Sustainability, Energy, and the Green Economy: An Interdisciplinary Course on Environmental Sustainability and Life Cycle Analysis

By Monika Sikand, Claudio Mazzatenta, Keith Wong, Joseph Bush, and Aaron M. Socha

Interdisciplinary education offers a collaborative approach to multifaceted topics, such as environmental sustainability. In this article, we present the conceptual framework and lessons learned from a team-taught course, entitled Sustainability, Energy, and the Green Economy (SEGE). Faculty from the departments of Physics, Chemistry, and Biology offered the course during the 2015–2016 and 2016–2017 academic years at Bronx Community College (BCC). The described interdisciplinary approach was intended to engage students through research-driven, project-based learning using life cycle analysis (LCA) of a simple consumer product. By teaching solution-oriented approaches, SEGE translates complex real-world problems into classroom learning for non-STEM majors. As compared to student performance and engagement data from three 100-level STEM courses at BCC, analyses of C or above grade performance, passing rate, and withdrawal rate indicate that SEGE effectively engaged and retained students. Additionally, student surveys are presented, and were used to guide instructional strategy for effective team teaching and assessment.

Interdisciplinary education integrates knowledge and perspectives from different disciplines by coherently drawing on concepts, theories, and methods to address common and complex problems (Spelt et al., 2009; Holley, 2009; DeZure, 2010; NASEM, 2018). One of today's critical and complex problems is sustainability—defined as "development that meets the needs of the present without compromising future generations' ability to meet their own needs" (WCED, 1987). Sustainability is an approach and a practice that draws from many disciplines, and is applied in many contexts, as a corrective way forward in the face of climate change, resource depletion, and environmental degradation.

Many universities and professional organizations are now considering the tenets of sustainable development as guiding principles for education and professional practices, and have begun to integrate the values of sustainability into different aspects of learning (Vargas et al., 2019). The emphasis on sustainability in education has evolved from general core curricula, in disciplines such as chemistry, environmental science, and engineering, to degree- and certificate-level programs in colleges and universities. Universities are engaging faculty, staff, and students by implementing "green projects" and higher-level coursework in sustainability (Shriberg & Harris, 2012; Barlett & Chase, 2013; Paletta & Bonoli, 2019). Teaching and learning an area of study as multifaceted and broad as sustainability from the vantage point of a single discipline limits scope of inquiry and understanding. Sustainability should be taught from an interdisciplinary perspective (Kurland et al., 2010; Coops et al., 2015, Ceulemans & Severijns, 2019). Sustainability in the Urban Environment, a graduate program at the City College of New York and a certificate program, Green Technologies and Sustainability, at Bergen Community College in New Jersey are two such interdisciplinary programs in the northeastern United States. These programs also offer hands-on skills training, such as solar/photovoltaic installation and blueprint reading, thus providing workforce preparation.

In 2010, Kurland et al. piloted the course "Interdisciplinary Perspectives on Sustainability" and initiated a curriculum that advanced organizational change to educate more students about sustainability. Coops et al. (2015) describe the development and preliminary implementation of an entry-level, interdisciplinary sustainability course as part of a university-wide initiative to promote sustainability curriculum in an integrated and holistic way. While these programs were successful, interdisciplinary sustainability programs for liberal arts and sciences students at two-year colleges remain limited.

Sustainability, Energy and the Green Economy, taught within the City University of New York (CUNY) integrates concepts of sustainability by covering theory, content, and methodology from different disciplines. Instructors from the three disciplines—physics, chemistry, and biology—collaborated to engage students in a research-based project, a life cycle analysis (LCA) of a simple consumer product. Four-year colleges and universities have used LCA in sustainability education (Cooper & Fava, 2000a, b; Evans et al., 2008; Lin et al., 2012; Meo et al., 2014), but to our knowledge, this is the first study of its kind from a North American community college. The major themes of the course, sustainability, energy, and economics, address some of the most pressing issues of our time. As local and global citizens, students and faculty can benefit from targeted discussions emerging from diverse perspectives in the classroom setting.

