in two or more disciplines to produce a cognitive advancement – e.g., explaining a phenomenon, solving a problem, creating a product, raising a new question – in ways that would have been unlikely through single disciplinary means. … the integration of disciplinary perspectives is a means to a purpose, not an end in itself" Rhoten, D., Boix Mansilla, V., Chun, M., & Klein, J. T. (2006).

- *Theoretical Synthesis*

A powerful synthesis emerges when UNESCO. (2017) Systems thinking, Bloom's taxonomy, green chemistry, and interdisciplinary education are integrated: they collectively foster holistic problem-solving, scaffolded learning, sustainability awareness, and cross-disciplinary collaboration—preparing students to tackle complex global challenges. These issues cannot be fully understood through linear reasoning or isolated disciplinary perspectives (Griggs et al., 2017). Education for Sustainable Development (ESD), therefore, demands pedagogical approaches that help learners perceive patterns, relationships, and feedback loops across ecological, technological, economic, and social dimensions (Peretz, R., 2025). Research synthesis is a broad term encompassing various approaches to combining, integrating, and synthesizing research findings. A theoretical synthesis of how systems thinking, Bloom's taxonomy, green chemistry, and interdisciplinary education can converge in an art–chemistry Collaboration: In an art–chemistry Collaboration, systems thinking frames both disciplines as interconnected parts of ecological and cultural networks, where materials, reactions, symbolism, and narratives converge to address sustainability. Bloom's taxonomy provides a scaffold for learning, guiding students from recalling chemical and artistic foundations to creating interdisciplinary works that embody sustainable chemistry and cultural meaning. By integrating sustainability into the design process, practitioners can achieve more than environmental benefits; they can also realize significant economic advantages by influencing capital costs and enhancing the perceived value of completed projects (Tang, 2023). Equally important is the role of Creativity in education. According to Martin (2025), fostering creative design capabilities is vital to achieving sustainable development goals, particularly among young learners. Newcomb (2017) posits that by encouraging interdisciplinary integration, experimentation, and creative problem-solving, educators can equip future generations to engage with real-world environmental challenges in innovative ways.

Green chemistry serves as the ethical grounding, encouraging the use of eco-friendly dyes, biodegradable resins, and non-toxic binders, thereby making material choices both scientific and moral decisions. Interdisciplinary education bridges the two fields, combining chemistry's material Science with art's symbolic expression, enabling learners to develop technical competence alongside creative storytelling, according to Frodeman, R., Klein, J. T., & Pacheco, R. C. D. S. (Eds.). (2017), Understanding how to teach issues in an interdisciplinary curriculum is one of the key factors of interdisciplinary learning. Due to the nature of unsustainability problems, interdisciplinary learning on this topic often requires Collaboration. Interdisciplinary green chemistry learning can be developed by exploring how cognitive, social, and emotional factors interact to promote Understanding of issues and problems. Interdisciplinary learning often also requires group experiences, whereby key elements of the development of thinking skills include reflection on the problems, the comparison of information from different disciplines, the promotion of the leverage effect of integration, and the willingness to critically evaluate Chen, M., Jeronen, E., & Wang, A. (2020). Together, these theories cultivate students who can design artworks—such as murals or sculptures from recycled polymers—that simultaneously demonstrate chemical sustainability and communicate powerful cultural narratives about environmental responsibility.

- *The Synthesis Matrix Interpretation.*

The synthesis matrix highlights how each framework contributes a distinct but complementary role in an art–

chemistry Collaboration. Systems thinking emphasizes the interconnectedness of chemical processes, ecological impacts, and artistic narratives, ensuring that projects are viewed holistically. Bloom’s taxonomy provides a scaffold for cognitive growth, moving learners from recalling foundational knowledge to creating interdisciplinary artworks that embody sustainability. Green chemistry serves as the ethical anchor, guiding material choices toward eco-friendly, safe, and renewable options that shape both scientific practice and artistic meaning. Finally, interdisciplinary education bridges the two domains, merging chemistry’s material science with art’s symbolic expression to cultivate learners who are technically competent and creatively expressive. Interpreted together, the matrix shows that these frameworks do not operate in isolation but form a synergistic model where scientific rigor, ethical responsibility, cognitive progression, and cultural creativity converge to produce sustainable, meaningful art–chemistry collaborations.

This synthesis positions art–chemistry collaboration as a transformative educational model: Systems thinking ensures holistic awareness, Bloom’s taxonomy structures cognitive progression, Green chemistry grounds the Collaboration in sustainability, and Interdisciplinary education empowers students to merge technical rigor with cultural Creativity. The result is learners who are both scientists and artists, capable of designing sustainable materials while expressing ecological narratives.

## III. METHODS AND MATERIALS

The study adopts a qualitative approach, observing participants as they carry out practical experiments in ceramics (glass recycling for glaze, firing, and glazing), a plastic paver-making project, aluminum recycling and casting, and polyethylene recycling projects. Kabale Regional Museum was visited for a scientific comparative study. A studio-based experimental approach was employed in combination with a conceptual inquiry into Collaboration. For environmental sustainability, three (3) photographs on environmental issues were presented to students to stimulate their thinking, which was well thought out. Observation checklists for the Teacher participants were developed together with discussion rubrics. Purposively a focused group of students who offered art and chemistry subjects was constituted. The research process involved the creation of finished experimental works encompassing ceramics, plastic pavers, a volleyball net, and an aluminum hummer. The materials explored include broken glass, plastic, polythene, and aluminum scrap. Through iterative experimentation and documentation, the study analyzed how these materials could, visually and conceptually, instigate a need for a Collaboration spillage that is interdisciplinary and pedagogical. Data were primarily generated from practice-led observations and visual analysis of the produced works. Strategic photographs and video recording were managed for future study(s)

### *A. The Results*

The results of an Art–Chemistry / Chemistry–Art Collaboration in Ugandan secondary schools focus on Creativity and engagement: Heightened Creativity. Students learn to represent chemical ideas through drawings, models, and symbolic art, encouraging imaginative approaches to problem-solving beyond rote memorization. There is Increased Engagement evident in Lessons becoming interactive and visually stimulating, reducing boredom, and Students connect chemistry to everyday life and cultural art forms, making it more relatable. Figures (3, 4, 7, and 8) are testament to this fact. More so is Improved Understanding, as a result of Visual and tactile experiences that help clarify abstract concepts (e.g., molecular structures, chemical reactions), and of Art providing alternative entry points for learners who struggle with purely theoretical explanations. Cross-disciplinary Skills, for instance, Collaboration that fosters teamwork between Science and art departments, and, importantly, Students develop communication, design thinking, and innovation skills useful in broader contexts.

In short, Collaboration between art and chemistry can transform classrooms into spaces of exploration and innovation. However, it requires careful planning, resources, and evaluation tools to balance Creativity with academic rigor. Hughes, J. M., & Morrison, L. J. (2020, July) posit that, however, reconfiguring one's classroom into a “makerspace” is one potential solution to this tension. A makerspace is a place where people come together to make things, build, hack, remix, take apart, and rebuild. Importantly, it is a community of people who learn through exploration, Collaboration, problem-solving, and Creativity and innovation. For this very reason, a few integrated chemistry topics and art projects have been carefully reviewed to provide a solid foundation for the art-chemistry/chemistry-art Collaboration. The selected chemistry topics include: Atomic and electronic structure, Bonding and structure, Thermochemistry and Electrochemistry, whereas art projects are: ceramics making, plastic paver project, aluminum melting and casting, and blacksmithing technologies. Integrating art and chemistry in secondary schools enriches learning by making abstract scientific concepts more tangible, fostering Creativity, and equipping students with problem-solving and Collaboration skills that are vital for real-world challenges. This interdisciplinary approach helps students connect Science to culture, heritage, and everyday life, making education more holistic and engaging. Ngendabanga, C., Nkurunziza, J. B., & Mugabo, L. R. (2025).

According to Chastrette, M., & Rao, C. N. R. (1992), a general trend in both developing and developed countries is to make chemistry courses more relevant to citizens' needs and to the country. Students become more enthusiastic about learning chemistry when they are aware of its importance to their own goals and interests (Brown, T. L., 2009). Consequently, they can easily develop an Understanding of fundamental concepts of chemistry. One way to achieve the latter is the use of art in teaching chemistry. According to Moore, J. W. (2001), students can develop a more complete Understanding of Science if it is taught artistically, imaginatively, objectively, and precisely to capture their imaginations, emotions, and best efforts.

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Thermochemistry is simpler than before, as students engaged in ceramics making, especially during the firing and glazing processes. By participating in the activities in Figs. 3 and 4, students are proactively involved, and, according to Bloom's Taxonomy (Fig. 2), higher-order thinking skills are achieved through critical analysis based on direct observation.

