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Research in the Classroom: Introducing Nanomaterials at a Two-Year College

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Abstract

This article illustrates how the authors transformed "research in the classroom" into chemistry courses at a two-year college in the form of a short course-based research experience. The students worked in groups to research nanomaterials, came up with a series of carbon nanoparticles precursors from waste materials, and developed simple and cost-effective methods to produce carbon nanoparticles. Not surprisingly, students became more active learners as they were in charge of learning and were given authority to modify lab activities with their learning experience progressing. A deeper approach to learning helped students better appreciate chemical sciences, increase conceptual learning, and become responsible citizens. The project helped improve students' critical thinking skills and raise awareness of the relevance between students' learning in chemistry and real-life experience. It also provided a platform to discuss sustainability, green chemistry, and nanomaterials. To increase the efforts for student success, academic technologies were utilized to aid the project.

Keywords: *Chemistry; Course-based Research; Nanomaterials; Academic Technology*

INTRODUCTION

Teaching and motivating students are challenging tasks in a typical chemistry course, especially in a two-year college environment (Widanski et al., 2009; Cohen et al., 2019). Most students view chemistry as math-intensive and irrelevant to their daily life. They also perceive the learning experience in chemistry courses as ineffective and uninspiring, quickly losing interest and eventually dropping out of the course. Given these circumstances, a perpetual endeavor among faculty members teaching chemistry is how to make students interested and excited in learning about the subject (Hagedorn et al., 2012; Chen, 2013). To promote and enhance the learning experience in chemical education to further student engagement, we implemented a short course-based undergraduate research experience (CURE) in general chemistry courses. The benefits of integrating a CURE into the course-context have been well documented (McDonald et al., 2019). In CUREs, students conduct authentic research in a classroom setting and gain four elements of research experience: the use of science practices, novel discovery, collaboration, and iterative feedback (Auchincloss et al., 2014). Providing CUREs in traditional courses could reach a broader audience of students who might be ineligible for taking part in a mentored early research experience (Hurtado et al., 2008; Kuh, 2008). CUREs also offer metacognitive benefits in problem-solving (Wei & Woodin 2011; Dahlberg et al., 2019). However, developing CURE courses requires strong logistical planning, institution-wide backing, and financial support (Bangera & Brownell, 2014). To overcome these barriers, the shorter (or mini) CUREs version is a growing alternative pedagogy (Tomasik et al., 2013). It has proved to be as effective as standard CUREs in enhancing the student approach to problem-solving (Stein et al., 2004; Dahlberg et al., 2019). It is also easy to integrate into an existing course as an embedded module (Howard & Miskowski, 2005). The overarching goals of the project are to increase awareness of environmental issues, connect learning from the classroom to the real world, and develop analytical and

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critical thinking skills. To achieve these goals in the form of a short course-based undergraduate research experience, students in general chemistry embark on a scientific journey to develop a facile preparation of carbon nanomaterials from biomass and/or waste. The students were introduced to nanoscience topics at the beginning of the semester as the authors shared their current research related to nanoscience to recruit potential STEM majors. To some extent, students deemed nanomaterials as aspects of their daily lives, from cosmetics to drug delivery (Ray et al., 2009), and learned of the integration of green chemistry to nanotechnology. The growing need to incorporate nanomaterials into undergraduate chemistry curricula has been widely discussed, yet there have been few activities at an entry-level (Ping, 2009; Sharma et al., 2012; ACS Curriculum Guidelines, 2015; Park, 2019).

THEORETICAL PERSPECTIVES

Research Method

"General Chemistry" is a four-credit course in which lecture and lab are combined, typically with twenty to twenty-four students enrolled, and four sections offered every semester. The short CURE was implemented to a first sequence of general chemistry for Science and Allied health program majors. It is noteworthy that the college offers a twelve-week schedule and two Community Days in the Fall/Spring semesters. In order to streamline instructions, well-planned Community Days, in-class lab activities, and a field trip to core science facilities are crucial to make the project fruitful.

