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Collaborative, Interdisciplinary and Student-Led Approaches in Undergraduate Research, Teaching, and Learning

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Over the past decade, education literature has extensively discussed collaborative, student-led, and interdisciplinary methodologies. Despite numerous studies on these aspects of education, concrete examples integrating all three elements are scarce. Chemistry and Art, a course developed at Brown University, addresses this gap by integrating all three methodologies into one practical educational setting. Utilizing the Karen T. Romer Undergraduate Teaching and Research Award (UTRA) Program, this student-centered course involves students as co-creators, enhancing the curriculum through their unique perspectives. Students also lead original research, the outcomes of which directly translate into teaching materials for the course. The course employs a case study method, traditionally used in professional schools, to engage students with real-life cases, fostering critical thinking and problem-solving skills. This method includes hands-on laboratory activities linked to lecture content, enriching the learning experience through active, student-led discovery and facilitated research. Taught by faculty from diverse disciplines, the Chemistry and Art course and its development demonstrate the positive impact of combining methodologies on student engagement and educational outcomes. Despite its success, methods used to create this course face challenges such as scalability in larger classes and resource limitations for student-led research. Future directions include developing comprehensive assessment tools, scaling activities for larger groups, and expanding interdisciplinary outreach. This adaptable model can be implemented in various undergraduate institutions, promoting student-led outcomes, collaboration, interdisciplinary learning, and effective integration of case studies into courses.

Keywords: Collaborative Education, Student-led Learning, Interdisciplinary Methodologies, Case Study Approach, Higher Education

Introduction

In the past decade, collaborative, student-led, and interdisciplinary education have been extensively discussed in education literature (Bada, & Olusegun, 2015; Shah, 2019; Cook-Sather, & Felten, 2017; Cook-Sather, et. al., 2023; Bovill, 2020; Marquis, et al., 2021; Bovill, & Bulley, 2011; Bengtson, et. al., 2017; Brooman, et. al. 2015; Tien, et. al., 2002; Iversen, et. al., 2015; Lubicz-Nawrocka, & Bovill, 2021; Wright, 2011; Rutherford, 2020; Kong, 2021; Wan, 2023; Chettiparamb, 2007; Dym, et. al., 2005; James Jacob, 2015; Ivanitskaya, et. al., 2002; Ye, & Xu, 2023; McDermott, et. al., 2014; Crowe, et. al., 2011; Garvin, 2003;. Cliff, & Wright, 1996; Yadav, et. al., 2010; Dori, et. al., 2003; Yadav, &

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Beckerman, 2009). However, there has been no concrete example that integrates all three elements into one practical model. No classes or practices effectively combine these approaches in a unified model, and there is a lack of case studies demonstrating such integration.

Our objective is to create a class that integrates collaborative, student-led, and interdisciplinary practices into a cohesive educational model. The integration of these methodologies in a course will enhance students' ability to tackle real-world challenges effectively and think beyond traditional classroom settings. We propose that this combined approach will result in a highly effective course that significantly benefits students by equipping them with practical skills and experiences applicable to real-world situations. This approach is expected to foster critical thinking, creativity, and problem-solving abilities, preparing students to address complex issues with a more comprehensive and innovative perspective.

Our Chemistry and Art course demonstrates how these theoretical frameworks can be effectively implemented in a real-world educational setting. Developed through the collaborative efforts of faculty and undergraduates at Brown University, this course leverages students as co-creators, working alongside faculty to lead projects and create student-centered outcomes. Our model disrupts traditional hierarchical structures in which faculty primarily direct the learning process, promoting a more interactive learning environment. Student insights are leveraged for their unique perspectives and experiences, enhancing the learning experience for their peers. This not only empowers students but also encourages a culture of continuous improvement and innovation in teaching methods. The Chemistry and Art course exemplifies how such an approach can lead to richer, more engaging educational experiences that prepare students for the complexities of the modern world.

Brown University is uniquely positioned with its offering of the Karen T. Romer Undergraduate Teaching and Research Award (UTRA) Program (Klara, et. al., 2013). This program allows students to work closely with faculty on research or course development, integrating their experiences to enhance courses. Incorporating student voices not only enhances student engagement and educational outcomes but also fosters a deeper understanding of the teaching and learning process. UTRA bridges the gap between research and teaching, enabling students to actively shape their educational experiences. Combined with the independent study program, which offers course credit for student-faculty-partnered projects, UTRA creates a robust framework for these initiatives.

We provide a tangible example of how collaborative, student-led, and interdisciplinary educational theories – all of which have been proven to have pedagogical benefits – can be successfully combined and applied in practice. This adaptable model has the potential to be implemented in various other undergraduate institutions. Through this approach, we aim to enhance the quality and impact of undergraduate education courses, fostering collaboration and interdisciplinary learning.

Courses created through this methodology allow students to draw connections between seemingly disparate fields, fostering a more integrated and holistic understanding of knowledge. Interdisciplinary approaches are crucial in addressing complex, real-world problems that require multifaceted solutions. By incorporating case studies into this teaching method, traditionally used in professional schools,

students are further prepared to engage with real-life cases, fostering critical thinking and problem-solving skills. By breaking down the barriers between disciplines, we equip students with the skills and mindset needed to tackle these challenges effectively.