According to Jonathan Andersson, the artist, the blue color comes from cobalt salts and the yellow from silver. These are added to the glass, and it is formed at high temperature in a sand mold. Firing to exactly the correct temperature and for exactly the correct time is necessary to achieve beautiful results. The process brings to mind the synthesis of a high-temperature superconductor, annealing of a shape-memory alloy, and many other scientific/technological procedures. It requires the artist the same attention to detail, observation, creativity, and record-keeping as would be required in a laboratory. Additional requirements are imagination, critical judgment, and an aesthetic sensibility—characteristics that are also useful in doing good Science, Young, Jay A. J. Chem. Educ. 1981, 58, 329–330. Both primary and secondary research have revealed that Art-Chemistry Collaboration is capable of;

- *Enhancing Understanding of Abstract Concepts*

Visual arts can illustrate molecular structures, chemical reactions, and processes in ways that are easier to grasp than text or formulas alone. Students gain deeper comprehension by drawing, modeling, or dramatizing chemical phenomena. For example, electrochemistry intersects with art in two primary ways: as a creative tool for artists to produce and manipulate materials, and as a scientific method for conservators to analyze, restore, and preserve artworks. Creative applications in art, Artists use electrochemical processes to create sculptures, jewelry, and prints with unique textures and effects. Electroforming and electrotyping: These processes use an electrical current to deposit a thick layer of metal, typically copper, onto a conductive surface.

- *Promoting Creativity and Innovation*

Encourages students to think outside the box and approach scientific problems with imaginative solutions. Builds design-thinking skills useful in engineering, product development, and sustainability. Ceramics, sculpture (metal or plastic casting techniques), artistic installations, or eco-art relate to Thermochemistry and show how Science drives creative industries. Thermochemistry, the study of heat energy associated with chemical reactions and phase changes, correlates with art in both traditional and contemporary methods. Heat is a medium that artists use to physically transform and manipulate materials, creating a wide range of aesthetic effects, from the subtle patinas of sculpture to dynamic, color-shifting paintings.

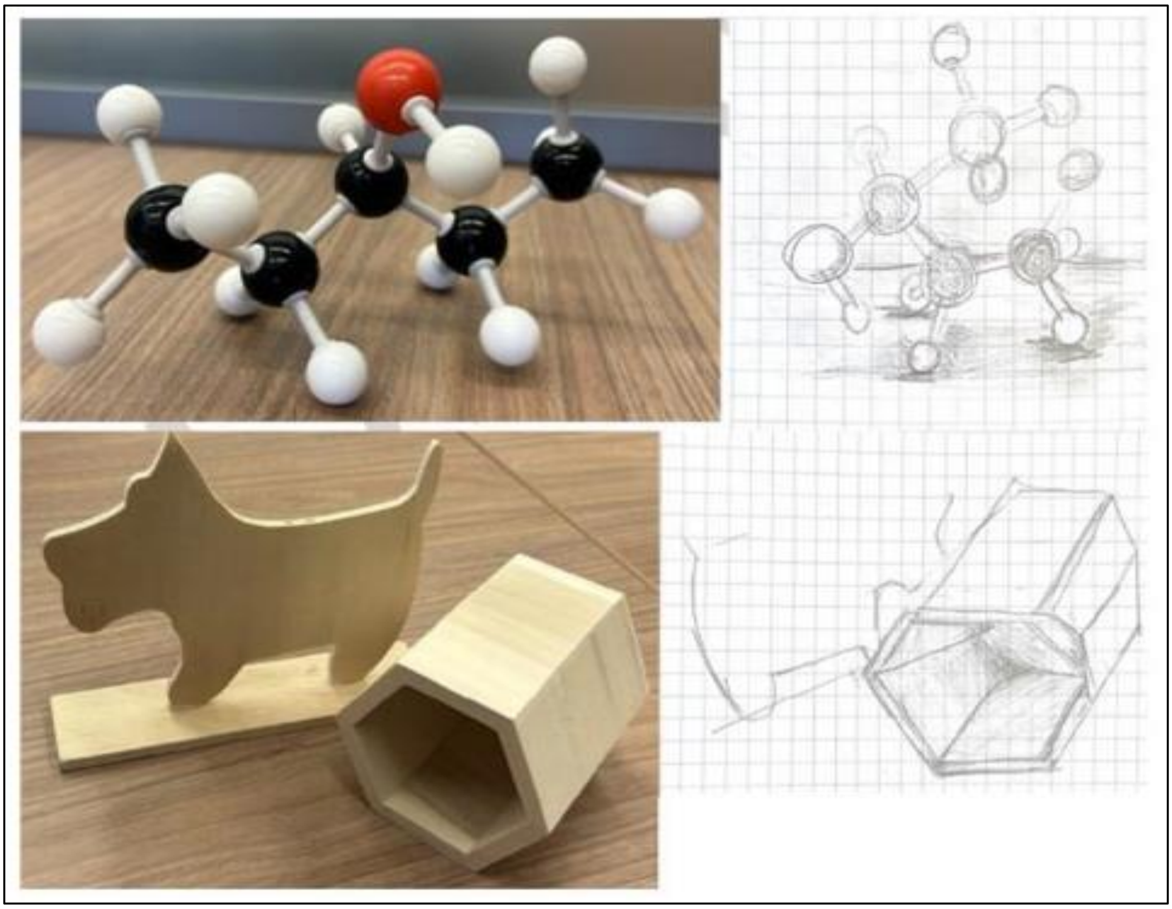

Fig 1 Still-Life Drawing Activities Using a Physical Molecular Model (Top) and Generic Objects (Bottom).
Source: Visual Skills in the Arts and their Potential in Chemistry

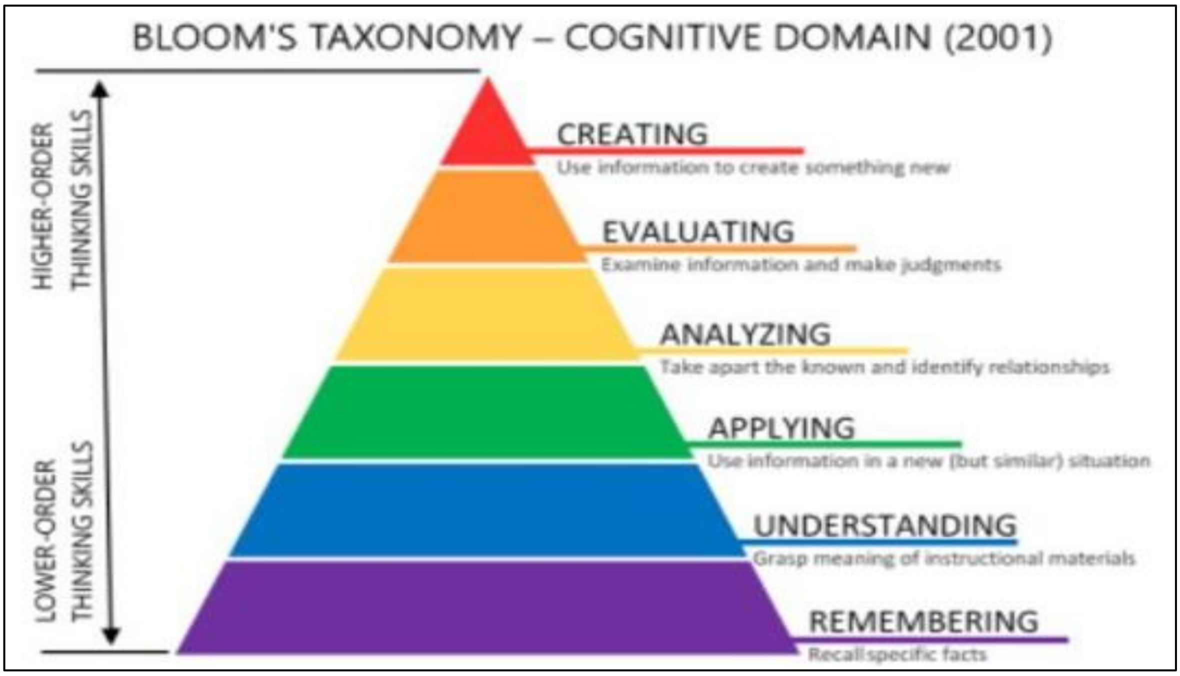

Fig 2 Bloom's Taxonomy-Cognitive Domain
Source: https://citt.it.ufl.edu/media/cittitufledu/images/Blooms-Taxonomy.png

Fig 3 (1,2,3,4): Immaculate Heart Girls School Rukungiri Students of Art-Chemistry During a

Fig 4 (1,2,3,4): Immaculate Heart Girls School Rukungiri Students of Art-Chemistry During a

- *Preservation and Restoration*

Art conservation relies heavily on organic chemistry to understand and reverse the effects of degradation.

- Controlling deterioration: A work of art is a dynamic chemical object that changes over time. Organic materials, such as the natural resins and oils in old paints, are especially vulnerable to decay. Conservators study these chemical changes to determine the best preservation strategies.
- Cleaning techniques: Art restorers use organic solvents to remove old, yellowed varnish layers without damaging the underlying paint. Modern techniques use responsive gels and microemulsions that can be precisely controlled to target specific layers, minimizing risk to the artwork.
- Creating new materials: Chemists develop synthetic resins for modern conservation. These materials are often more stable, more soluble, and less harsh than traditional ones, making them easier to remove during future restorations.
- Chemical analysis: Techniques such as gas chromatography–mass spectrometry (GC-MS) are used to analyze small samples of art to identify the organic materials the artist used. This helps authenticate and understand historical works.
- Bio-inspiration and emerging art forms; Artists and chemists are increasingly collaborating to create new materials and techniques inspired by organic chemistry and biology. Bio-inspired materials are synthetic materials that replicate the properties of natural systems, such as the optical qualities of seashells or the self-healing properties of some organic structures. New artistic techniques draw from natural organic processes.

Examples include creating pigments from foraged plants or charcoal, or using plant-based media like soymilk.

