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The Implementation of a Service-Learning Component in an Organic Chemistry Laboratory Course

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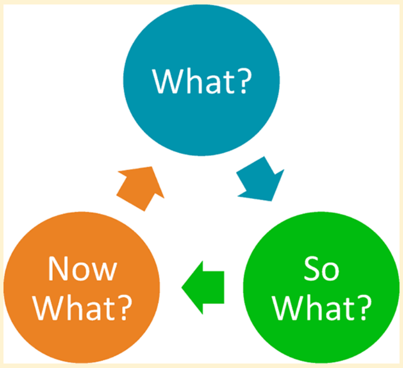
Supporting Information

ABSTRACT: Education institutions globally are increasingly expected to explore avenues for the implementation of service-learning into their curricula. A second-year undergraduate organic chemistry laboratory experiment, in which the undergraduate students make azo dyes, can provide a vehicle for a service-learning module in which university undergraduate students then teach students from resource-limited secondary schools how to make azo dyes. Evidence is provided to show how the theory is reinforced for both sets of students through a shared practical experience. The practical application of chemistry is conveyed through the use of the synthetic azo dyes to dye t-shirts. The results of this study show that the service-learning experience clearly assists undergraduate students to appreciate the role of chemists in the broader society while at the same time increasing awareness of the inequalities in school education systems.



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A new challenge facing education institutions today is incorporating learning in activities that not only gives the undergraduate student a mark at the end of the course, but also has a positive influence on the surrounding community.[1] Worldwide there is a call for higher education to produce people with civic competencies and responsiveness to the society in which they live.[2]

There is a need for more people to be educated in the fields of science, engineering, and technology (SET)[3−6] in general and in chemistry in particular[7] and to keep young people interested in science.[8,9] There is a lack of qualified science teachers[10−13] in secondary schools and in many schools there are few opportunities to do practical laboratory work.[14,15] The lack of practical science teaching at resource-limited schools provides a window of opportunity for universities to work with these schools to provide some form of practical science experience in university laboratories.[16] Experiential methods of education that incorporate engagement with the community have been used to increase the number of science graduates,[12,17,18] and it is hoped that such community engagement will benefit more undergraduate students in the future.

The traditional chemistry laboratory approach has been criticized for being a "cookbook" or verification exercise that does little to help students learn concepts,[19,20] with students following a recipe and not necessarily thinking about the purpose of the laboratory work. A practical laboratory session needs to be appropriately designed and managed because, if students do not see the value in the experience, the enthusiasm of both teachers and students quickly declines.[21] Thus, if the purpose of the exercise is hidden, very little learning will take place. It is necessary to evaluate students' learning during the laboratory session in the context of these reasons and conditions for doing laboratory work.

The aim of this research was to explore the learning that takes place during a structured laboratory session within a service-learning context. Bringle and Hatcher[22] define service-learning as a

> *"course-based, credit-bearing educational experience that allows students to participate in an organized service activity that meets identified community needs and reflect on the service activity in such a way as to gain further understanding of course content, a broader appreciation of the discipline, and an enhanced sense of civic responsibility."*

With particular emphasis on the undergraduate students, the research aimed to discover how these areas of learning impact on the awareness of the parties involved with regard to the discipline of chemistry, as well as the complex social issues that characterize modern and developing multicultural societies. Changes in individuals' ideas about themselves and their

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discipline, as well as the value of the knowledge they gain at university, were investigated.

In the context of this research, "graduate students" were employed by the university to facilitate the running and marking of laboratory practical classes (referred to here as "labs") and "observers" were participant observers including the researcher, the graduate students, and lecturers. There was also an "independent" observer who was outside of the chemistry department and was not a participant in the running of the lab.

■ IMPLEMENTATION

Introduction Activity

This service-learning module was part of an organic chemistry laboratory course at the second-year undergraduate level. Undergraduate students were given a lecture introducing the concept of service-learning, and at the lecture they were given an assignment, viz. to write an essay on "The Chemistry of My Favorite Color". The aim of the essay was to promote an interest in the chemistry of dyes and to provide undergraduate students with the necessary background in dyes and dyeing and the chemistry related to the dye industry before they entered the laboratory.