The structure of the short course-based research project addressed herein required three full class sessions and two Community Days; students worked in groups of three to four on the project.

In session one, students learned about nanomaterials and their applications. As a group, they were given reading materials on carbon nanomaterials as well as relevant articles from Scientific American and Chemical and Engineering News (C&EN). They brainstormed what potential carbon nanomaterials precursors could be of interest. Topics included food waste, waste cooking oil, waste orange peels, and dairy waste. However, an article on the environmental threat of acid whey in the production of Greek yogurt (Erickson, 2017) piqued the students' interest most as they were introduced to "Fermentation Process and Metabolism" in a previous lab activity of Energy. Making Greek yogurt is another way to connect the concept of the fermentation process to real-life applications, as well as recapture a large amount of dairy waste created in the process. Approximately 67% of the milk used in Greek yogurt production becomes acid whey (Wherry et al., 2019). Acid whey, with a pH between 3.57 and 5.10, is not allowed to be discharged to sewage because it contains large amounts of lactose, which increases biochemical oxygen demand, perils aquatic and microbial lives (Alsaed et al., 2013).

After discussing their project, students leveraged the two Community Days to extend their experiential learning outside of the classroom to collect their research material. Students called and visited yogurt manufacturers around New York City collecting acid whey, while some brought it from homemade yogurt (Figure 1).

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Figure 1. Acid whey collected during strain

In session two, each group shared their experiential learning experience on Community Days and then synthesized carbon nanomaterials from their acid whey. The carbonization of acid whey is straightforward as it contains lactose, a good source of carbons: 1.5 mL of concentrated sulfuric acid was mixed with 20 mL of acid whey, and the mixture was heated for forty-five minutes. The aliquot was taken about every fifteen to thirty minutes to observe its fluorescence under UV. The series of aliquots are shown in Figure 2 in daylight (top) and under a UV lamp (bottom). The as-prepared carbon nanomaterials were irradiated by a UV lamp at 365 nm wavelength, further separated by filtration and centrifuge. This part could be done in a three-hour lab period.

In session three, the students measured their products by UV-Vis spectrophotometer and collected Transmission Electron Microscopy (TEM) images (Figure 3). As the college lacks advanced instrumentation, the students took a field trip to the Advanced Science Research Center (ASRC) nearby and observed how their data is being collected by Fluorescence spectrophotometer and TEM. The activity fostered a collaborative learning community, enhanced engagement by comparing data across all other groups, and provided opportunities to brainstorm ideas for writing a comprehensive lab report. In addition, the students were required to upload their work to ePortfolio for evaluation.

Incorporation of Academic Technology:

ePortfolio is a way for our students to create a digital narrative of their academic journey by collecting and showcasing the work they complete throughout their time at the college. ePortfolios have become an important teaching tool, emerging as a way for students to present an evidence-based, professional account of their knowledge and skills (Parkes et al., 2013). These portfolios can be shared with professors, other students, the college as a whole, and publicly as well.

A template of the project was created and shared with all students, which allowed them to view instructional prompts, easily re-create sections or content areas, and find other information required to complete the assignment. A tutoring session was offered to provide technical support in creating the ePortfolio and adding artifacts to the sections included in the template. Sections included an abstract, pre-lab question, field trip report, experimental methods and observations, data, graphs, conclusions, post-lab questions, and references (Figure 4). Not only does this framework offer a convenient space for students to upload their work, but they can also easily submit the project for review.

FINDINGS AND DISCUSSION

The project provided benefits by incorporating undergraduate research opportunities to students who otherwise don't have the time commitment for traditional early research experience. As our students prepared bright blue fluorescent carbon nanoparticles by heating acid whey in the presence of a catalytic amount of concentrated sulfuric acid and monitored its fluorescence intensity by 365 nm UV as shown in

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Figure 2, they investigated that fluorescence intensity was maximum after forty-five to sixty minutes of heating. After forty-five minutes of heating, the aliquot was chosen as their sample and further characterized.