- Chemical art: Some artists have begun using chemical reactions as a creative medium, incorporating processes such as precipitation, separation, and burning into their work.

Fig 5 (1,2,3,4): Immaculate Heart Girls School Rukungiri Students of Art-Chemistry during a Aluminium Melting and Casting Project. Photo by the School Camera Officer.

Fig 6 (1,2,3): Conventional African vs Modern Blacksmith Technologies. Photo @Mmmoses

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Fig 7 The Starry Night by Van Gogh Post Impressionist Painter

Fig 8 (1,2,3,4) Immaculate Heart Girls School Rukungiri Students of Art-Chemistry during a Polythen Recycling Project. Photo by the School Camera officer.

The ancient art of bronze casting relies fundamentally on thermochemical processes. Artists melt bronze ingots at extremely high temperatures (around 900–1,000°C) and pour the molten metal into a ceramic mold. Enthalpy of fusion: The energy absorbed by the bronze as it transitions from a solid to a liquid is a direct application of thermochemistry. Solidification and texture: As the molten metal cools and solidifies, it expands slightly to fill every detail of the mold before contracting. Artists must understand the thermal properties of the metal and mold to avoid cracks and achieve the desired finish—ceramic firing and glazing. The creation of ceramics involves a high-temperature firing process that causes profound thermochemical changes in the clay and glazes. Phase changes: The immense heat in a kiln induces permanent chemical changes, vitrifying the clay into a durable ceramic object. Glaze chemistry: Artists use glazes, which are powdered minerals that melt during firing. The thermochemical reactions of the oxides, silicates, and other compounds in the glaze determine its final color, texture, and opacity. Encaustic painting is an ancient technique that uses heated beeswax combined with colored pigments. The artist applies the molten mixture to a surface, where it cools and solidifies, creating a durable, luminous paint layer. The entire process relies on the thermodynamics of wax melting and cooling. Kinetic art: Artists incorporate these paints into murals, fabrics, and objects that change appearance when touched or exposed to heat sources such as sunlight. A viewer's touch or breath can temporarily transform the artwork, adding a kinetic, personal dimension to the piece.

### ➢ *Holistic Education*

Integrating art into Science fosters critical thinking, communication, and collaboration—skills often missing in traditional STEM teaching (Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J. M., Morisseau, T., Bourgeois-Bougrine, S., ... & Lubart, T., 2023). Students learn to balance precision with expression, preparing them for diverse careers in Science, technology, and creative fields. For instance, in Atomic and electronic structure, according to Reyes, R. L., & Villanueva, J. A. (2024), the correlation enables learners to grasp complex concepts through narratives and translate them into mental imagery, which opens new pathways to comprehend chemical principles, fostering higher-order cognitive functions and nurturing logical and creative information processing (Namukasa, S., 2024). Artists are inspired by the unseen structures of matter and use artistic forms to interpret and explore fundamental scientific concepts, for instance, (Fig. 7) The Starry Night by Van Gogh. Gamwell, L. (2020) posits that in many ways, science and art are profoundly similar. The best of each rises from the depths of human Creativity, nurtured by an individual’s commitment and passion to the discipline. The visualization of atomic and electronic structures offers artists a rich source of geometric and abstract imagery. This embodiment empowers the critical-thinking skill, which spills over into Creativity. In the projects they carry out, Chemists must use their spatial Understanding to visualize 3-D structures and processes from 2-D representations. At the core of learners’ mental modeling is imagistic reasoning. This refers specifically to the process of spatial visualization, which involves generating and manipulating perceived analog image-like mental representations and perspective taking for spatial thinking; its role is considered intrinsic to STEM problem solving (Kiernan, N. A., Manches, A., & Seery, M. K., 2024)

- Models of the Atom: Early models, like the Bohr model, with electrons orbiting a central nucleus, have inspired simplistic yet iconic imagery, though scientists know the actual structure is more complex. The plum pudding model is an obsolete scientific model of the atom. It was first proposed by J. J. Thomson in 1904 following his discovery of the electron in 1897, and was rendered obsolete by Ernest Rutherford's discovery of the atomic nucleus in 1911. Thomson, J. J. (1904). XXIV. Other artists use digital graphics to create more scientifically accurate, non-pictorial interpretations of quantum physics. (Cooper, 2020; Rivet *et al.*, 2016)) informs that Educators are urged to question (1) what do we really want students to know from a course/program (core ideas), (2) what do we want students to do with that knowledge (scientific practices), and (3) what productive lenses or tools can be used to explore phenomenon within and across disciplines (crosscutting concepts Underwood, S. M., Kararo, A. T., & Gadia, G. (2021). The above questions point to the 4 generic skills that can be effectively developed through Collaboration.
- Molecular Structures: Molecular structure, which refers to the three-dimensional arrangement of atoms and chemical bonds within a molecule, defining its shape, connectivity, and physical properties, is key in art production. The intricate, three-dimensional shapes of molecular bonds and crystalline lattices provide beautiful and complex visual motifs for artists (Fig. 1) of still-life drawing activities is a good example). These can be represented through various media, from physical sculptures to computer-generated animations. Sculptor Rebecca Kamen, for example, creates abstract sculptures of elements using materials such as mylar and fiberglass rods, with complexity reflecting the atomic number.
- Atomic Theory and Composition: atomic theory, ancient philosophical speculation that all things can be accounted for by innumerable combinations of hard, small, indivisible particles (called atoms) of various sizes but of the same basic material; or the modern scientific theory of matter according to which the chemical elements that combine to form the great variety of substances consist themselves of aggregations of similar subunits (atoms) possessing nuclear and electron substructure characteristic of each element Encyclopedia Britannica, Inc. Artists have explored the idea that all matter is composed of atoms. Some have even created microscopic works of art by manipulating individual iron and copper atoms, highlighting the fundamental building blocks of reality. Quantum mechanics: In the late seventeenth century, Isaac Newton discovered classical mechanics, the laws of motion of macroscopic objects. In the early twentieth century, physicists found that classical mechanics does not accurately describe the behavior of very small particles, such as electrons and atomic nuclei. A set of laws describes the behavior of such particles: quantum mechanics (Lashkaripour, A., 2021). The non-

intuitive, mathematical nature of quantum mechanics has inspired artists to make these concepts more accessible and comprehensible to the public. The dual wave-particle nature of electrons can be explored through light, sound, and interactive installations. In 1905, Einstein extended Planck’s hypothesis to explain the photoelectric effect, which is the emission of electrons by a metal surface when it is irradiated by light or more energetic photons. The kinetic energy of the emitted electrons depends on the frequency ν of the radiation, not on its intensity; for a given metal, there is a threshold frequency ν0 below which no electrons are emitted. Furthermore, emission occurs as soon as light shines on the surface; there is no detectable delay.

- *Cultural and Heritage Connections*

Chemistry-art projects can highlight local heritage practices (e.g., traditional dyeing, pottery, metallurgy). This strengthens students’ sense of identity while linking science to community-based knowledge systems. In Uganda, such integration can empower students to see chemistry not as abstract but as embedded in cultural preservation and innovation. See figure 6(1), a scientific blacksmithing technology from Kabale Regional Museum. It fully demonstrates the cultural preservation that meets scientific innovation in both Fig. 6(2 & 3).

- *Improved Engagement and Motivation*

Students often find Science chemistry in particular intimidating; art makes it accessible and enjoyable. Collaborative projects (murals, exhibitions, science-art fairs) build school pride and teamwork. This approach reduces dropout rates in STEM by making Science welcoming and inclusive. Students relate to the environment as they carry out chemistry-linked artistic projects. As a result, they become so motivated that their passion and love for Science grow even further. The art of ceramics-making simplifies complex chemical concepts such as matter, gases, salts, and bases.

- *Chemical Processes in Art Media*

The very materials artists use are created through chemical bonds and structures. The production of artistic media is an act of applied chemistry. Pigment and dyes: The colors in paints and inks are derived from chemical compounds. For millennia, artists have relied on chemical bonding to create and modify pigments. For example, Egyptian blue is a pigment made from a calcium-copper silicate glass, and Prussian blue was one of the first modern synthetic pigments. Photography: Early photography depended entirely on chemical processes to create images. The magic of an image appearing in a darkroom involved chemical reactions with silver halides. Glass and ceramics: The firing of clay and glass involves chemical transformations that determine the material's final structure, color, and texture. Glazes, for example, are a chemical mixture that can produce a range of vibrant colors when heated. At the university level, art integration has led to courses for analytical chemistry students and art history students working on X-ray fluorescence of art pieces, similar to topics covered in the field of art conservation (Nivens, D. A., Padgett, C. W., Chase, J. M., Verges, K. J., & Jamieson, D. S., 2010). In university, there have also been projects that aim to incorporate the liberal arts into general chemistry to improve Science literacy (Miller, D. M., & Czegan, D. A. C., 2016).

- *Creating Visual Effects with Exothermic Reactions*

"Painting" with combustion Artists can use controlled exothermic reactions to create art. Instead of adding color, they use fire to burn or scorch materials such as wood or metal, creating marks and patterns. This technique uses the heat released by combustion to fundamentally alter the medium's surface, with the energy output directly shaping the final form. Chemists know that chemistry is the study of matter and how it changes. Artists use pigments, binders, media, solvents, brushes, and other things, and these are all examples of matter. Many of the pigments used by artists have color, and this color has a chemical and physical basis. There is interest within the college chemistry community in connecting the teaching of chemistry and art (Smieja, J. A., D’Ambruoso, G. D., & Richman, R. M., 2010; Francisco, N., Morais, C., Paiva, J. C., & Gameiro, P., 2017).