Azo Dye Labs

The azo dye laboratory work was based on the experiment of the same name.[23] Because the aim of service-learning was to work collaboratively and interact with others to reach conclusions, this particular experiment, where there was both individual and group work, was ideal. This dye lab was carried out over two, 4-h sessions separated by a week, with undergraduate students working in pairs. During the first week, each pair made a different colored azo dye (instructions to students are included in the Supporting Information) and planned for the following week's lab when grade 12 secondary-school students from resource-limited schools would join them. During both labs, graduate students helped and advised the students with the practical aspects of the laboratory work and evaluated the lab reports afterward.

In the first lab, the principle of combinatorial chemistry was shown by generating a number of brightly colored dyes using one common reaction, the diazo coupling, and two common reactants with minor variations in their substituents. Each undergraduate student bench was turned into an individual "well" in terms of combinatorial chemistry. At the conclusion of this experiment, students were asked to discuss the relationship between chemical structures and function when comparing the dye chemical structures and the cotton strips treated with their azo dyes. The pedagogical value of this experiment lay in a demonstration of the structure−function relationship with bright colors; there was a tangible way to see the effect that a minor chemical structural change can have on the color of a dye.[15] During the first lab undergraduate students stuck their dyed strips onto a grid drawn on the board in the laboratory. The grid was arranged and labeled in the same way as the benches. This enabled the whole laboratory to see the changes in color and shading as a result of the different substituents used. A poster with chemical structures, dye colors, and UV spectra was produced after the first lab, and from this, students could compare all probable resultant dye molecules, the resultant dye colors, the UV spectra, and the reaction scheme (poster is included in the Supporting Information).

As part of the preparation for the service-learning component, undergraduate students completed a prereflection and planning task (see the Supporting Information) while they were busy with the initial dye preparation. This task was based on a simplified version of Kolb's Learning Cycle.[24] This "What? So what? Now what?"[25a] model prompted students to think more deeply about the experience of carrying out an experiment for the first time. Answering the "What" question involved students asking themselves the question, "What am I doing?" The next step involved understanding the reasons why these skills or concepts are important (So what?), which is a critical thought process. Extending their recently acquired practical experience and associated skills to plan for the future, in this case the second lab with the grade 12 secondary-school students (Now what?), was a decision-making step. The "Now what?" stage was the most important aspect of the process in terms of encouraging undergraduate students to plan for and think about the service activity and think of ways to incorporate secondary-school students into the experience.[25a] Graduate and undergraduate students all commented on how this activity encouraged them to think about the synthesis of azo dyes in a new way, and undergraduate students commented in their reflections that they understood the chemistry behind the experiment much more thoroughly than they usually did.

For the second week of the lab, 14 grade 12 secondary-school students from two resource-limited schools were invited to join 36 second-year students in the laboratory to make azo dyes and to dye t-shirts.[26] Undergraduate students were briefed as to the level of understanding to expect from secondary-school students and as to the prior knowledge they might have. They were also made aware that not all secondary-school students would necessarily be at the expected level. A group of two or three secondary-school students was assigned to each laboratory bench of three or four pairs of undergraduate students. Undergraduate students were tasked with leading the secondary-school students through the preparation of an azo dye in the laboratory, explaining the theory, and emphasizing laboratory safety. The most important aspect of the exercise was that undergraduate students were given "control over their learning by allowing them to make decisions in directing their own learning".[25b] Undergraduate students decided for themselves how they would engage secondary-school students in the lab work required to make the dyes. Although the diazo coupling reaction was beyond the scope of the grade 12 chemistry curriculum, as it was an electrophilic substitution reaction, undergraduate students were able to connect the mechanism to the prior knowledge of the secondary-school students. This also provided an opportunity for the secondary-school students to revisit functional groups and to see the difference these made in the color of the dyes. A motivation throughout the lab was that undergraduate students would use their synthesized dye to dye a t-shirt, using tie-dye methods, which would be given to the secondary-school students as a visible record of achievement in the laboratory. These t-shirts were left to dry and then washed at the chemistry department before being given to the teachers at a later date to return to each secondary-school student. This was to ensure that no unreacted starting materials or excess dye remained on the t-shirts.

This service-learning in organic chemistry lab has subsequently been repeated twice, with 140 undergraduate students interacting with 50 secondary-school students from five different schools and one lab where the community partners were teachers from local schools.

Post-Lab Exercise

Post activity group reflections were based on the "What? So what? Now what?" model (see the Supporting Information).[25a] The undergraduate students and secondary-school students were asked to focus on what they learned, how the experience was deemed to be useful, and also how the whole exercise could be improved upon for future courses. This group reflection was recorded in writing and fulfilled the requirement that peers, community, and staff should be involved in reflection and discussion.