Our experience with the Chemistry and Art course suggests that the integration of collaborative, student-led, and interdisciplinary methodologies is not only feasible but also highly beneficial. The success of this course underscores the value of this approach, and highlights the potential for broader application across different academic disciplines and institutions. By sharing our model, insights, and challenges associated with implementing such methodologies, we hope to guide other educators in adopting similar strategies, and ultimately contribute to the development of innovative courses in undergraduate education.

Literature Review

Constructivist Theory proposes that knowledge is actively constructed by learners through their interactions with the environment and peers; learning is a dynamic, socially-mediated process. In educational settings, this theory underscores the importance of understanding students' perspectives to tailor teaching methods more effectively (Bada, & Olusegun, 2015). Teachers must understand the psychological and pedagogical background from which new educational ideas emerge to develop and implement more effective pedagogical approaches (Shah, 2019).

These principles are shown through studies that demonstrate the positive impact of collaboration between students and faculty. Student-faculty pedagogical partnerships enhance student engagement, perceptions of increased classroom equity, and improve educational outcomes such as better retention rates (Cook-Sather, & Felten, 2017; Cook-Sather, et. al., 2023; Bovill, 2020; Marquis, et al., 2021). A comprehensive analysis of 32 publications on student-faculty pedagogical relationships underscores that these partnerships provide faculty with valuable insights into student perspectives, foster the development of equitable teaching practices within dedicated spaces and times, and enhance students' sense of agency (Cook-Sather, et. al., 2023).

Bovill et al. further shows that incorporating students into curriculum design leads to greater ownership and motivation (Bovill, & Bulley, 2011). For instance, a curriculum redesign at Uppsala University involving collaboration between students and teachers resulted in significant improvements, including the introduction of new seminars, redesigned lectures, and updates to course literature, ultimately increasing student satisfaction (Bengtson, et. al., 2017). Similarly, Brooman et al. reported the transformative impact of student involvement in higher education curriculum development (Brooman, et. al. 2015). Informed by student feedback, their curriculum redesign led to notable enhancements in feedback quality, attendance rates, and academic performance, revealing valuable insights that traditional feedback mechanisms might overlook.

Student-led initiatives also exemplify constructivist principles by leveraging peer interactions to enhance learning outcomes. The peer-led team learning model described by Tien et al. illustrates the benefits of near-peer instruction in undergraduate organic chemistry courses. Students learn from peers who had recently mastered the

material themselves, resulting in improved academic performance, retention rates, and positive attitudes toward the course (Tien, et. al., 2002). The concept of "learner-led approaches in education" (LED) underscores a flexible, student-centered learning process that adapts to individual needs and contexts, shifting the educational focus from teaching to learning. This approach capitalizes on student motivation and fosters meaningful engagement (Iversen, et. al., 2015).

While collaborative and student-led approaches have been widely discussed and implemented in educational settings, few studies have explored course designs that are initiated and led by students, with faculty serving primarily in a supportive and advisory role. Most of the literature focuses on students co-creating curricula in higher education, emphasizing student-centered learning, and engaging students in shaping their educational experience (Lubicz-Nawrocka, & Bovill, 2021; Wright, 2011; Rutherford, 2020). Our model offers a new perspective on applying constructivist principles by having students take full responsibility for conceptualizing the course, developing activities and materials, and delivering content, with faculty providing feedback and guidance as needed.

Experiential Learning Theory, grounded in the constructivist approach, emphasizes the importance of real-world experiences in the learning process (Kong, 2021). Learners achieve deeper understanding and retention by participating in hands-on activities, reflecting on their experiences, and applying their insights to new situations. This process involves concrete experience, reflective observation, abstract conceptualization, and active experimentation. By integrating these stages, experiential learning fosters a learner-centric environment that enhances motivation and engagement, making learning more relevant and applicable to real-life contexts.

In parallel, interdisciplinary education provides substantial advantages by encouraging students to integrate knowledge from diverse fields. Wan highlights that crossing conventional boundaries promotes innovative ideas and solutions (Wan, 2023). Real-world challenges seldom fit neatly into a single discipline, necessitating a broad, integrative approach (Chettiparamb, 2007; Dym, et. al., 2005; James Jacob, 2015). By engaging in interdisciplinary projects, students develop crucial collaboration and communication skills across different fields, essential for professional success (Ivanitskaya, et. al., 2002). Interdisciplinary learning has been shown to cultivate "4C Skills" (critical thinking, communication, cooperation, and creativity) (Ye, & Xu, 2023). McDermott et al. add that interdisciplinary projects often present complex challenges, requiring students to navigate uncertainty and develop robust problem-solving strategies (McDermott, et. al., 2014). As such, case studies from design programs implementing interdisciplinary curricula demonstrate enhanced student outcomes and innovative project results.

Building on this foundation, case study methods align closely with experiential learning principles. They enhance the benefits of interdisciplinary education by offering real-life examples and practical applications of theoretical concepts. Case studies in higher education allow for students to engage in active learning, think creatively, and develop problem solving skills (Crowe, et. al., 2011). These examples reinforce the theoretical concepts learned and allow students to apply their knowledge in realistic contexts, fostering the ability to think within the realm of the real-world. Typically, this method of teaching is predominantly used in professional programs,

including business, medical, and law schools (Garvin, 2003). A smaller number of STEM classes has utilized this approach. Still, the case study teaching method has been used to teach human anatomy and physiology, mechanical engineering, biotechnology, plant pathology, and other STEM courses Cliff, & Wright, 1996; Yadav, et. al., 2010; Dori, et. al., 2003; Yadav, & Beckerman, 2009). Even fewer STEM-humanities interdisciplinary courses have adopted this method.