- *Rusting is a Slow Exothermic Process*

The rusting of iron is a slow, exothermic oxidation reaction. Artists intentionally use this process on steel sculptures to create a rich, rusty-red patina. The controlled corrosion is a thermochemically driven process that produces an aesthetically desirable and durable surface finish over time. Organic chemistry and art are deeply intertwined, with organic compounds playing a crucial role in creating, preserving, and restoring artworks. Beyond the practical applications, the principles of chemistry also provide a framework for artistic creation. Color and creation: At the most fundamental level, organic chemistry provides the molecules that give art its color (Bopegedera, A. M. R. P., 2005).

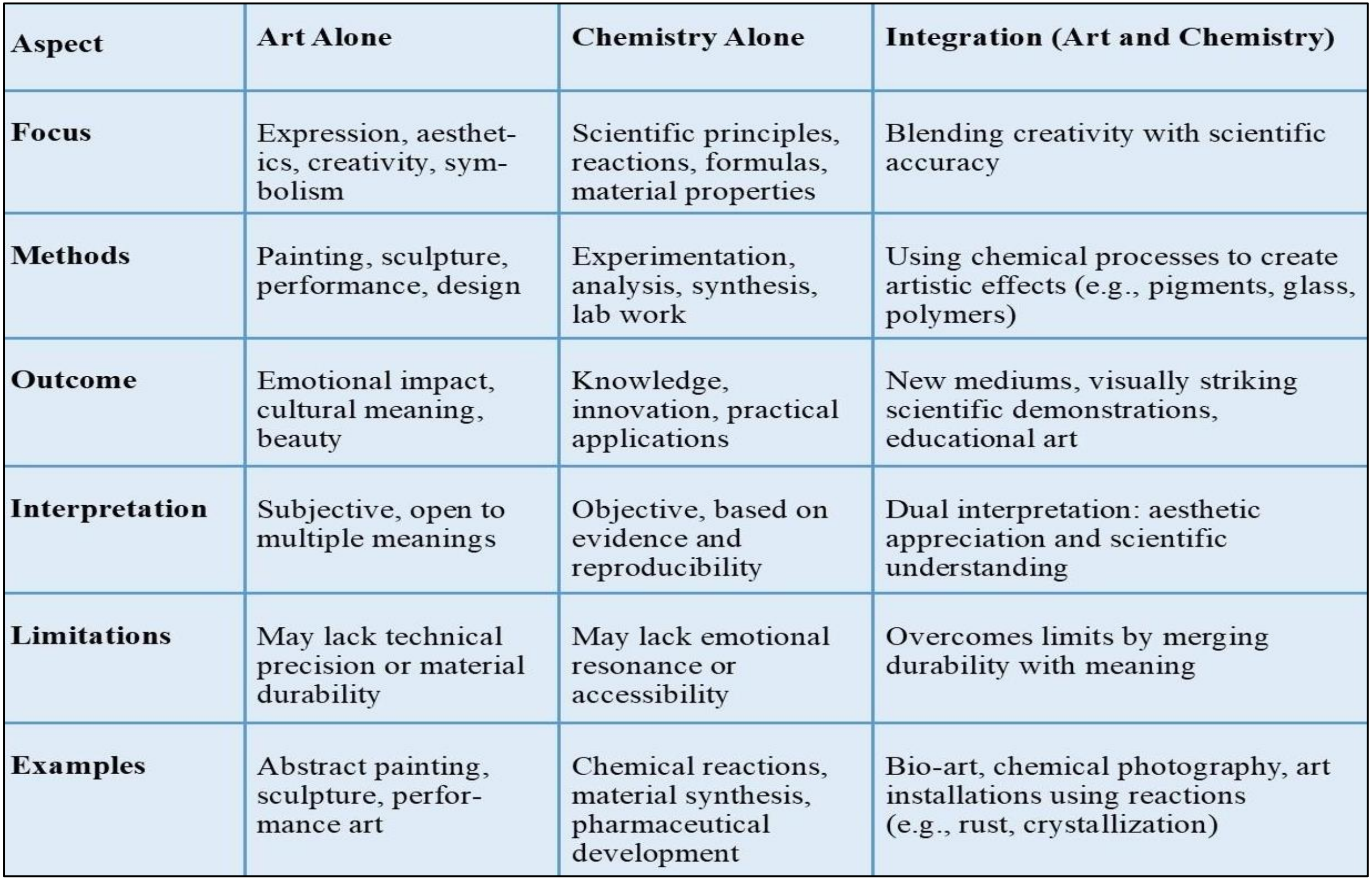
- Pigments and dyes: Many of the most brilliant and vivid colors used in painting are derived from organic compounds. Natural organic pigments: Historically, artists extracted pigments from organic sources. Examples include red cochineal from insects, Tyrian purple from mollusks, and indigo from the *Indigofera* plant. Synthetic organic pigments: Since the 19th century, organic synthesis has allowed chemists to create a vast array of new pigments with enhanced properties. Examples include the brilliant blue and green phthalocyanines, intense quinacridones (red, violet, and orange), and a wide variety of azo pigments for yellows and reds.
- Chemistry of materials: The malleability, color, and luster of metals like iron and copper, determined by their electronic structure, are exploited by artists for specific effects. Zhao et al. (2008, p. 681007-8) posit that scientific analysis of the painting (Fig. 7) has confirmed Van Gogh’s use of ultramarine and cobalt blue for the sky, with Indian yellow and zinc yellow for the stars and moon. Using multispectral imaging to retrieve the spectral reflectance factor of each pixel in a painting, the artist's palette was approximated with ten oil pigments, selected from a large database of pigments used in oil paintings

and from a priori analytical research on one of his self-portraits, executed during the same time period. The pigment mapping was based on a single-constant Kubelka-Munk theory. It was found that the region of blue sky where the stars were located contained predominantly ultramarine blue, while the swirling sky and the region surrounding the moon contained predominantly cobalt blue. Emerald green, used in light bluish-green brushstrokes surrounding the moon, was not used to create the dark green in the cypresses. A measurement of lead white from Georges Seurat's La Grande Jatte was used as the white when mapping The Starry Night. The absorption and scattering properties of this white were replaced with those of a modern dispersion of lead white in linseed oil, and it was used to simulate the painting's appearance before the natural darkening and yellowing of lead white oil paint. Zhao, Y., Berns, R. S., Taplin, L. A., & Coddington, J. (2008, February). The chemistry of pigments, solvents, and other materials is also crucial for conservation and restoration. Art of the Atomic Age: The nuclear age has a distinct artistic movement known as "Atomic Art" that explores themes of nuclear energy and weaponry. This includes paintings, photography, film, and literature that respond to the profound cultural impact of the atomic structure.

- ➢ *Bonding and Structure;*

Bonding and structure correlate with art through visual inspiration, the use of chemical processes in artistic media, and metaphor. At its heart, this connection highlights the common ground between the creativity of artistic expression and the underlying principles that govern the physical world. Artists draw directly from the microscopic world of chemistry, using it as a source of aesthetic inspiration. The intricate, three-dimensional shapes of proteins, DNA, and other biological molecules offer a rich visual vocabulary for art. The work of molecular biologist and artist David Goodsell, who creates vibrant watercolor paintings of cellular interiors, is a prime example of this fusion of science and art. The ordered, symmetrical arrangement of atoms in crystals provides a foundation for geometric art. Crystals, from the graphite in a pencil to precious gems, possess a regular, repeating pattern that can be translated into stunning geometric designs and sculptures. Students exposed to art-based chemistry activities have significantly higher mean scores on the chemistry concept Understanding test than the students exposed to non-art-based activities. Moreover, student creativity in chemistry was demonstrated by integrating art into chemistry teaching. This was confirmed by the students in their reactions, such as: “Art was integrated in each activity, making chemistry easier, and it brought out the Creativity in every one of us!” Chemistry and the arts have more to offer each other than men assumed. The potential integrations between the various arts-based fields and chemistry are largely unexplored and present an opportunity to improve education in both fields while creating more well-rounded students (Drescher, K. M., 2023). Table 1 below compares Art vs. Chemistry alone vs. Integration.