Conceptual framework of the course

Leadership at BCC's Center for Sustainable Energy (CSE) directed the conceptual framework of the SEGE course. The CSE was established at BCC in 2004 to promote research and public awareness, and offer certificate-based workforce training programs in solar/photovoltaics and biofuels. SEGE was designed in 2014 for nonSTEM majors to fulfill a general education science requirement, and subsequently approved by the CUNY curriculum committee to be cross-listed in Physics, Chemistry, and Biology as PHY/CHEM/BIO 100. In any given semester, the course was team taught by one faculty member from each department. Students enrolled in SEGE through any of the three departments at BCC, and credits are transferable to all other CUNY colleges. Additionally, SEGE fulfills the scientific world general education requirement in the Associate in Science (A.S.) degree in the Liberal Arts and Sciences program at BCC. A version of the SEGE course was also offered to high school students under College Now, a CUNY-wide summer program allowing high school students to earn credit toward an undergraduate degree. This version of the course incorporated a lab, and ran successfully during the 2015–2017 summers as a recruitment tool for bioenergy/engineering courses developed under BCC's NSF Advanced Technical Education project.

Syllabus: To balance and integrate the content from three different disciplines, the 14-week syllabus (see Appendix A at https://www.nsta.org/online-connections-journal-college-science-teaching) was divided into physics, biology, and chemistry. The physics section covered basic physics of climate change, including concepts from oceanography, geography, and mathematics. The biology section covered ecosystems, threats to ecosystems, and relationships between humans and their environments and integrated anthropology, history, sociology, and politics. The chemistry section covered carbon, water, biomolecules and other materials, the global energy portfolio, and burgeoning renewable energy sector by exploring connections between consumption and quality of life using consumer economic trends. The last section of the course reflected on the following question: What is the road to sustainability? Maintaining the mission of the CSE, the course included an introduction to careers in renewable energy. Each instructor graded student work assigned during their individual teaching sessions; this included two quizzes (35% of the final grade) and classroom contributions and/or homework assignments (20%). Collectively, the instructors scored the midterm exam, which required students to outline their individual LCA research papers (10%). The final LCA research paper (30%), and an accompanying presentation (5%) was also assessed by the teaching team. For the LCA, each student selected one consumer product (e.g., an "energy beverage") and compared and contrasted two brands of this product type (e.g., Red Bull Energy Drink versus Bigelow Green Tea) in terms of LCAs. The goal of the final LCA project/presentation was to research, validate, and convince other students (i.e., consumers) about the LCA of the product and specific metrics by which to rank its overall sustainability.

Methods of instruction: The course format included two hours of lecture, plus a 50-minute recitation occurring after the lecture period to discuss lecture content, problems, or other relevant subjects. Each instructor coordinated and developed lectures based on syllabus content. Some lectures were taught by individual instructors, and some in a team-teaching format. The instructional strategies included traditional lecture-based methodology (including synchronous digital lectures), assignments, and quizzes. Nontraditional strategies included activities such as

TABLE 1

Number of enrolled students per semester in the four courses analyzed.

	SEGE	BIO	CHEM	GIS
Spring 2016	15	89	91	34
Fall 2016	11	94	75	43
Spring 2017	17	116	78	48
Average	14	100	81	41

energy scavenger hunts, "calculate your family's carbon footprint," and media screenings (*The Future of Energy,* Vice, 2017; *An Inconvenient Truth,* Guggenheim, 2006; *Before the Flood,* Stevens, 2016). These activities provided context to effectively discuss sustainability. The research-based LCA project was the most comprehensive activity of the course. It provided scientific literacy and dimensional analysis skills needed to understand the sustainability (or lack thereof) of products or processes. On the final exam day, students submitted a LCA research paper, along with a 15-minute presentation of their results.