Our course uniquely combines the science-humanities approach with case study methods. The team of students involved in course creation came from diverse academic backgrounds, including students from neuroscience, geology, biochemistry, and English departments, as well as an illustration student from the Rhode Island School of Design (RISD). As such, the course was developed from many unique points of view, reflecting the various backgrounds that many prospective students may also come from. By integrating these diverse perspectives along with our practical case studies, we provide students with a comprehensive learning experience that prepares them for real-world applications.

Overall, the literature shows that a combination of the previously mentioned pedagogical approaches have not yet been combined and implemented within an educational setting. Integrating these methodologies with a case study-oriented approach has the potential to yield numerous benefits for students. With this combination, educational institutions can create more engaging and effective learning environments. This can lead to enhanced student performance, satisfaction, and development of critical thinking skills necessary to tackle real-world challenges effectively.

Strategies used in Course Creation

This paper focuses on advancing collaborative, interdisciplinary, and student-led approaches in undergraduate research, teaching, and learning. This will be done by exploring the creation of our novel Chemistry and Art course, which was developed through this methodology. Our course explores the intersection between science and humanities while promoting critical thinking, creativity, and a holistic understanding of knowledge.

One of the novel approaches used to create this course involves the translation of undergraduate research results directly into teaching materials. Unlike other collaborative methodologies in the literature, this type of collaboration among faculty and students has scarcely been reported. The collaboration is primarily student-driven, with students leading the creation of new research, while faculty act as facilitators. Brown University's UTRA program enables outstanding and diverse undergraduates to collaborate with professors in researching and developing innovative teaching materials and hands-on activities. Through this collaborative endeavor, the undergraduates involved in original research and its translation into teaching gain valuable research experiences and critical thinking skills through close interactions with faculty. They also produce highly engaging educational products based on their research findings.

Furthermore, a case study-oriented approach is used throughout the Chemistry and Art course. Departing from traditional teaching methods, students engage with real cases by reading literature or news articles, then bring questions for discussion in class, with the instructor leading the discourse. This teaching method aims to enhance critical thinking and problem-solving skills. In our course, the relevance of real-life cases motivates students to learn, and our case studies are directly linked to lecture content and laboratory activities in order to further enrich students' learning experiences.

A schematic illustration of the strategies used in creating and implementing the Chemistry and Art course is provided in Figure 1. More details will be discussed in the following sections.

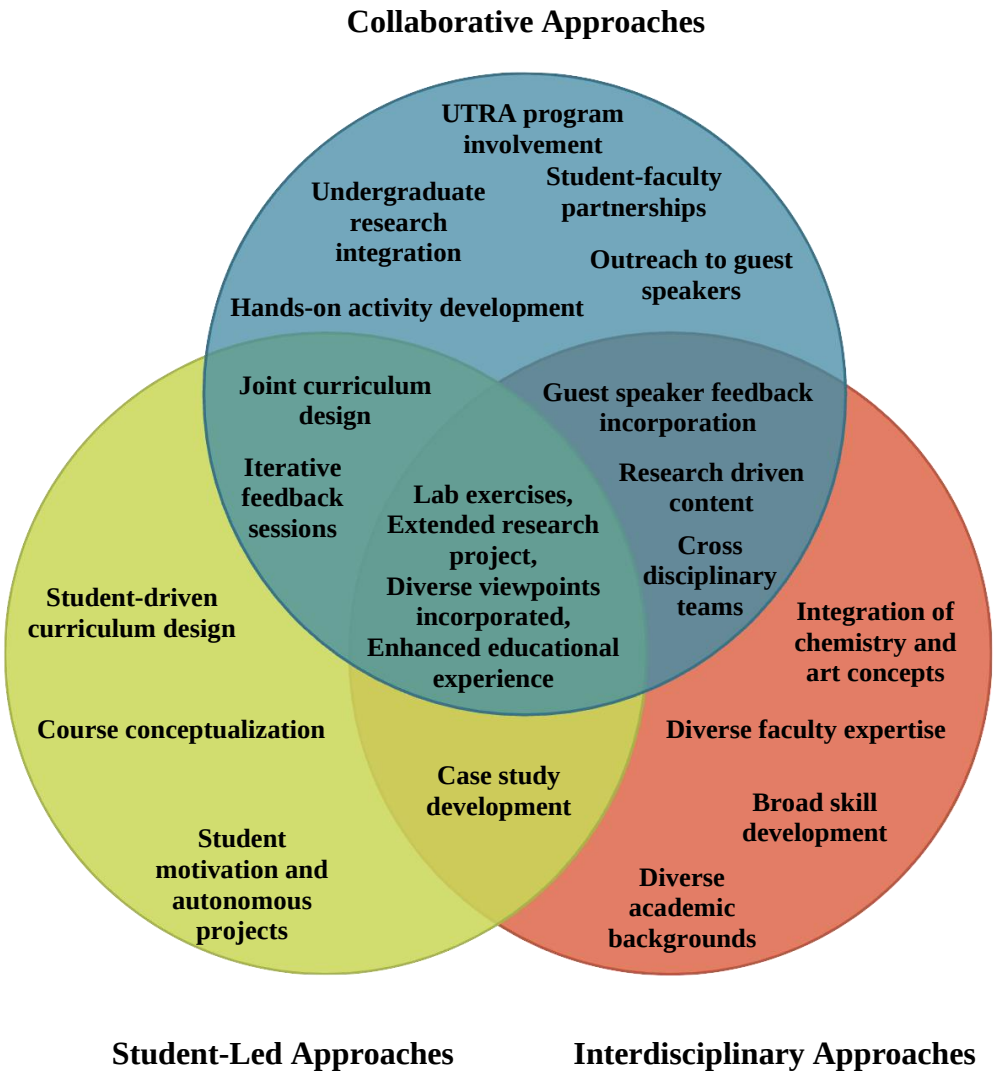
Chemistry and Art is a small 13-15 student course that covers several key areas, including the origin of color, chemical composition and application of paints, processes and materials involved in creating ceramics, and the techniques and chemistry involved in preserving art objects. These diverse topics integrate together scientific and artistic realms. One of the primary objectives of the course is to increase students' creative, critical thinking, writing, communication, collaborative, and analytical skills. The course aims to broaden students' knowledge of fundamental chemical principles behind art and art-making.