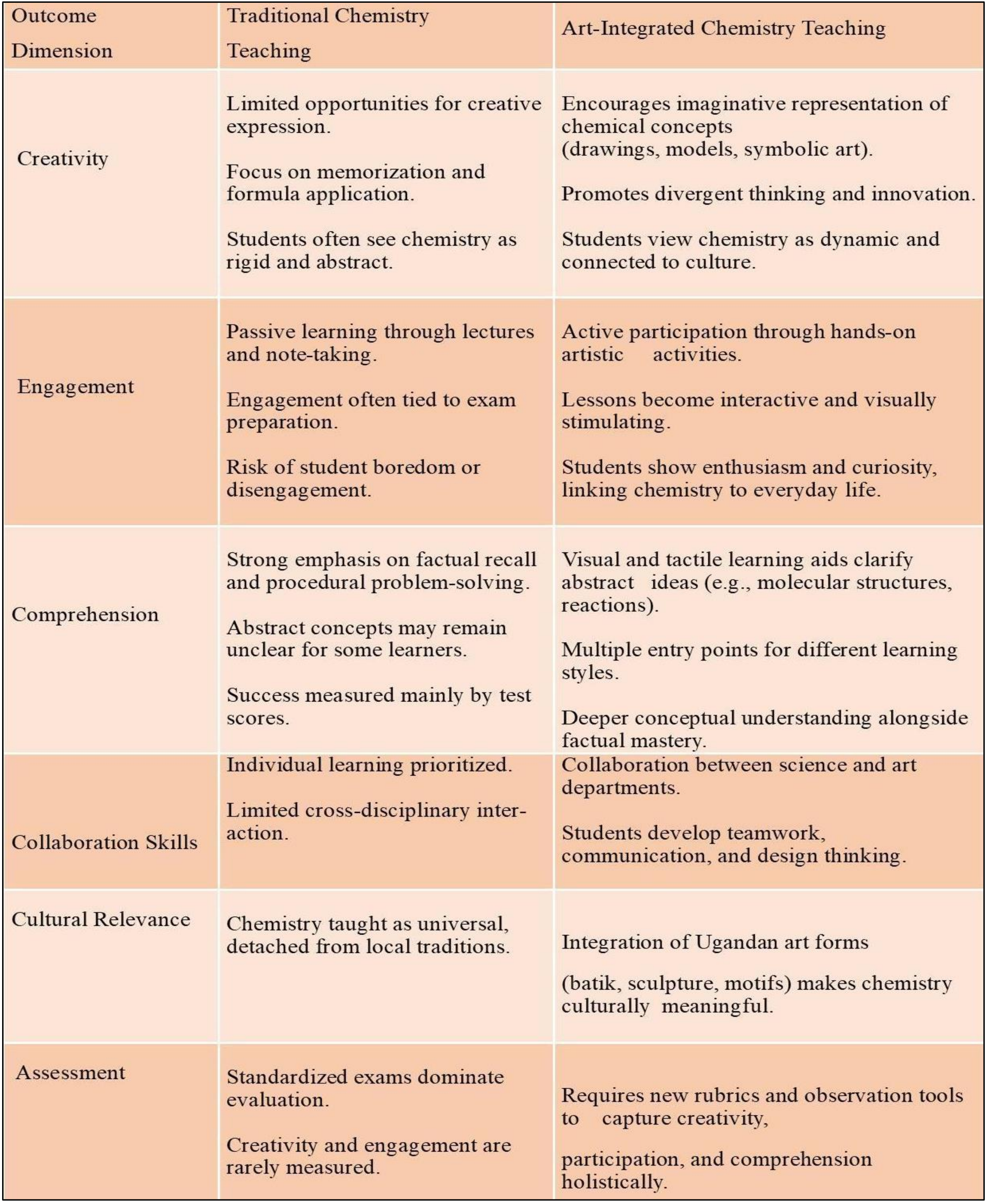
Table 1 Comparison Table: Art vs. Chemistry, Alone vs. Integration



| Aspect | Art Alone | Chemistry Alone | Integration (Art and Chemistry) |
|---|---|---|---|
| **Focus** | Expression, aesthetics, creativity, symbolism | Scientific principles, reactions, formulas, material properties | Blending creativity with scientific accuracy |
| **Methods** | Painting, sculpture, performance, design | Experimentation, analysis, synthesis, lab work | Using chemical processes to create artistic effects (e.g., pigments, glass, polymers) |
| **Outcome** | Emotional impact, cultural meaning, beauty | Knowledge, innovation, practical applications | New mediums, visually striking scientific demonstrations, educational art |
| **Interpretation** | Subjective, open to multiple meanings | Objective, based on evidence and reproducibility | Dual interpretation: aesthetic appreciation and scientific understanding |
| **Limitations** | May lack technical precision or material durability | May lack emotional resonance or accessibility | Overcomes limits by merging durability with meaning |
| **Examples** | Abstract painting, sculpture, performance art | Chemical reactions, material synthesis, pharmaceutical development | Bio-art, chemical photography, art installations using reactions (e.g., rust, crystallization) |

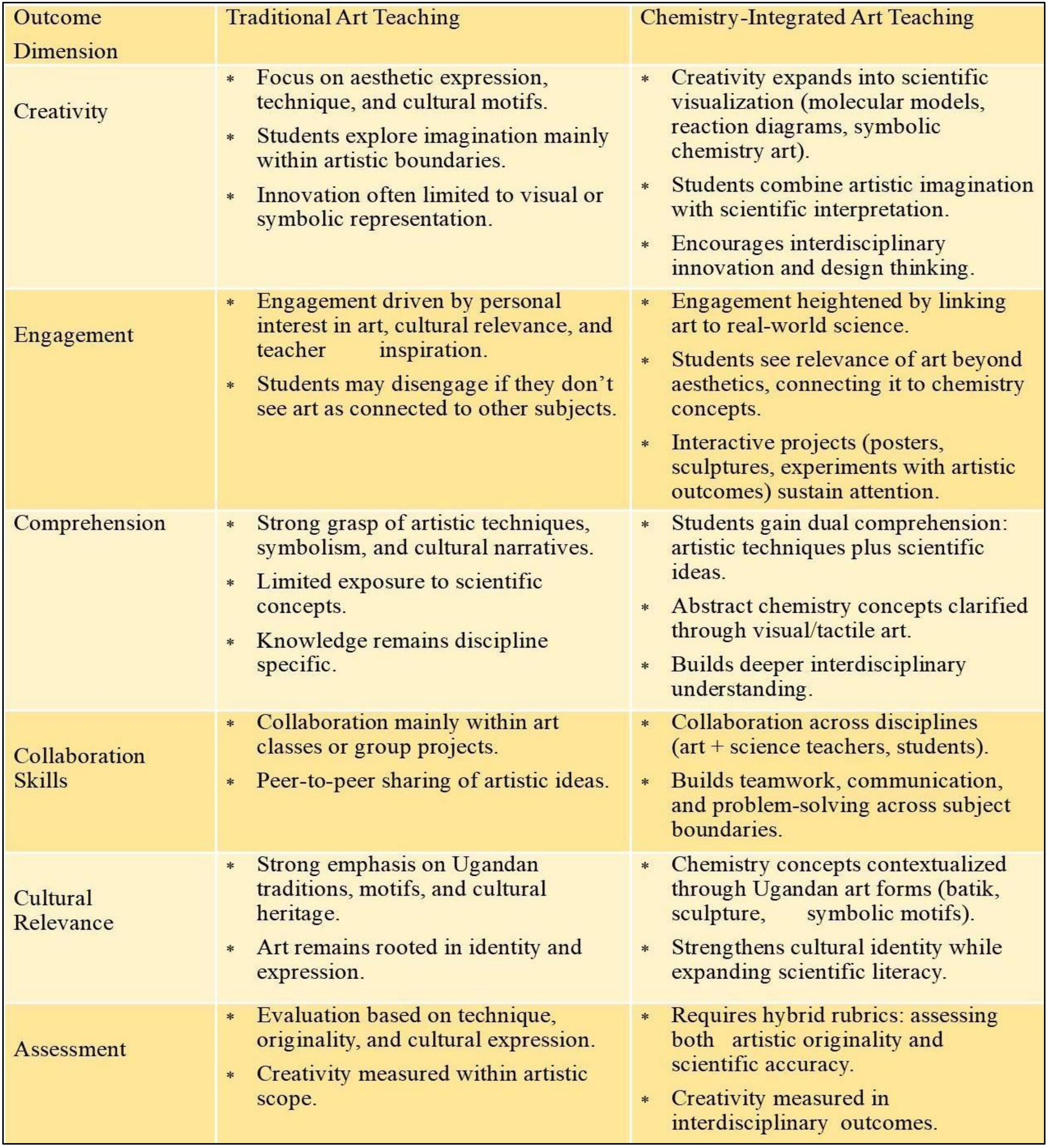
Scientific applications in art conservation and analysis, Conservators and art historians use electrochemical techniques to study and protect cultural heritage without causing damage.

Table 2 A Comparative Framework Showing how Student Outcomes Differ Between Traditional Chemistry Teaching and Art-Integrated Chemistry Teaching in Ugandan Secondary Schools



| Outcome Dimension | Traditional Chemistry Teaching | Art-Integrated Chemistry Teaching |
|---|---|---|
| Creativity | Limited opportunities for creative expression.<br>Focus on memorization and formula application.<br>Students often see chemistry as rigid and abstract. | Encourages imaginative representation of chemical concepts (drawings, models, symbolic art).<br>Promotes divergent thinking and innovation.<br>Students view chemistry as dynamic and connected to culture. |
| Engagement | Passive learning through lectures and note-taking.<br>Engagement often tied to exam preparation.<br>Risk of student boredom or disengagement. | Active participation through hands-on artistic activities.<br>Lessons become interactive and visually stimulating.<br>Students show enthusiasm and curiosity, linking chemistry to everyday life. |
| Comprehension | Strong emphasis on factual recall and procedural problem-solving.<br>Abstract concepts may remain unclear for some learners.<br>Success measured mainly by test scores. | Visual and tactile learning aids clarify abstract ideas (e.g., molecular structures, reactions).<br>Multiple entry points for different learning styles.<br>Deeper conceptual understanding alongside factual mastery. |
| Collaboration Skills | Individual learning prioritized.<br>Limited cross-disciplinary inter-action. | Collaboration between science and art departments.<br>Students develop teamwork, communication, and design thinking. |
| Cultural Relevance | Chemistry taught as universal, detached from local traditions. | Integration of Ugandan art forms<br>(batik, sculpture, motifs) makes chemistry culturally meaningful. |
| Assessment | Standardized exams dominate evaluation.<br>Creativity and engagement are rarely measured. | Requires new rubrics and observation tools to capture creativity,<br>participation, and comprehension holistically. |