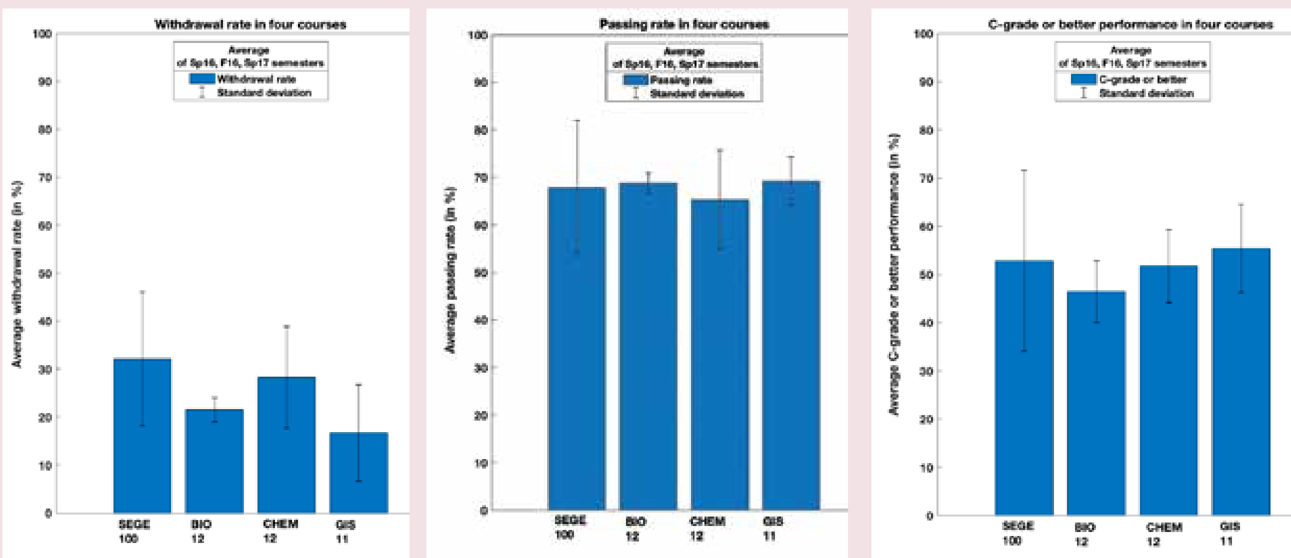
Textbooks and resources: The two textbooks used in the course were *Sustainability: A Comprehensive Foundation*, by Tom Theis and Jonathan Tomkin (2015), and *Environmental Issues: Looking Towards a Sustainable Future*, by Robert. L. McConnell and Daniel C. Abel (2012). A professional education short course, "Energy, Sustainability and LCA," by Timothy G. Gutowski (2014), was used as a reference to develop the project-based learning for the LCA research paper.

Results and discussion

Students from the liberal arts and sciences program and diverse major disciplines such as business administration and criminal justice enrolled in the SEGE courses. Student performance and retention in SEGE were compared with those in three other 100-level courses at BCC. General Biology II (BIO) and General Chemistry II (CHEM) are well-established second-semester courses typically taken by STEM majors. Geographical Information Systems I (GIS) was developed in 2015. All four courses analyzed fulfill the CUNY scientific world general education requirement in the Associate in Science degree in

FIGURE 1

Average data for (a) withdrawal rate, (b) passing rate and (c) C grade or better for SEGE versus BIO, CHEM, and GIS over three semesters (Sp16, F16, Sp17).



the liberal arts and sciences at BCC and were offered during spring 2016, fall 2016, and spring 2017 semesters. Due to its novelty and fewer section offerings, SEGE had lower average enrollment than the three other courses (Table 1).

Data sets from each course were quantified as percentages of students (1) withdrawing from the course, (2) receiving a passing grade, and (3) receiving a C grade or higher. Three semester averages ($n = 3$) for each data set were calculated and are presented in Figure 1. Analysis of variance was performed on all data (Harris, 2007) to compare SEGE to each individual course (e.g., SEGE versus BIO; SEGE versus CHEM; SEGE versus GIS). All statistical calculations are provided as supplemental data (see https://www.nsta.org/online-connections-journal-college-science-teaching). Passing rate

TABLE 2

Syllabus of the Sustainability, Energy, and the Green Economy (PHY/CHEM/BIO100) course offered during three semesters in the 2015–16 and 2016–17 academic years.