The course employs a bottom-up approach, making learning practical and engaging. Students are taught the foundational elements of each unit, building up to more complex concepts that they can apply through hands-on activities directly tied to lecture content. A novel semester-long research project is integrated throughout the course, encouraging students to apply their learning meaningfully. The course also uses case study and inquiry-based methods, with students writing papers based on research findings and current literature. Students read literature or news articles and bring questions for class discussions, led by the instructor. These components are woven together to create a cohesive learning experience that enhances students' creativity, critical thinking, and collaboration.

Application of Pedagogical Approaches to Create and Implement the Course

As shown in Figure 1, the collaborative nature of the course is emphasized through the integration of faculty expertise and student input during course design. Students contribute their perspectives and creativity to ensure a well-rounded learning environment, while faculty provide specialized subject knowledge. Throughout the duration of course development, constant feedback sessions are held, while guest lecturers and speakers are invited to deliver lectures and provide additional ideas for improvement.

Figure 1. Strategies used in the Creation and Implementation of the Chemistry and Art Course Brief Course Description

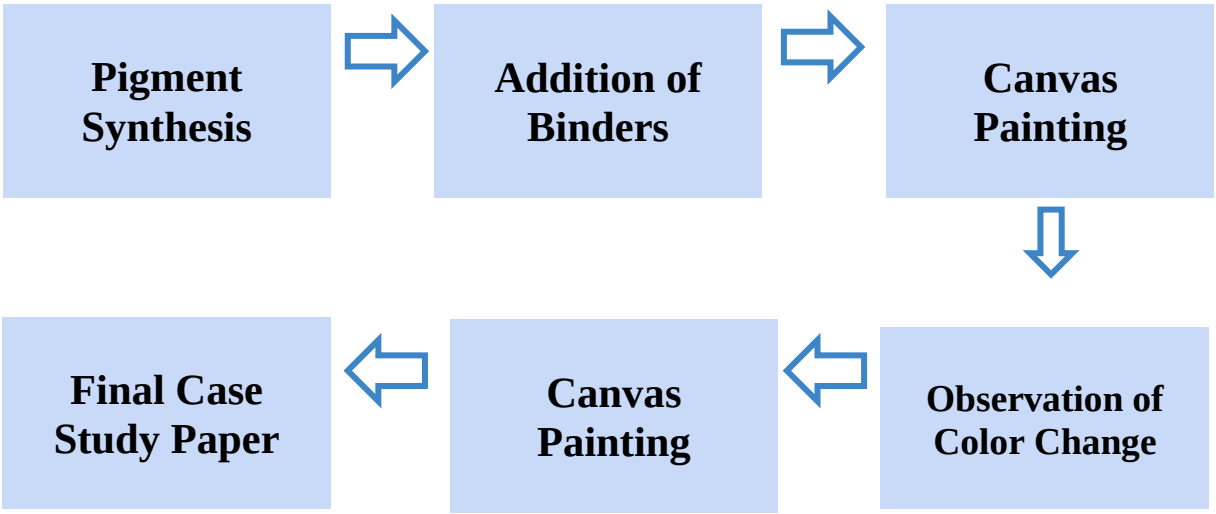


To develop laboratory exercises that accurately reflect the course materials, original research on pigments and ceramic glazes was conducted through a close collaboration between two students and chemistry faculty. Supported by the UTRA awards, these students initiated and led the research projects, with faculty providing support and guidance. In total, two independent projects were conducted: one focused on pigment synthesis and color change, and the other on creating ceramic glazes and observing their color changes as a function of kiln temperatures. The students worked together and consulted with the faculty weekly, who encouraged them to think creatively. This student-led effort, characterized by innovative thinking and collaboration, resulted in two publications (Hills-Kimball, et. al. 2022; Peng I, et.al. 2022)

The research findings on the chemistry of color changes in synthesized blue copper-based pigment when mixed with an oil binder, were directly utilized to

create a novel lab activity and a semester-long research project. As shown in Figure 2, the blue copper-based pigment was synthesized, mixed with oil and acrylic binders, painted on canvas, observed for color changes, and followed by a series of research inquiries using various analytical tools. Unlike previous chemistry and art educational activities that mainly focus on the analysis of museum art objects or other pre-created objects (Wells, & Haaf, 2013; Nivens, et. al., 2010; Harmon, et. al., 2009), this study employed a bottom-up approach where students created their pigments, observed color changes, and related these changes to art conservation and art history.