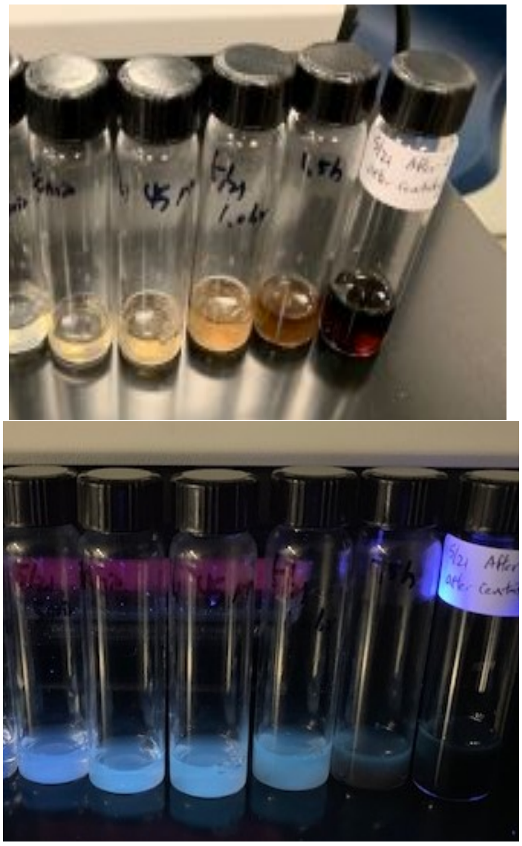

Figure 2. Sample aliquots in daylight (Top), under 365 nm UV irradiation (Bottom).

Figure 2 is shown that fluorescence was most intense after about forty-five to sixty minutes of heating.

Each group analyzed their aliquot solution by UV-Vis spectrophotometer. Measuring and interpreting spectra provides students with the development of analytical skills and techniques. However, some of the characterizations were challenging as the college lacks advanced instrumentation. But in collaboration with the ASRC, students were able to measure the size of their product.

Prior to measuring the size of their carbon nanomaterials, the class reviewed the scale of the nano world, learned about the functions of transmission electron microscopy (TEM), and prepared samples by dropping five microliters of their sample on a 300 mesh TEM grid with carbon support film. At the ASRC, the students observed how their samples were measured on a 200 kV Themis, learned of the morphology as well as the size of their particles and recognized the agglomeration of carbon nanomaterials on the grid. The size distribution of each sample showed around 10-20 nm, providing a teaching and learning moment in which students discussed why their sample needs to be called carbon nanoparticles, not carbon quantum dots, as the latter is defined by size less than 10 nm (Li et al., 2012). Using their critical thinking skills, students speculated that particles less than 10 nm could be observed if there were no agglomeration on the grid, suggesting that the sample be centrifuged at a much higher speed or change reaction conditions

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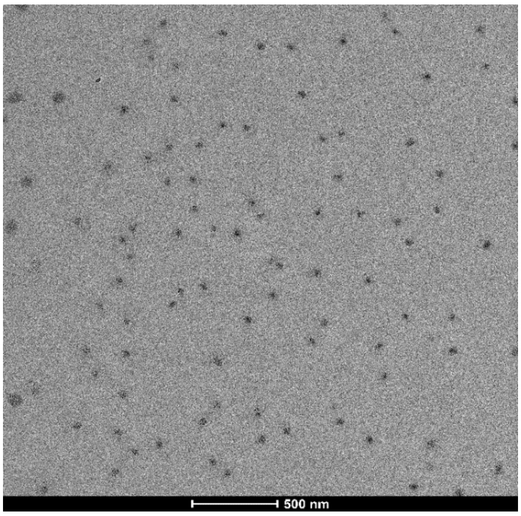

Figure 3. TEM image

The project represents ten percent of the final grade in the course. The extent to which students accomplished the learning goals was measured through course performance based on group presentations, notebook keeping, individual progress lab reports, comprehensive group lab report, individual and group quizzes related to the project to reinforce a team effort, as well as a voluntary and anonymous written student survey. Overall, the students genuinely enjoyed synthesizing carbon nanomaterials from dairy waste and visiting the cutting-edge core science facilities to observe the characterization of their products.