Week	Instructors	Resources
Week 1: Introductions and a brief history of sustainability	**Team-teaching PHY/CHEM/BIO**	Pisani (2006); Theis & Tomkin (2015), module 1
Week 2: Mathematical principles and introduction to life cycle analysis (LCA)	**Team-teaching PHY/CHEM/BIO**	Theis & Tomkin (2015), module 9.1
Week 3: Principles of sustainability	**BIO**	McConnell & Abel (2012), part 1
Week 4: Threats to ecosystems	**BIO**	McConnell & Abel (2012), part 6
Week 5: Carbon and other raw materials	**CHEM**	Theis & Tomkin (2015), module 9 (9.1, 9.2, 9.3)
Week 6: Climate change	**PHY**	McConnell & Abel (2012), part 3; Theis & Tomkin (2015), chapter 3; Henson (2011); instructor notes from AMNH Seminars on Science Online Courses for Educators
Week 7: Screening of media followed by discussion: *An Inconvenient Truth: A Global Warning* or *Before the Flood*	**Team-teaching PHY/CHEM/BIO**	Guggenheim (2006); Stevens (2016)
Midterm	**Team-teaching PHY/CHEM/BIO**	LCA research paper outline submission
Week 8: Introduction to energy LCA research paper discussion begins during the postmidterm recitation periods.	**PHY**	McConnell & Abel (2012), part 4; Theis & Tomkin (2015), module 8
Week 9: Introduction to renewable energy	**PHY**	Theis & Tomkin (2015), Module 8; Vice (2017)
Weeks 10: Consumption and the quality of life	**CHEM**	McConnell & Abel (2012), part 5
Week 11: Jobs and the green economy	**Team-teaching PHY/CHEM/BIO**	Theis & Tomkin (2015), module 11; Ottman (2011); Llewellyn et al. (2008)
Week 12: Practicing sustainability in urban environments	**CHEM**	McConnell & Abel (2012), part 7
Week 13: The road to sustainability	**Team-teaching PHY/CHEM/BIO**	Theis & Tomkin (2015), module 9.4
Week 14: Review student presentations (scheduled one-on-one with instructor)	**Team-teaching PHY/CHEM/BIO**	Gutowski (2014)

included all letter grades of A+ thru D-, and withdrawal rate included all four types of withdrawal grades possible at BCC. While GIS is a relatively new course at BCC, BIO and CHEM are well-established courses, offering multiple sections per year.

The most closely related data sets were obtained when comparing withdrawal rates between SEGE and the three other courses. Approximately 32 ± 14% of SEGE students withdrew from the course over the three semesters offered, as compared to 28 ± 11% for CHEM ($p < 0.2$), 22 ± 2.5% for BIO ($p < 0.4$), and 17 ± 10% for GIS ($p < 0.05$). The average passing rate for SEGE was 68 ± 14%, which compared well to CHEM 65 ± 10% ($p < 0.4$), and GIS 69 ± 5% ($p < 0.3$). Analysis of C grade or higher data revealed no statistically significant comparison between SEGE and any of the other courses analyzed ($p > 0.5$).