Figure 2. Schematic of Student Investigation into the Color Changes of Blue Copper-Based Pigment



Similarly, research into copper-based ceramic glazes was translated into an activity where students created their glazes, fired them at various temperatures, and analyzed the results. They also made their own mini ceramic art pieces with their created glazes. This activity helped students understand the chemical transformations during the firing process and the factors affecting glaze color and texture. These hands-on laboratory exercises linked classroom theory with practical application, fostering a deeper appreciation for the intersection of art and chemistry. Engaging lab activities allow students to explore and learn interactively. Integrated with lectures and case studies, they provided a cohesive learning experience.

The case study approach was used throughout the entire semester. In each unit, students were introduced to several case study papers to read and discuss before and during class. For example, one case study focused on the change and fading of color in Van Gogh's paintings. In addition to quizzes and exams, finals of this class included two case study papers, one of which was based on the semester-long research project. In this paper, students needed to explain the chemistry behind a surprising phenomenon: the blue pigment changing color when mixed with an oil binder but not showing color change when mixed with an acrylic binder. The guidelines encouraged students to use their critical, creative, and analytical thinking skills.

Students were asked to provide scientific data or evidence that addressed the chemistry behind the color change, relate the color change to art or art history, and write the paper in an engaging manner appropriate for the general public. In the second case study final, students brainstormed a new case study based on existing literature and/or art history, requiring their own creative and critical thinking. This model mirrors the research frameworks used by previous chemistry and art courses, allowing students to apply scientific principles to artistic contexts (Wells, & Haaf, 2013; Harmon, et. al., 2009; Marteel-Parrish, & Harvey, 2019).

Our student-led development of the Chemistry and Art course ensures that the course content is relevant and engaging from the perspective of those who best understand their peers' academic and intellectual interests. By integrating their insights and experiences into the course design, student designers create a learning environment that is both innovative and responsive to their peers' needs and learning styles. At the middle and end of the semester, student feedback on their perceptions of course content and lab exercises helps drive the improvement and development of course content. This iterative process benefits the current cohort and sets a precedent for future iterations of the course, ensuring it remains attuned to contemporary student interests.

To emphasize the interdisciplinary nature of the course, guest speakers from diverse fields were introduced. A RISD Museum Conservator provided insights into the conservation of art objects, bridging the gap between scientific analysis and art preservation. A Cognitive, Linguistic, and Psychological Sciences (CLPS) professor explored how eyes perceive color, linking biological and psychological aspects with chemical principles. An East Asian Studies professor discussed "Scientific Light on Traditional Ceramic Studies: Qing Dynasty," highlighting the historical and cultural significance of ceramics, complemented by scientific analysis.

Research Methodologies

This study employed a mixed-methods approach to evaluate the effectiveness of the collaborative, student-led, and interdisciplinary Chemistry and Art course. Due to space constraints in the laboratory, which limited class size to 15-16 students, participants were selected based on a survey conducted at the outset of the course. This survey aimed to curate a diverse group of students from various academic backgrounds, ensuring a rich mix of perspectives and skills, selected by the lead professor. The selection process involved identifying students who expressed interest in integrating multiple disciplines and demonstrated a willingness to engage in a collaborative learning environment.

To assess the effectiveness of the course, we employed a combination of pre-class and post-class surveys. The pre-class survey gathered baseline data on students' motivations for enrolling, their background knowledge, and confidence in certain initial skills. This information provided a benchmark for evaluating the development of skills throughout the course. At the end of the semester, a post-class survey was administered to evaluate students' perceptions of the course's impact on their skill development, critical thinking, creativity, and problem-solving abilities.

The analysis of these surveys focused on whether the course met its objectives by equipping students with practical skills and experiences applicable to real-world situations. We compared pre-class and post-class responses to measure changes in students' skills and perceptions. Additionally, qualitative feedback from students was analyzed to gain insights into their experiences and the overall effectiveness of the course in fostering a comprehensive and innovative learning perspective.

By combining quantitative and qualitative data, the study aimed to provide a robust evaluation of the course's impact and effectiveness, aligning with our hypothesis that this integrated approach would significantly benefit students in their academic and professional development.

Results

The results from the Fall 2023 Chemistry and Art course (n = 16) showed that the class was able to enhance students' confidence in applying interdisciplinary knowledge, foster critical thinking and creativity, and improve collaborative and communication skills.