Table 3 A Comparative Framework Showing how Student Outcomes Differ Between Traditional Art Teaching and Chemistry-Integrated Art Teaching in Ugandan Secondary Schools

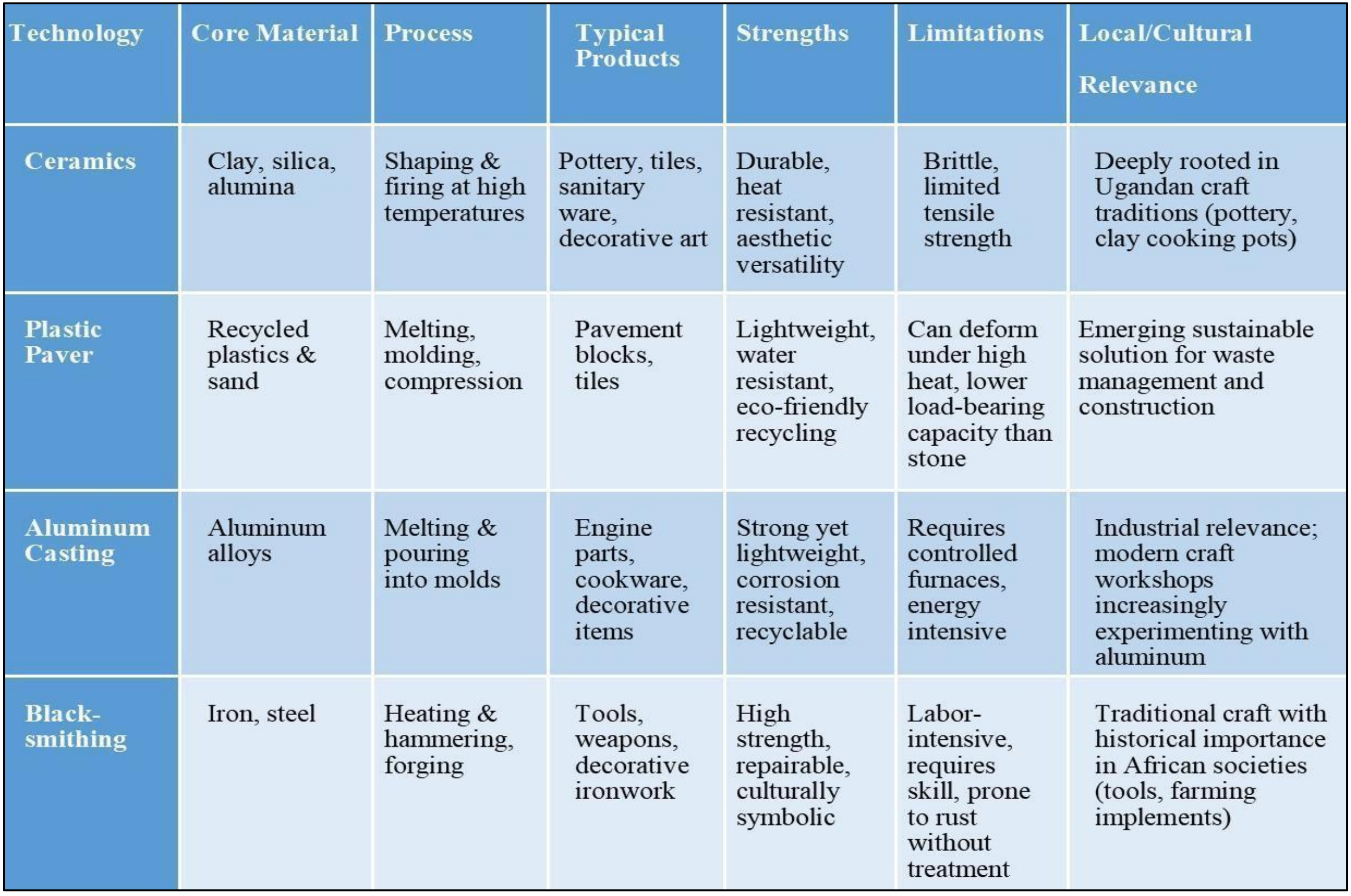


| Outcome Dimension | Traditional Art Teaching | Chemistry-Integrated Art Teaching |
|---|---|---|
| Creativity | ∗ Focus on aesthetic expression, technique, and cultural motifs.<br>∗ Students explore imagination mainly within artistic boundaries.<br>∗ Innovation often limited to visual or symbolic representation. | ∗ Creativity expands into scientific visualization (molecular models, reaction diagrams, symbolic chemistry art).<br>∗ Students combine artistic imagination with scientific interpretation.<br>∗ Encourages interdisciplinary innovation and design thinking. |
| Engagement | ∗ Engagement driven by personal interest in art, cultural relevance, and teacher inspiration.<br>∗ Students may disengage if they don't see art as connected to other subjects. | ∗ Engagement heightened by linking art to real-world science.<br>∗ Students see relevance of art beyond aesthetics, connecting it to chemistry concepts.<br>∗ Interactive projects (posters, sculptures, experiments with artistic outcomes) sustain attention. |
| Comprehension | ∗ Strong grasp of artistic techniques, symbolism, and cultural narratives.<br>∗ Limited exposure to scientific concepts.<br>∗ Knowledge remains discipline specific. | ∗ Students gain dual comprehension: artistic techniques plus scientific ideas.<br>∗ Abstract chemistry concepts clarified through visual/tactile art.<br>∗ Builds deeper interdisciplinary understanding. |
| Collaboration Skills | ∗ Collaboration mainly within art classes or group projects.<br>∗ Peer-to-peer sharing of artistic ideas. | ∗ Collaboration across disciplines (art + science teachers, students).<br>∗ Builds teamwork, communication, and problem-solving across subject boundaries. |
| Cultural Relevance | ∗ Strong emphasis on Ugandan traditions, motifs, and cultural heritage.<br>∗ Art remains rooted in identity and expression. | ∗ Chemistry concepts contextualized through Ugandan art forms (batik, sculpture, symbolic motifs).<br>∗ Strengthens cultural identity while expanding scientific literacy. |
| Assessment | ∗ Evaluation based on technique, originality, and cultural expression.<br>∗ Creativity measured within artistic scope. | ∗ Requires hybrid rubrics: assessing both artistic originality and scientific accuracy.<br>∗ Creativity measured in interdisciplinary outcomes. |

➢ *Key Insight*

- Traditional teaching ensures exam readiness but risks disengagement and limited Creativity.
- Art-integrated teaching fosters Creativity, engagement, and deeper comprehension, though it requires new assessment frameworks and resources.
- Traditional art teaching nurtures cultural identity and aesthetic Creativity but remains discipline-bound.
- Chemistry-integrated art teaching broadens Creativity, boosts engagement, and deepens comprehension by merging artistic imagination with scientific Understanding.

Table 4 A Comparative View of Ceramics, Plastic Pavers, Aluminum Casting, and Blacksmithing Technology in Relation to Art-Chemistry Collaboration.



| Technology | Core Material | Process | Typical Products | Strengths | Limitations | Local/Cultural Relevance |
|---|---|---|---|---|---|---|
| **Ceramics** | Clay, silica, alumina | Shaping & firing at high temperatures | Pottery, tiles, sanitary ware, decorative art | Durable, heat resistant, aesthetic versatility | Brittle, limited tensile strength | Deeply rooted in Ugandan craft traditions (pottery, clay cooking pots) |
| **Plastic Paver** | Recycled plastics & sand | Melting, molding, compression | Pavement blocks, tiles | Lightweight, water resistant, eco-friendly recycling | Can deform under high heat, lower load-bearing capacity than stone | Emerging sustainable solution for waste management and construction |
| **Aluminum Casting** | Aluminum alloys | Melting & pouring into molds | Engine parts, cookware, decorative items | Strong yet lightweight, corrosion resistant, recyclable | Requires controlled furnaces, energy intensive | Industrial relevance; modern craft workshops increasingly experimenting with aluminum |
| **Black-smithing** | Iron, steel | Heating & hammering, forging | Tools, weapons, decorative ironwork | High strength, repairable, culturally symbolic | Labor-intensive, requires skill, prone to rust without treatment | Traditional craft with historical importance in African societies (tools, farming implements) |

- *Comparative Insights;*

Material Source: Ceramics rely on natural clay; plastic pavers recycle waste; aluminum casting uses industrial alloys; blacksmithing depends on iron/steel. Energy Demand: Ceramics and blacksmithing use fire/charcoal; aluminum casting requires higher industrial energy; plastic pavers use moderate heat. Durability: Blacksmithing and aluminum casting yield strong, load-bearing products; ceramics excel in heat resistance but are brittle; plastic pavers balance sustainability with moderate strength. Cultural Anchoring: Ceramics and blacksmithing are deeply traditional; plastic pavers and aluminum casting represent modern, sustainable/industrial innovations. This comparative view highlights how traditional crafts (ceramics, blacksmithing) and modern technologies (plastic pavers, aluminum casting) can complement each other in curriculum design—bridging heritage, sustainability, and industrial relevance.