■ STUDENT ASSESSMENT DISCUSSION

The service-learning exercise was assessed on a number of levels. During the two labs, undergraduate students were observed, and all undergraduate students were required to do reflections, as well as complete questionnaires. The marks undergraduate students achieved for the service-learning module counted 4% toward their final semester mark.

First Lab Exercise

To answer the question: "How does service-learning change the way chemistry is learned and perceived by a student?", a comparison was made with a "normal" chemistry lab, where students often see the lab as a process of following a recipe.[19,20] Critical thinking is rarely employed, and a deeper conceptual understanding of the processes being "practiced" and their connection to the real world is obscure. When these undergraduate students entered the laboratory for the initial dye lab, most of them had researched and written the first draft of their essay on dyes and dyeing. From the essay, they learned that the discovery of dye synthesis was the start of the modern chemical industry and, thus, realized the importance of the lab and dye synthesis.

All observers (graduate students and a lecturer) noted that there was a change in the levels of engagement within the class; undergraduate students were asking many more detailed, chemistry-related questions than usual and asking fewer questions specifically related to the writeup of the lab work. The graduate students, who had worked in the class over the whole term, concluded that this improvement in approach to the lab was a direct a result of the reflection grid the undergraduate students needed to complete during the lab session. Another possible factor was that students needed to know the chemistry to teach the grade 12 secondary-school students the following week.

Undergraduate students were more interested in *why* processes in the lab were done in a certain way and *what* was happening chemically at each step. Graduate students felt challenged because, in the past, the undergraduate students had always accepted "quick answers" to their questions, but in this format they probed deeper into the graduate students' knowledge to gain a better understanding.

An experienced graduate student observed that students were more interested and excited about the dye lab than previous labs. The same graduate student noted that, in order to prepare for the second lab, undergraduate students thought more about what they were doing in the lab experiment in order to explain it successfully to secondary-school students the following week. The result was a critical examination of the practical aspects of azo dye preparation and a self-evaluation of their own laboratory skills and limitations. In the graduate students' opinion, students were excited and were enjoying chemistry more because "it wasn't just book chemistry, you know?"

All observers were aware that many undergraduate students were anxious about their impending interaction with secondary-school students the following week. Many undergraduate students took the responsibility seriously and expressed concerns that their own understanding of the material was not good enough to be able to teach it properly. This self-reflection showed that, while students were seeking to understand the chemistry, they were also focusing on the learning outcomes for secondary-school students and that this preparation guided their own learning and helped them to focus on the various aspects of the process.

Observers agreed that the completion of the reflection and planning task during the course of the lab was a valuable learning tool that prompted undergraduate students' critical engagement with the chemistry involved. Undergraduate students also commented on the value of the reflection task, saying that it made them think about the lab more and guided them to ask the right questions so that they could understand each aspect of the lab work better. Many undergraduate students were enthusiastic about the impending service-learning and said they had enjoyed writing an essay on the chemistry of their favorite color. These observations were corroborated by undergraduate students' written reflections and their responses to open-ended questions in the questionnaires.

Second Lab Exercise

Of particular interest during the second lab was the learning that took place among the second-year students and the interaction with grade 12 secondary-school students. Observers were instructed to look at interactions between secondary-school students and undergraduate students, as well as comment on undergraduate students' knowledge of the chemistry of azo dyes, aspects of laboratory safety, and undergraduate students' ability to simplify and explain the theory and to involve secondary-school students in the lab experience.

The independent observer noticed a level of excitement and enjoyment between both undergraduate and secondary-school students and that secondary-school students were getting individual attention from undergraduate students. Teachers of secondary-school students were equally excited about the level of attention given to secondary-school students and grateful for the unique opportunity for lab skills development that the exercise provided. Teachers thought that undergraduate students explained the theory well and integrated secondary-school students successfully into the laboratory practice, for whom it was all a new experience.