Table 1. Change in Student Confidence Levels in Skills Before and after the Chemistry and Art Course. 1 = Very Low Confidence; 5 = Very High Confidence

Skill Evaluated	**Mean**	**Median**	**Range**
Critical thinking	0.50	0.5	0 - 1
Analytical thinking	0.56	0	0 - 2
Writing	0.44	0	0 - 2
Case study exploration and research	0.94	1	0 - 3
Presentation	0.69	1	-1 - 4
Ability to apply chemistry concepts while creating artistic products	1.56	1	0 - 4
Knowledge of chemistry concepts	0.94	1	-1 - 2
Knowledge of artistic concepts	1.06	1	-1 - 3
Knowledge of the interdisciplinary approach combining chemistry and art	1.63	1.5	-1 - 3

Students demonstrated a notable increase in their ability to apply chemistry concepts in artistic contexts, with a mean change score of 1.56, indicating a substantial boost in confidence in this area. The knowledge of the interdisciplinary approach combining chemistry and art showed the highest increase in confidence (mean change score of 1.63). This suggests that students felt more adept at integrating

chemistry with artistic practices, reflecting a successful blending of content knowledge across disciplines. Students' knowledge of chemistry concepts and artistic concepts also showed improvements (mean change scores of 0.94 and 1.06, respectively). While these increases are less dramatic compared to the interdisciplinary approach, they still indicate a positive shift in understanding and application of these concepts.

In terms of communication skills, the course provided various opportunities for presentations and discussions. The average change in presentation skills (mean change score of 0.69) reflects a moderate improvement. This suggests that while there was some enhancement in presentation abilities, there may still be room for further development in this area.

In the post-class survey, students were also asked to rate their agreement with course evaluation statements.

Table 2. Student Agreement with Course Evaluation Statements after Completing the Chemistry and Art Course. 1 = Strongly Disagree; 5 = Strongly Agree

Course Evaluation Statements	**Mean**	**Median**	**Range**
I enjoyed this course	4.69	5	3 - 5
I learned a lot from this course	4.56	5	3 - 5
The course has contributed to the enhancement of my critical, analytical, and writing skills	4.13	4.5	2 - 5
Our unique semester-long research project, which investigated the unexpected color change in synthesized copper-based paint through case study, inquiry, and collaborative approaches, improved my critical thinking, analytical, and writing skills	4.31	4.5	3 - 5

The semester-long research project, which involved investigating color changes in synthesized paint, was highly valued by students. This project received high agreement scores (mean of 4.31) for improving critical thinking, analytical, and writing skills. The case study approach allowed students to engage deeply with real-world problems, enhancing their ability to think critically and creatively. Students appreciated the opportunity to develop their own theories and apply various analytical methods, which contributed to their growth in these areas.

Collaboration was a central element of the course, and student feedback underscores its success. The collaborative nature of the semester-long project was particularly well-received, with students expressing that it improved their problem-solving and analytical skills. The collaborative projects allowed students to work together to address complex problems, reflecting the effectiveness of the course's interdisciplinary and student-led approach. Students valued the opportunity to work with peers and professionals, enhancing their understanding through teamwork and diverse perspectives.

Student feedback provides strong evidence that the course met its objectives and supported our hypothesis. Here are some key quotes that highlight the success of the course in fostering critical thinking, creativity, and interdisciplinary integration:

- "The course successfully helped me apply chemistry concepts to my artistic work. The mix of real-life case studies and chemistry presentations really helped connect the field of art and chemistry together."
- "This course has exceeded my expectations! Initially, I wanted hands-on activities that would help me understand larger, more complicated concepts, and that is exactly what this course did. It has also improved the way I think about the interdisciplinary field, which is really beneficial for me."
- "Overall, this course has brought me greater insight into the chemistry side of art. The science behind color has enriched my artistic background, and I think I have a newfound appreciation for chemistry."
- "I really enjoyed problem-solving the blue color change of our synthesized paint. I also enjoyed applying what we learned to my second case study. It was fun to solve the mystery of the color change and try to explain it in simpler terms."
- "The [semester-long case study] helped me to build my skills by allowing us time to develop our own theories and take us thoroughly through all of the different methods of analysis, giving us an incentive to truly understand all of these concepts as well."

The Chemistry and Art course effectively met its objectives by integrating interdisciplinary content, fostering critical thinking, and enhancing collaboration. The positive student feedback, supported by specific comments, confirms that the course was successful in achieving its goals while providing valuable insights for future improvements.

Discussion

A Combination of Pedagogical Approaches

The combination of collaborative, student-led, and interdisciplinary methodologies leads to a synergistic outcome that would be difficult to achieve through any single approach alone. Students are active contributors who shape the learning environment, fostering a sense of community through collaborative projects, encouraging open dialogue and mutual respect.

The approach used in this work emphasizes close collaboration among students and faculty in performing original research and translating this research into novel teaching materials. Unlike most previous studies, which primarily focus on obtaining feedback from students, this collaborative effort involves active participation in research and course material development. This collaboration extends across different fields and among students themselves. In contrast to previous approaches where former students led discussions, this study's student-led approach focuses on allowing

students to create new pedagogical materials. These new methodologies significantly enhance undergraduate learning and research experiences, providing a model that can be adopted by other institutions.

This combination of approaches also facilitates the innovative integration of undergraduate research into teaching practices, exemplifying how research and pedagogy can mutually reinforce each other. The course's hands-on activities, such as creating and analyzing pigments and glazes, are core components that bridge together theory and practice. These activities, designed through student-initiated projects and collaborative efforts, draw on interdisciplinary research and are continuously refined based on student feedback. This approach provides students with experience in scientific inquiry and artistic creation, fostering an appreciation for the interconnectedness of the two fields and instilling critical thinking skills relevant for their future careers.