## IV. DISCUSSION AND RECOMMENDATIONS

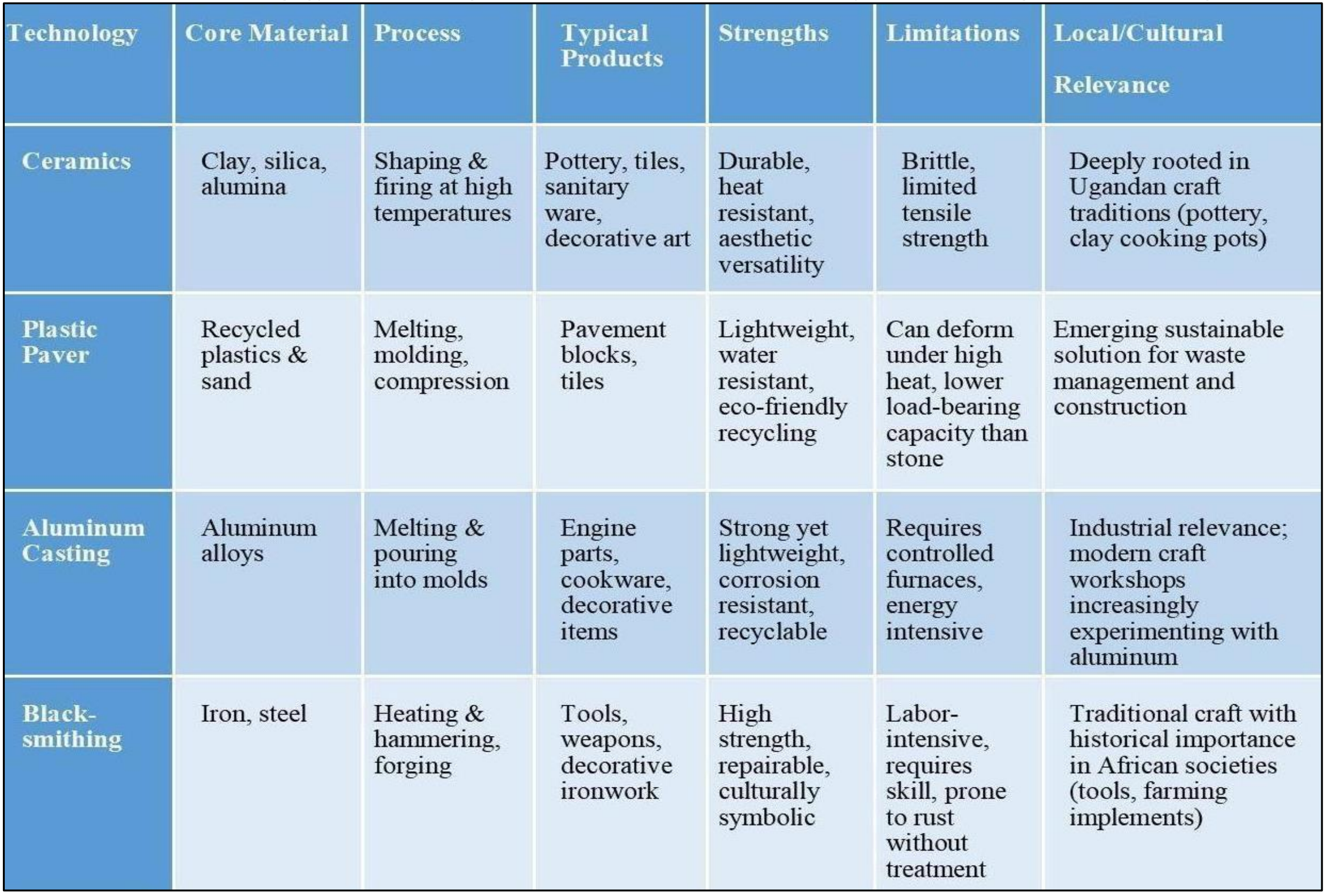
A structured discussion outline was used to explore the topic of evaluating the impact of collaborating art and design with chemistry teaching on secondary student creativity and engagement in Ugandan schools:

- *Contextual Background*

Ugandan secondary education often emphasizes exam preparation and mastery of scientific content. Creativity and engagement can sometimes be sidelined. Art and design integration offers a way to make abstract chemistry concepts more tangible, relatable, and culturally grounded—potential Benefits: Enhanced Creativity. Students can express chemical concepts through visual metaphors, models, and symbolic design. Encourages divergent thinking—seeing chemistry not just as formulas but as patterns, colors, and structures. Improved Engagement: Hands-on artistic activities (drawing molecular structures, designing posters, sculpting models, ceramics-making, addressing environmental cross-cutting issues) make lessons interactive. Links chemistry to everyday life and cultural practices, increasing relevance. Art, as a practical skill, exposes students to artistic creations that are themselves chemistry-oriented, thereby simplifying complex chemistry concepts. Cross-disciplinary Skills: Builds Collaboration between Science and arts departments. Fosters problem-solving, communication, and innovation—skills valuable beyond school.

The Collaboration facilitates the higher-order thinking - cognitive learning as suggested by Bloom's Taxonomy in Fig. 2: the collaborative pedagogical approach creates room for analyzing, evaluating, and creating skills as part of the higher order of learning needed within the 21st Century. The systems thinking approach provides for a holistic teaching and learning style, and, as a result, realizes a well-equipped generation ready to solve prevailing societal and environmental problems. This ‘whole theory’ derived from systems thinking provides that the integration of Science, art-chem in particular, should be emphasized in Ugandan secondary schools' curriculum since this shall be the response to the Sustainable Development Goals (SDGs) Agenda 2030. Art-Chemistry Collaboration meets the requirements of Green Chemistry and serves as a vehicle for environmental sustainability. Table 4: A comparative view of ceramics, plastic pavers, aluminum casting, and blacksmithing technology in relation to Art-Chemistry Collaboration affirms the need for an interdisciplinary approach to teaching and learning chemistry in the Ugandan secondary school curriculum. A comparative framework shown in both Tables 2 and 3 illustrates the student outcome of the interdisciplinary and pedagogical approach. Benefits of art and chemistry Collaboration (Table 2) such as; Blending Creativity with scientific accuracy, Using chemical processes to create artistic effects (e.g., pigments, glass, polymers), New mediums, visually striking scientific demonstrations, educational art, Dual interpretation: aesthetic appreciation and scientific Understanding, Overcomes limits by merging durability with meaning, Bio-art, chemical photography, art installations using reactions (e.g., rust, crystallization) are so evident in the Figures 3-7.

Table 5 Comparative Pedagogy Matrix; Using the Matrix to Assess Interdisciplinary Growth Through the 4 Technologies below.



| Technology | Core Material | Process | Typical Products | Strengths | Limitations | Local/Cultural Relevance |
|---|---|---|---|---|---|---|
| Ceramics | Clay, silica, alumina | Shaping & firing at high temperatures | Pottery, tiles, sanitary ware, decorative art | Durable, heat resistant, aesthetic versatility | Brittle, limited tensile strength | Deeply rooted in Ugandan craft traditions (pottery, clay cooking pots) |
| Plastic Paver | Recycled plastics & sand | Melting, molding, compression | Pavement blocks, tiles | Lightweight, water resistant, eco-friendly recycling | Can deform under high heat, lower load-bearing capacity than stone | Emerging sustainable solution for waste management and construction |
| Aluminum Casting | Aluminum alloys | Melting & pouring into molds | Engine parts, cookware, decorative items | Strong yet lightweight, corrosion resistant, recyclable | Requires controlled furnaces, energy intensive | Industrial relevance; modern craft workshops increasingly experimenting with aluminum |
| Black-smithing | Iron, steel | Heating & hammering, forging | Tools, weapons, decorative ironwork | High strength, repairable, culturally symbolic | Labor-intensive, requires skill, prone to rust without treatment | Traditional craft with historical importance in African societies (tools, farming implements) |

➢ *Local Relevance (Ugandan Secondary Context)*

- Materials: Clay, banana fibers, dyes, and locally available chemicals can be used to merge cultural art practices with chemistry. Themes: Sustainability, indigenous knowledge, and environmental chemistry can be explored through artistic expression. Observation Instruments: Fillable sheets tailored for Ugandan classrooms could track how students integrate cultural motifs into their chemical Understanding.
- Pedagogical Principles: 1) Experiential Learning: Students conduct experiments (chemistry) and create artifacts (art). 2) Comparative Observation: Structured checklists and coding schemes capture both scientific and artistic outcomes. 3) Cross-Disciplinary Reflection: Learners analyze how chemistry enables durability while art gives meaning. 4) Local Relevance: Use Ugandan contexts—clay sources, plastic waste, scrap aluminum, traditional blacksmithing—to make lessons culturally grounded.

➢ *Recommendations*

An abridged Art–Chemistry Syllabus; a condensed, abridged Art-Chemistry Integrated Syllabus outline showing the dual flow of Art-Chemistry and Chemistry-Art (Table 5) should be adopted to cater for the art-chemistry Collaboration in Ugandan secondary schools. At Lower Secondary (S1–S2) Matter & Atomic Structure; Drawing atomic models, clay molecule sculptures, Mixtures & Solutions; Color blending exercises, symbolic paintings of separation techniques, and

Acids & Bases; Tie-dye, batik, mural design linked to neutralization. At Middle Secondary (S3–S4) Energy & Combustion; Pottery firing, flame-inspired painting, photography of light, Electrochemistry; Electroplating for decorative art, battery-powered installations, Environmental Chemistry; Recycling plastics into sculpture, conservation-themed murals. Whereas at Upper Secondary (S5–S6), Organic Chemistry, Natural dye extraction, polymer-based sculpture and resin art, Industrial Chemistry; Comparative study of traditional Ugandan craft materials vs. synthetic ones, Applied Chemistry in Art; Glasswork, ceramics, metal casting as chemical transformations.