Undergraduate students were nervous to begin with and initially explained the chemical structures to secondary-school students, showed them the material safety data sheets, and how to do necessary calculations. Undergraduate students found the poster with chemical structures, dye colors, and UV spectra a useful teaching tool (poster is included in the Supporting Information) to show secondary-school students the chemistry behind the lab work. Because secondary-school students were assigned to groups of undergraduate students rather than to specific individuals, undergraduate students were able to share the responsibility for secondary-school students in ways that suited their strengths. There were a few undergraduate students who did not interact easily with secondary-school students, even though their understanding of the chemistry was above average. On the other hand, some undergraduate students were observed to be excited and enthusiastic about teaching

Table 1. Questions Used in the Pre- and Post-Questionnaires

Question	Pre-Service-Learning Questionnaire (Figure 1A)	Post-Service-Learning Questionnaire (Figure 1B)
1	I think that I shall learn from the community members.	I learnt from the community members.
2	I will have the opportunity to apply my knowledge.	I had the opportunity to apply my knowledge.
3	Service-learning will assist in preparing me for the world of work.	Service-learning assisted in preparing me for the world of work.
4	Service-learning will help me gain insight into my role as a responsible citizen.	Service-learning helped me gain insight into my role as a responsible citizen.
5	Service-learning will contribute to my growth and personal development.	Service-learning contributed to my growth and personal development.
6	—	Service-learning contributed to my understanding of diversity.
7	-	All students should do service-learning modules.

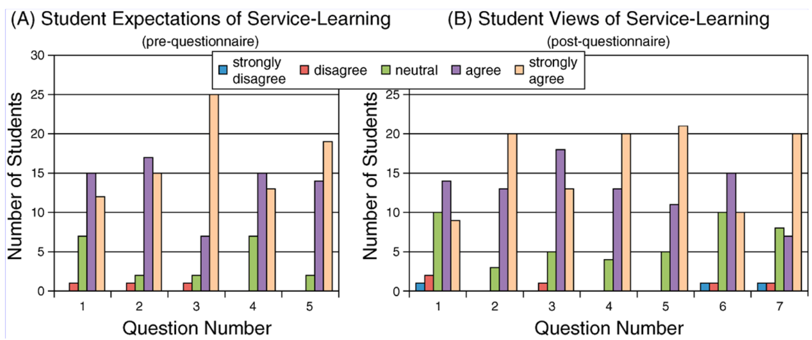

Figure 1. Bar graph showing undergraduate student responses to Likert-scale statements about their (A) expectations before the lab and (B) views after the lab.

secondary-school students, even though they did not fully understand the chemistry. Most undergraduate students' engagement with secondary-school students improved as the lab continued.

One undergraduate student commented that she never asked questions in lectures, but she had been so inspired by the secondary-school students' quest for knowledge that she had resolved to ask more questions in lectures. The experience had also made her realize what an opportunity she had to learn and that she had previously taken the university experience for granted until the service-learning exercise.

The independent observer was involved to pay more attention to secondary-school students and their participation. From her observations, it was clear that secondary-school students valued being participants and were excited about how they were shown and enabled to make measurements, to add chemicals, and to assemble the required laboratory equipment. At several levels, this was an unprecedented opportunity for secondary-school students to interact with science, especially in a university laboratory environment, something that had been foreign and inaccessible to them. Secondary-school students also spoke about how this experience had increased their interest in chemistry as a subject. Secondary-school students were able to speak in the "language of chemistry" when questioned by the independent observer.

A teacher from one of the schools involved also mentioned her delight at the individual attention her secondary-school students were getting. She pointed out that it was an ideal situation—one child with two experts—and spoke about how undergraduate students were really explaining well and involving secondary-school students. A teacher from a second school involved in the project pointed out that everything was new for her secondary-school students and articulated that in her classroom she could say things such as "You are supposed to wear a lab coat and goggles," but that her secondary-school students had never seen them in reality and the school did not have them. She said, excitedly, "they get to see what will actually happen if they study science."

The lab highlighted the application of science in industry and everyday life,[27] as well as the value of science in society. For secondary-school students, this lab activity provided a hands-on experience that supports this learning outcome, as well as the more specific organic chemistry mentioned earlier.

Post-Lab Exercise

Reflections were carried out in groups, with secondary-school and undergraduate students reflecting together on the lab experience. Participants noted how the lab had made the chemical theory real to them and had put chemistry into context. Most undergraduate students within the groups articulated that they had learned significantly more than in other lab exercises, by explaining the chemistry to secondary-school students and, without prompting, had identified this as one of the fundamental reasons for doing the lab with secondary-school students. Some groups had even suggested an extension of the lab session, requesting more time to explain and show secondary-school students the equipment.