The interdisciplinary nature of the course further facilitates the sharing of ideas between different fields. To join the course, students must submit a survey administered during the first class. Students from diverse academic backgrounds are chosen to bring a range of unique perspectives, enriching discussions and leading to innovative problem-solving approaches. A student with a background in psychology might offer insights into the perception of color, while a chemistry student could explain the molecular basis of pigment properties. This blending of perspectives cultivates a holistic understanding of different concepts.

Outreach activities such as museum visits and guest lectures from professionals in various fields further connect classroom learning with real-world applications. These interactions provide students with insights into potential career paths and the practical implications of classroom content. Allowing students to engage with the community reinforces the importance of collaboration in addressing multidisciplinary societal issues.

The integration of collaborative, student-led, and interdisciplinary methodologies with a case study approach creates a dynamic and effective learning environment. This multifaceted approach not only enhances the educational experience but also prepares students to tackle complex problems in their future careers by fostering critical thinking, creativity, and collaboration across disciplines.

Student Feedback on Course Benefits & Future Improvements

This course aims to increase students' critical thinking, writing, communication, and analytical skills through a series of case studies in active learning settings. Inquiry-based class discussions, lectures, hands-on activities, writing assignments, and a final presentation are all integrated into one course. Furthermore, this course teaches the fundamental chemical principles behind art-making, stimulating students' interest in STEM while also increasing their appreciation of art.

In the end-of-semester survey, students consistently highlighted two main themes regarding whether the course met their expectations: their enjoyment of the lab activities and case studies, and their appreciation for the interdisciplinary aspects of the course. Lab activities such as synthesizing pigments, exploring ceramic glazes, and investigating unknown color changes required students to actively engage with

the content and collaborate with their peers. This active participation enhanced their learning experience and allowed them to develop critical thinking and problem-solving skills. Overall, the majority of comments shared were positive. For instance, a student noted, "I really enjoyed problem-solving the blue color change of our synthesized paint. I also enjoyed applying what we learned to my second case study." Another remarked, "The lab was very helpful in terms of applying lecture information in a real-life context."

The course also facilitated community engagement through various outreach activities. Students participated in museum visits and guest lectures, which enhanced their learning experience and fostered connections with the broader community. These interactions provided real-world insights and helped students see the practical applications of their studies. Involving museum curators and professionals from different fields created a dynamic learning environment that benefited both students and the community. One student shared, "My favorite parts of the course were the out-of-class excursions and learning from professional art curators/ conservators/ scientists." Another mentioned, "The RISD museum trips were awesome, as well as the tours of equipment Brown has."

While the course achieved its primary objectives, there were suggestions for improvement. Students expressed a desire for more seminar-style discussions, which could further enhance engagement and communication skills: "I wish we had more chances to discuss ideas seminar style." Feedback also suggested a need for more time dedicated to art history and additional case studies: "It would be nice to have a seminar style class. I do wish there was more time to just discuss and 'be off-topic,' especially during the first few classes." A new class is being developed that will build on the Chemistry and Art course, with a greater emphasis on art history and delivered in a seminar-style format.

Overall, the integration of real-world experiences into the curriculum underscored the practical relevance of the course content and enriched the educational experience. As one student summarized "[the course] did an excellent job blending both lecture-based, conceptual content with interactive activities that also engaged community members and other faculty members from both RISD and Brown. I enjoyed the blend of the two." Another student added, "I wanted to apply my chemistry knowledge to art in a hands-on way, and we did just that through lab activities, museum visits, and our semester-long case study."

UTRA Program

The UTRA program at Brown University plays a critical role in facilitating collaborative projects and translating research into various initiatives (Klara, et. al., 2013). UTRA supports outstanding undergraduates by enabling them to collaborate with faculty on curriculum development and fostering innovative teaching materials and hands-on activities. This program is unique in its emphasis on student involvement in research and teaching, designed to nurture a collaborative environment.

Collaborative activities in undergraduate chemistry courses significantly increase student engagement and improve learning outcomes (Reid, et. al., 2022). Students working in collaborative environments are more likely to participate actively, share

ideas, and develop a deeper understanding of the material. This aligns with the goals of the UTRA program, which seeks to promote close collaboration between students and faculty, thereby enhancing the educational experience.

In addition to fostering collaboration and integrating research into teaching, the UTRA program emphasizes the development of problem-solving skills. Interdisciplinary studies promote critical thinking, creativity, and the ability to synthesize information from various fields, skills increasingly important in today's world. The incorporation of research-led teaching in higher education fosters a research culture among students and enhances their engagement with the subject matter (Healey, & Jenkins, 2009). By working together on projects and sharing insights, students enhance their learning through peer interaction and collective problem-solving, preparing them for real-world scenarios where collaboration and teamwork are essential.

The program's flexibility allows for a wide range of projects, from scientific research to the development of multimedia educational content. This adaptability ensures that the UTRA program can meet the diverse interests and needs of students, providing them with opportunities to engage in meaningful, relevant research and teaching activities. Whether students are delving into complex scientific experiments or creating innovative digital learning tools, the UTRA program equips them with the skills and experiences necessary for their academic and professional futures.

Moreover, UTRA fosters a sense of ownership and motivation among students by involving them directly in the educational process. This hands-on approach not only enhances their understanding of the subjects they study but also instills a passion for continuous learning and inquiry. By empowering students to take an active role in their education, UTRA helps cultivate the next generation of scholars, educators, and leaders who are well-equipped to address the multifaceted challenges of the modern world.