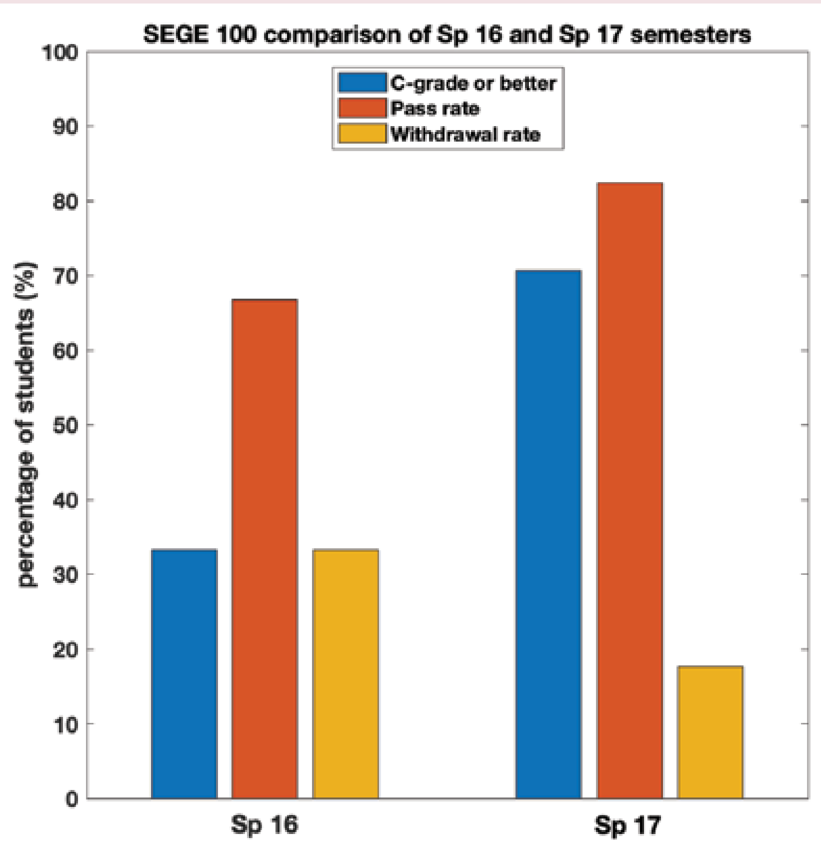
Though direct comparisons to more established courses were challenged by sample size, analysis of SEGE data alone, over three semesters, showed clear trends for student performance and acceptance of the course. Figure 2 shows the percentage of students receiving a C grade or higher increased from 32% to 71% from spring 2016 to spring 2017. Additionally, the number of students passing the SEGE course increased 67% to 82%, while the withdrawal rate dropped from 33% to 17%.

Student comments collected during university-administered course evaluation surveys also provided valuable feedback for improved course delivery by collaborating faculty. The survey did not prompt students with targeted questions, it simply provided a blank sheet for students to write their opinions about the course. Figure 3 presents the percentage of positive and negative comments received in student surveys in spring 2016 and spring 2017 course offerings. It is noteworthy that negative comments decreased from 40% to 0% over one year of course surveys.

Life cycle analysis: The LCA final assignment demonstrated all levels of Bloom's Taxonomy of Learning: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (Bloom et al., 1956). Students were allowed to select their own products on which to perform the LCA. The LCA technique investigates the product's cradle-to-grave CO_2 footprint from raw materials, to production, to storage/delivery, to end-of-life disposal/recycling. Ideally, a product's life cycle is determined using a comprehensive thermodynamic approach and quantified in greenhouse gas emissions (Bakshi et al., 2011). For SEGE, students performed basic calculations for mass and energy balances, such as a product's transportation and storage "costs" in terms of CO_2 emissions (see Appendix B at https://www.nsta.org/online-connections-journal-college-science-teaching). They identified a product, performed a search of the

FIGURE 2

Comparison of C grade or better performance, passing rate, and withdrawal rate of students enrolled in SEGE 100 (PHY/CHEM/BIO 100) course during Sp16 and Sp17 semesters.



literature including scientific reports, journal articles, and other material in library databases, and then developed a basic LCA to quantify its environmental impacts in terms of its energy consumption and CO_2 emissions. The small, active-learning modules, such as “calculate your family’s carbon footprint,” were created during class to build the learning needed for the LCA research (e.g., dimensional analysis with units of distance, time, mass, temperature, volume, power and work).

Critical-thinking skills are essential for scientific literacy (Koenig et al., 2012; Zhou et al., 2016; Wood et al., 2018), and were introduced through the LCA project. The LCA research paper guidelines were provided during the midterm in the presence of all instructors, and later posted on the course website. Students engaged in discussions relevant to the LCA research paper during the postmidterm recitation periods. In preparation for the LCA paper, students collected consumer product data and performed basic dimensional analysis calculations to understand the carbon footprint. Model calculations performed in LCA of the product are presented in Appendix B (see https://www.nsta.org/online-connections-journal-college-science-teaching). The number of submitted LCA research papers showed that the desired learning outcome of engaging students was realized through inquiry-based learning. In spring 2017, nearly 90% of students completed this assignment (Figure 4).