A further important reflection to note is that of a lecturer who became involved in the running of this lab in its second year. Initially, the lecturer believed the lab to be too time-consuming, both administratively and practically. However, once she had experienced the increased level of engagement the undergraduate students had with the work, she was convinced that the service-learning lab was an important learning experience.

■ UNDERGRADUATE STUDENT ATTITUDES

Pre- and post-questionnaires were designed to evaluate the attitudes and experiences of undergraduate students toward chemistry and community service and to see if there were changes in the perceptions of undergraduate students as a result of their participation in the service-learning component of the lab. The questions used in the pre- and post-questionnaires are

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provided in Table 1. Figure 1 outlines the undergraduate students' expectations before and after the service-learning experience, respectively, with the question numbers correlating with the question numbers in Table 1.

In general, the questionnaire responses indicated that undergraduate students' expectations of the service-learning were met or exceeded. When this appeared not to be the case, a look at the individuals' responses to other open-ended questions and their reflections indicated that sometimes there were differences in perception as to the value of different types of learning, and whether certain changes in perception were seen as learning by the participants.

Question 4, which inquired whether the service-learning provided insight into undergraduate students' role as responsible citizens, had a much more positive response compared to the pre-questionnaire. The change in perception showed that the service-learning experience provided citizenship learning outcomes. A similar situation was seen with undergraduate students' opinions of their growth and personal development (question 5). Although undergraduate students in the pre-questionnaire were not negative in response to this question (Figure 1A), the increase in neutral responses (Figure 1B) could be due to different value systems attaching meaning to learning and development. Some students might not see overcoming obstacles and learning to work better independently or in a group situation as areas of personal development. Two questions were added to the post-questionnaire (questions 6 and 7 in Table 1, Figure 1B). The responses to these questions implied that the majority of students saw the value of the service-learning module.

Undergraduate students were also asked about what service-learning had taught them in terms of citizenship and responsibility (Table 2). The responses to the Likert-scale questions are shown in Figure 2.

Table 2. Questions in the Post-Questionnaire Related to Citizenship and Responsibility

Question (Figure 2)	Question: The service-learning experience has affected me in the following ways:
8	Enhanced the value of my education
9	Changed my awareness of my immediate world in relation to the wider community
10	Changed the way I see my responsibilities as a person involved in Science
11	Made me more aware of inequality in our society
12	I believe it is important for me, as a person in science, to engage with the public and share my knowledge and experience with them.
13	I will get involved in other community engagement activities as a result of my experience in this course

Responses to questions 8 and 13 indicated that students felt that service-learning had enhanced their education (question 8), and the majority of students were influenced to take part in other forms of community service (question 13). Responses to questions 10 and 12 showed that students realized their responsibilities to communicate science to others. From the responses to questions 9 and 11, students became more aware of the wider society in which they lived and the great inequalities in society.

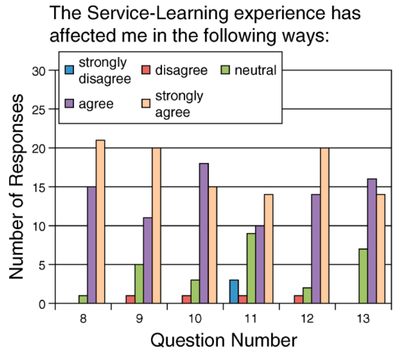

Figure 2. Bar graph showing undergraduate student responses to Likert-scale statements regarding their experience of service-learning in terms of citizenship and responsibility.

■ CONCLUSION

The service-learning module, which consisted of (i) an essay on dyes and dyeing, (ii) one lab in which undergraduate students learned to make azo dyes, (iii) a second lab during which undergraduate students taught grade 12 secondary-school students from disadvantaged schools to make azo dyes and then tie-dyed t-shirts, and (iv) reflection, was mutually beneficial to both undergraduate students and grade 12 secondary-school students. Undergraduate students interacted with experimental chemistry more than they had in previous labs because they realized that dyes have practical application and because they had to prepare themselves for teaching the secondary-school students. Undergraduate students also learned about diversity, being responsible citizens, and became more aware of doing community service to help others.

Secondary-school students, in turn, were exposed to lab work (some, for the first time), had the opportunity to interact with undergraduate students, and, most importantly, saw that, with this positive exposure to a university environment, tertiary education was accessible despite a disadvantaged background.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Student handout, including lab report form and planning and reflection task; instructors' notes; poster. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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