An Assessment & Observation Checklists: Scientific accuracy + artistic Creativity, Coding Schemes: Conceptual clarity, aesthetic representation, local relevance, Matrices: Direct pairing of chemistry topics with art practices. This abridged version is designed for quick curriculum mapping and observation planning. Art-Chemistry/Chemistry-Art Collaboration Pedagogy can be framed as a deliberate integration of creative practice and scientific inquiry, in which each discipline enriches the other in both the classroom and fieldwork. Let me sketch out a structured approach you could use to design such pedagogy:

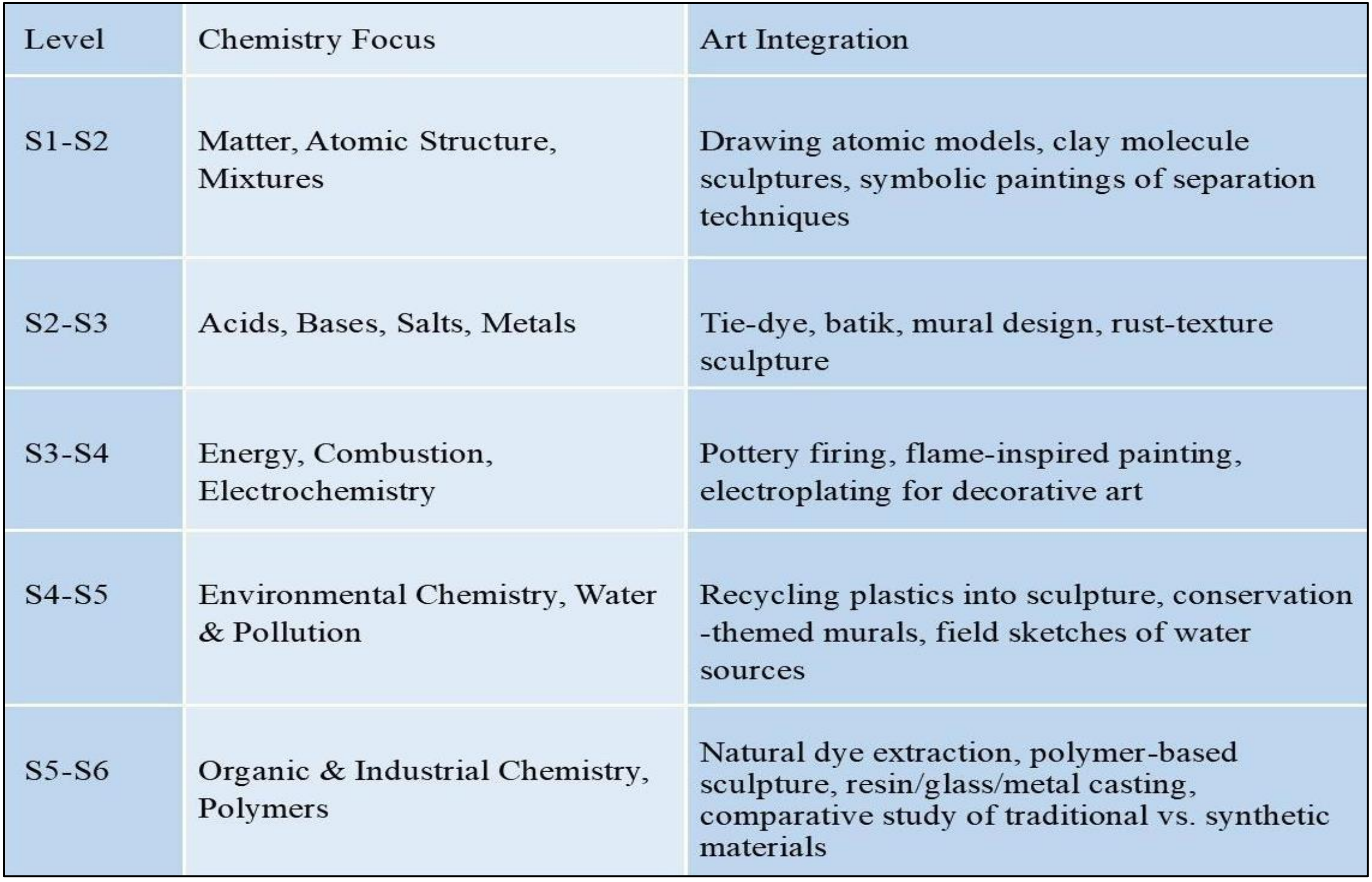
- *Conceptual Foundations*

Art into Chemistry: Use visual design, sculpture, and symbolic representation to make abstract chemical concepts tangible (e.g., molecular structures as sculptural forms, reaction pathways as narrative art). Chemistry into Art: Employ chemical processes as artistic media (e.g., pigments, material transformations, crystallization, corrosion, polymerization) to teach both chemistry and creative practice. Shared Pedagogical Goal: Foster *dual literacy*—students learn to think scientifically and aesthetically, seeing chemistry as a creative act and art as a structured exploration.

- *Pedagogical Strategies*

Co-Teaching Modules: Pair chemistry and art instructors to design joint lessons (e.g., “Color in Chemistry and Art” exploring spectroscopy and pigment history). Encourage students to produce both a lab report and an artistic artifact. Observation & Reflection Tools: Structured checklists for observers: noting Creativity, accuracy, material use, and symbolic interpretation. Coding schemes that capture both scientific precision and artistic innovation. Project-Based Learning: 1) Example: “Sculpting Molecules,” where students build 3D models using local materials, then analyze the chemical relevance. 2) Example: “Chemical Landscapes,” where corrosion or crystallization is used to create art, with accompanying chemical analysis. Comparative Matrices; Map outcomes across disciplines: e.g., how a chemistry experiment’s precision compares to an art project’s expressiveness.

Table 6 An Abridged Art–Chemistry / Chemistry–Art Syllabus that Distills the Integration into a Simple Matrix-Style Outline Designed for Quick Curriculum Mapping and Observation use.



| Level | Chemistry Focus | Art Integration |
|---|---|---|
| S1-S2 | Matter, Atomic Structure, Mixtures | Drawing atomic models, clay molecule sculptures, symbolic paintings of separation techniques |
| S2-S3 | Acids, Bases, Salts, Metals | Tie-dye, batik, mural design, rust-texture sculpture |
| S3-S4 | Energy, Combustion, Electrochemistry | Pottery firing, flame-inspired painting, electroplating for decorative art |
| S4-S5 | Environmental Chemistry, Water & Pollution | Recycling plastics into sculpture, conservation -themed murals, field sketches of water sources |
| S5-S6 | Organic & Industrial Chemistry, Polymers | Natural dye extraction, polymer-based sculpture, resin/glass/metal casting, comparative study of traditional vs. synthetic materials |

➢ *Challenges and Possible Gap*

- Curriculum Constraints: National syllabi may prioritize content coverage over creative exploration. Teachers may feel pressure to “teach for the exam.” Resource Limitations: Art materials may be scarce in rural schools. Training teachers to balance both disciplines requires investment.
- Assessment Difficulties: Creativity and engagement are harder to measure compared to test scores. Need for observation tools, rubrics, and coding schemes tailored to Ugandan classrooms.

## V. CONCLUSION

In conclusion, therefore, Chemistry is the Science of transformation: it makes materials durable, strong, and functional, whereas Art is the Science of meaning: it shapes those materials into culturally resonant and aesthetically powerful forms. The Comparative View (Table 4:) of ceramics, plastic pavers, aluminum casting, and blacksmithing technology in relation to Art-Chemistry Collaboration shows that every process is a dialogue between Science and Creativity—whether it is clay becoming pottery, plastic becoming patterned pavement, aluminum becoming sculpture, or steel becoming tools. In short: Chemistry makes permanence possible; art makes permanence meaningful. Art–Chemistry Pedagogy Framework in Figures 3-7; for instance, in ceramics making, Chemistry focuses on the Mineral composition of clay, dehydration, vitrification, glaze chemistry, and Chemical reactions during firing (loss of water, formation of silicates) while Art Focuses on forming expressive shapes (pots, sculptures) and Decorative glazing, and symbolic motifs. The intermediate Pedagogical Integration is in a way that Students experiment with glaze oxides (chemistry) and record color outcomes (art). The Observation sheets link firing temperature to both structural strength and aesthetic finish, and the two form a profound foundation for art-chemistry Science. The reviewed theories of Bloom’s Taxonomy, Systems Thinking, Interdisciplinarity, and Green Chemistry offer multifaceted, enriching artistic and scientific considerations for developing art-chemistry collaborations and for assessing the impact of integrating art and design with Chemistry teaching on secondary students' Creativity and engagement in Ugandan schools. To this end, Ugandan education policymakers, curriculum developers, educationists at all levels, and all stakeholders need to rethink how best to design art-chemistry Collaboration syllabi to address learners' primary needs within the interdisciplinary pedagogical process.

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