Reflections: Notable experiences and lessons learned

The course presented both successes and challenges in conceptual framework and implementation.

FIGURE 3

The percentage of positive and negative student comments collected during university administered course evaluation surveys. The survey did not prompt students with targeted questions; it simply provided a blank sheet for students to write their opinions about the course.

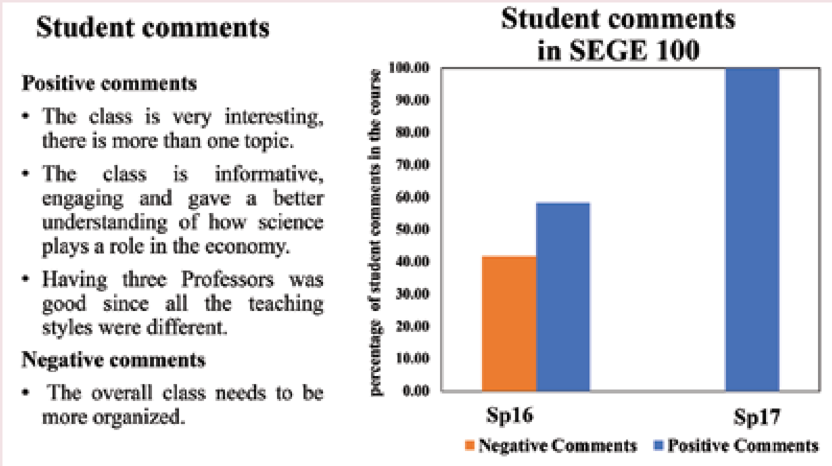
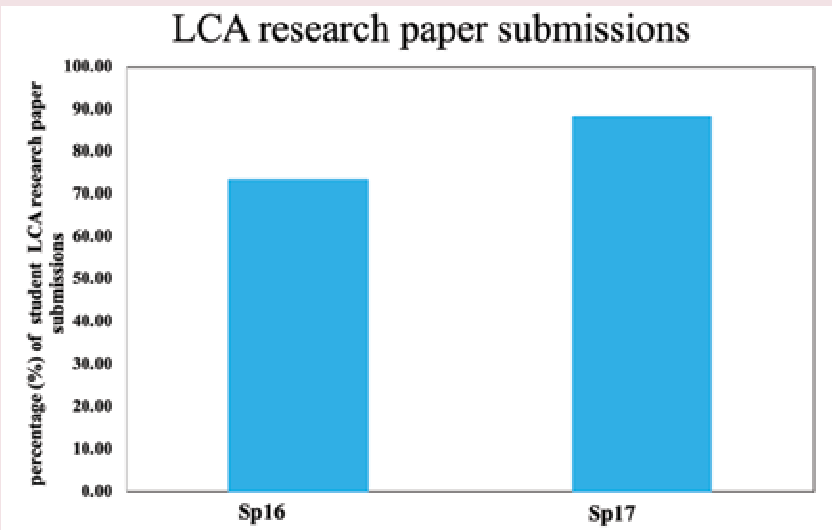


FIGURE 4

The percentage of LCA research paper submissions by students during the semesters Sp16 and Sp17 in SEGE 100 (PHY/CHEM/BIO 100) course. The research-based LCA project was the most comprehensive pedagogical activity of the course. The overall assessment of the student performance included quizzes, classroom contributions and/or homework assignments, the midterms, which included an outline of the LCA research paper, the final LCA research project, and an accompanying PowerPoint presentation.