The UTRA program at Brown University exemplifies the powerful impact of collaborative, student-led, and interdisciplinary methodologies in higher education. By supporting student-faculty partnerships and integrating research into teaching, UTRA enhances student engagement, learning outcomes, and the overall educational experience. The program's adaptability and emphasis on critical thinking and problem-solving ensure that it remains relevant and beneficial to students with diverse interests and aspirations, making it a model for other institutions seeking to innovate and improve undergraduate education.

Challenges

Some of the approaches described in this paper face implementation challenges, especially in large undergraduate classes. The case study approach requires extensive discussion and active participation from all students. Facilitating meaningful discussions and ensuring that each student has the opportunity to contribute can be logistically challenging. It may also be difficult for instructors to provide personalized feedback to each student, decreasing the efficacy of the case study approach.

The creation of novel teaching materials by students may be less feasible for universities lacking grants to support undergraduate summer research projects. These projects often require funding for materials, resources, and student stipends.

Without access to such grants, universities may struggle to implement this aspect of the course, limiting students' opportunities to engage in hands-on research and creative development of course materials.

Due to the course schedule and activities, this class can only accommodate a limited number of students. The constraints of some activities, such as laboratory exercises that require specialized equipment and close supervision, necessitate smaller class sizes to ensure a safe and effective learning environment. This limitation can restrict the number of students who can enroll in the course each semester, making it less accessible to the broad student population.

Furthermore, it is difficult to meaningfully and quantitatively assess this course's effectiveness. With a limited number of students enrolled each semester, it can be challenging to gather statistically significant data that accurately reflects the course's impact. This can hinder the ability to make data-driven decisions about course improvements and to demonstrate the course's value to stakeholders.

Future Directions

Future work will focus on specific initiatives to further enhance the Chemistry and Art course, emphasizing the integration of collaborative, student-led, and interdisciplinary methodologies.

Developing new comprehensive assessment tools that are better suited to small sample sizes will be crucial. This may include qualitative assessments through student interviews, focus groups, and detailed feedback surveys. By gathering in-depth feedback, we can gain a better understanding of the course's impact on students' learning experiences and identify areas for improvement.

Furthermore, with the course's current limitations in student enrollment, it is essential to explore ways to scale certain activities and methodologies for larger class sizes without compromising quality. This could involve adapting and re-designing how various components of the course are delivered. For instance, creating online modules for theoretical content can free up in-person class time for interactive, hands-on activities. Incorporating peer-led workshops and study groups can help manage larger groups while maintaining the collaborative and student-centered nature of the course.

Expanding the range of outreach into the community will further enrich the course and increase its interdisciplinary nature. Future iterations could incorporate collaborations with more departments, such as environmental science or sociology, to provide students with a broader perspective. Developing projects that address real-world problems, such as sustainability in art materials or the impact of art in community health, can provide practical applications for interdisciplinary learning. To emphasize this, more guest speakers and demonstrations from those in various disciplines can be incorporated into the course.

Finally, continuing to establish a feedback loop for continuous course refinement based on student and faculty input will ensure the course remains relevant and effective. Course materials, activities, and methodologies should be updated for each year in response to feedback, helping to maintain high student engagement.

By addressing these initiatives, we aim to significantly enhance student outcomes in the Chemistry and Art course, establishing it as a benchmark for integrating collaborative, student-led, and interdisciplinary education in higher education. These efforts will ensure that the course meets the educational needs of current students and becomes more accessible to a broader audience. By continuously refining and expanding the course, we aspire to create an inclusive, dynamic learning environment, setting a standard for innovative teaching methodologies.

Conclusions

The strategies discussed in this paper – combining collaborative, student-led approaches with interdisciplinary methodologies in a case study setting – demonstrate significant potential for application across various academic institutions. By fostering collaborative efforts, students are encouraged to work together, share ideas, and learn from each other's perspectives. Student-led work empowers students to take charge of their education, instilling a sense of ownership and motivation that is often lacking in traditional instructor-led courses. This heightened engagement helps students develop critical thinking, problem-solving, and teamwork skills. The combination of interdisciplinary and case study methodologies enable students to see the connections between different fields of study, leading to more meaningful and impactful educational experiences. This holistic approach prepares students for real-world challenges, where solutions frequently require knowledge and skills from multiple disciplines.

Programs like UTRA provide a robust framework for implementing these innovative strategies. UTRA bridges the gap between research and teaching, offering students the opportunity to engage in hands-on, practical projects that complement their academic studies. By participating in such programs, students can actively shape their educational experiences, tailoring their learning to their interests and career goals.

For schools that do not have programs like UTRA, there are several ways to adapt and implement similar collaborative and student-centered approaches with limited resources. Schools can make use of existing resources, such as faculty expertise and student enthusiasm, to develop collaborative projects. Faculty can guide students in research and curriculum development, creating a dynamic learning environment without requiring additional funding. Encouraging faculty to involve students in curriculum development and research can create opportunities for student-led initiatives, tapping into the creativity and energy of the students.

The combination of collaborative, student-led, and interdisciplinary methodologies, implemented through a case study approach, offers a versatile strategy that can be applied in any educational setting. These methods foster a more engaging and comprehensive learning experience, equipping students with the knowledge necessary to navigate and address real-world problems. By adopting these strategies, educators can enhance the quality and impact of education across diverse academic disciplines.

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