Determining the degree to which the project increases student success needs a larger sample data. However, we found that 83.3% of students earned grades of C or better in the short CURE embedded course, as compared to 67% in the traditional general chemistry course. The performance rate herein excludes students who withdrew prior to commencing the project. The outcome indicates that the integration of this experience increases students' motivation, retention, and completion. Moreover, course evaluations and feedback on the project were very positive, saying the activity provided opportunities to discuss current scientific issues and the applications of waste, collect and interpret data, and gain knowledge of STEM-related career paths. In addition, some of the students went on to present their work at the 67th Annual Undergraduate Research Symposium (URS) - New York American Chemical Society (ACS). We also asked our students to anonymously write about their experiences. Some comments included:

Chemistry is part of our life, and I learn better and never forgot what I learned about nanomaterials from waste.
Things I found valuable about doing this project is being able to make nanomaterials from dairy waste, never thought I could do this.
The project was really fun and interesting. I want to explore new ways to make carbon dots and do more informative experiments.
A visit to the research center made me reconsider my current major path.

Having this project submitted through ePortfolio is also helpful to our assessment processes. The same platform allows us to collect and house submitted assignments for review during the college's assessment days. We can look at student work and evaluate it according to program and course learning outcomes. Most students were well versed in the use of ePortfolio and did not require supplementary help with the program. Few students experienced issues with incomplete assignments due to not publishing the finished pages of their ePortfolio or incorrectly submitting the assignment. With continuous use of academic technologies, the hope is that students will have an enhanced learning experience and develop transferable skills to take with them when they transition to a four-year institution.

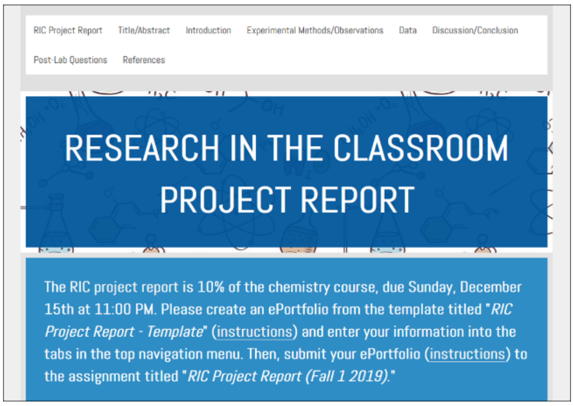

Figure 4. ePortfolio template

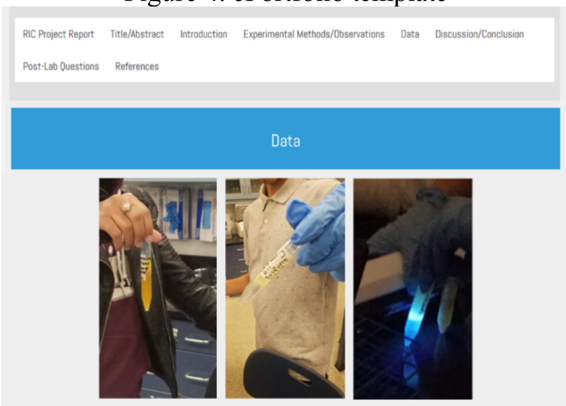

Figure 5. ePortfolio student submission

CONCLUSION

The integration of a short CURE into the course has reinvigorated how learning, teaching, and research can increase students' retention and engagement. The project, without a doubt, has provided students with chemistry-related research experience in the context of cultural and societal issues and cutting-edge scientific research on nanoscience to increase understanding of nanomaterials applications. It also helps improve students' critical thinking skills and raise awareness of the relevance between students' learning in chemistry and real-life experience. The instrumentation needed for the project, however, required well-planned collaboration with other institutions for the integration of a field trip to the core science facilities. The visit provided the students with an enhanced learning experience, interaction with other research scientists, and learning about their research projects and careers in STEM areas.

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