1. Course enrollment: The course ran satisfactorily for three semesters with students enrolled from a range of disciplines. Most of the enrolled students were from the liberal arts and sciences majors, and some were from the business administration, criminal justice, engineering services, and digital arts majors. The course had no prerequisites; students of all levels and all majors had the opportunity to be part of this interdisciplinary learning experience. The course also listed corequisites in basic English, mathematics, reading, and language to ensure all students understood the discussion and calculations required for an introductory study of environmental sustainability. The instructors made minor revisions to the syllabus each semester to reorganize the flow of content, and increase suitability for BCC students with diverse academic interests.
2. Cross listing the course separately as PHY 100, CHEM 100, or BIO 100 under each department's course catalog caused unnecessary confusion for students during the enrollment process. It is therefore important to house the course under one department, and use a single course code (e.g., PHY 100). The CUNY Blackboard online system created the course site to provide the syllabus, office hours, and contact information for the three professors, as well as related resources and announcements. Because the course was listed under three separate departments, the Blackboard system initially created three separate course sites with a split class roster of students enrolled from the different departments. It was crucial to have only one online course site with the complete class roster.
3. Team-teaching model: Team-teaching required high levels of coordination to properly organize the interdisciplinary nature of the course. All instructors coordinated time to discuss the lecture content before or after the lecture period to maintain the cohesion of the course. All instructors were comfortable using the Blackboard online platform that assisted in enhanced coordination.
4. Institutional support: It is essential to recognize that implementation of innovative pedagogies, such as the LCA research paper and team teaching, require more support from the institution as compared to standard, established courses. Rather than divide the content into three parts, a truly interdisciplinary course benefits from co-teaching the content and connecting the perspectives from the different disciplines. The instructors were eager to teach an important topic of sustainability and attract more students to SEGE. Though the cost of employing three instructors for a small interdisciplinary course is obviously higher than employing one instructor for a standard one, we believe it to be a worthwhile investment for subjects as timely and broad reaching as sustainability.
5. Student course evaluations: Overall, students provided satisfactory feedback via course evaluations (Figure 3). A clear set of guidelines, a welcoming intellectual environment, and a common vocabulary used by all instructors are critical during class introductions. In all three semesters, all team members were present during the first day of class. Though some students were initially intimidated by the idea of team teaching, and at times felt the need for better course coordination, there is synergistic value in team teaching. Attention to detail during planning and clearly defined roles could strengthen coordination in team teaching. Some students also struggled to relate SEGE subjects to their chosen major discipline. As part of the class activities, case studies relevant to specific disciplines could mitigate this challenge.
6. Student communication skills: Peer-to-peer demonstrations of sustainability, relevant outside the classroom, were a key learning objective of the course. The LCA presentation provided an opportunity for students to communicate to a broad audience. However, students required more attention than anticipated in terms of public speaking, computer presentation skills, and overall communication needed to effectively articulate their research results. A module on technical communication could be included in the syllabus to address this challenge.

Conclusion and future outlook

The authors describe a unique interdisciplinary teaching model developed from the synergy of three natural sciences to facilitate understanding of the principles of sustainability and the environmental effects of local, regional, and global socioeconomic trends. The model is centered on a LCA of a simple consumer product, such as a can of soda. The basic science required to comprehend and perform the calculations required for the LCA presented challenges to some students that were largely overcome by practice problems and open-discussion recitation sessions. The recitation session is a shorter class attached to the lecture that allows students to focus on critical discussions in a smaller setting. It is known that learning is facilitated by conceptually moving between different contexts (Anderson & Kalman, 2010), and believed that our interdisciplinary model of sustainability education provided a multifaceted perspective to complex topics, and thus facilitated active learning by students. Lectures were reinforced by real-world activities such as determination and discussion of one's own carbon footprint and lively recitation session. Due to variance in data resulting from disparate course enrollments over the three courses and semesters analyzed, the only significant comparison was between withdrawal rate of SEGE versus GIS ($p < 0.05$). This result is not surprising when considering that these two courses are the most similar in terms of their enrollment and novelty within the BCC curriculum. Upward trends for SEGE student grades and course interest highlight the value of interdisciplinary science education on topics such as environmental sustainability and provide encouragement for development of similar courses and comparative assessments to bridge undergraduate curricula.

Author note

Dr. Monika Sikand is currently co-lead of Diversity and Inclusion Working Group at the Interagency Arctic Research Policy Committee (IARPC). Dr. Aaron M. Socha was the director, Dr. Joseph Bush was the associate director of the Center for Sustainable Energy, and Keith Wong was adjunct faculty in the Department of Chemistry at Bronx Community College in Bronx, New York. ■

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