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Lowering Barriers to Undergraduate Research through Collaboration with Local Craft Breweries

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Supporting Information

ABSTRACT: Laboratory research experiences are highly impactful learning environments for undergraduate students. However, a surprising number of chemistry students do not research. These students often do not research because they lack the time, interest, opportunity, or awareness. Course-based undergraduate research experiences can reach out to these nonresearching students by lowering the barriers to research. Classroom research opportunities typically harness undergraduate efforts to benefit faculty research. Here we introduce a research course that harnesses undergraduate efforts to benefit an outside company: a local brewery. The benefits of the course design were 3-fold. First, the course attracted students not engaged with existing research opportunities. Second, the students produced data that helped the brewery make significant business decisions. Third, the students developed personally and professionally: learning to design an experiment, to work in teams, and to enjoy science. Similar research courses with local breweries are feasible and could improve student engagement in research at other educational institutions.

KEYWORDS: *Second-Year Undergraduate, Upper-Division Undergraduate, Analytical Chemistry, Laboratory Instruction, Inquiry-Based/Discovery Learning, Food Science, Applications of Chemistry, Instrumental Methods, Student-Centered Learning, Undergraduate Research*

INTRODUCTION

Research-Based Courses

Undergraduate students report that most of their learning and growth occurs outside the classroom.[1,2] To bring this learning under the guidance of the department, chemistry instructors typically encourage students to join research laboratories,[3] where students learn to think scientifically and understand scientific research.[4] However, for a variety of reasons, many undergraduates never participate in research.[5−7] Chemistry departments should find new ways to engage these students. Here we describe one course-based solution: a research course where student teams work with a local brewery. By creating a new type of research opportunity, the course attracts students who would not otherwise research as undergraduates. The students displayed significant professional, cognitive, and personal development.

The Course

Analytical Chemistry of Craft Beer (CHEM 4330) is a 2-credit research class at Cornell University offered in each spring semester since 2014. In the course, food science and chemistry students aid the Ithaca Beer Company in evidence-based decision making. Student groups of four work for one semester. Each student averages about 4 h per week of lab time for a total of 240 person-hours in lab per project. The main techniques are analytical chemistry methods (UV−vis and GC−MS), although sensory science has also been used. Students must have completed or be concurrently enrolled in Analytical Chemistry (CHEM 3020) or Food Analysis (FDSC 2100), which opens the course to sophomores, juniors, and seniors. A variety of research-based analytical chemistry courses have been described in the literature.[8−11] The course here, however, supports an outside company, which is unique from previous analytical chemistry research-based courses. The collaboration with a for-profit business also differentiates the course from previous service learning courses.

A graduate student supervises the work, while chemistry or food science professors grade the students. Grading is based on an experimental proposal, literature review, lab work, poster, and paper (see the course timeline in Figure 1). Groups present findings at existing university-wide and department poster sessions and summarize results in a paper in the format of a short scientific article. Individual contributions are graded using self-assessment and peer assessment rubrics for (1) experimental design and lab work and (2) poster and paper creation and presentation. Rubrics for research courses are available in the literature.[12] Students also complete ungraded reflection essays describing their personal experience with the course.

Craft Brewing

The largest two American beer producers (AB InBev and SABMiller) produced over 600 million barrels of beer in 2015: about 30 times the combined output of the 4,000+ American craft breweries. Despite the small volume, however, craft beer has a retail dollar share about 20% of the $100 billion U.S. beer

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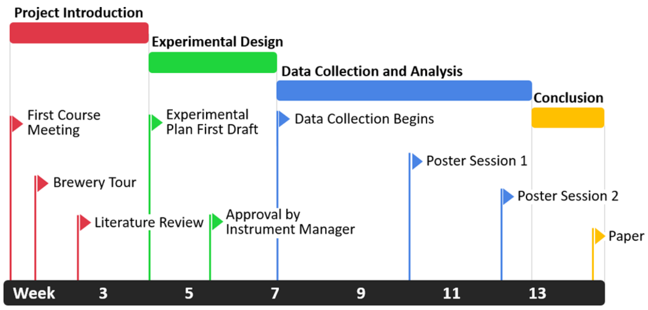

Figure 1. Course timeline within the semester. Each period of the project featured opportunities to check student progress with assignments such as a literature review, experimental plan approval, and poster sessions.

market and is growing by about 15% year over year.[13] Furthermore, the financial impact of craft beer is spread throughout the country. The average American lives within 10 miles of a brewery.[14] Therefore, craft brewing represents an important addition to the American economy and a tremendous opportunity for analytical chemistry.

As individual companies, craft breweries are suitable partners for chemistry teachers interested in new collaborations. First, craft brewing presents a variety of scientific problems for analytical chemists. For example, breweries inspecting for bacterial contamination require microbiological expertise, while breweries experimenting with dry hopping require solid–liquid extraction expertise. Second, undergraduate students enjoy learning about beer, because of its practical application and verboten status. Third, collaborations with local breweries improve town–gown relations. Chemistry instructors can help students understand science's impact on the local community.

Establishing Collaborations with Local Industry

In late 2013, the author contacted several local companies about potential student projects. One potential partner was a local data firm that tracks the exact location of known environmental hazards in New York State. A project was developed that involved students measuring radiological contamination near abandoned oil and gas drilling sites. The project was ultimately abandoned, because of administrative concerns about the highly contentious debates about hydraulic fracturing occurring at the time. Furthermore, it was very difficult to schedule time with the data firm employees. Time spent on the student projects took the staff away from billable hours as construction consultants. Working with a business based on billable hours will always be a challenge.

Therefore, the author concentrated on two breweries as potential collaborators: Hopshire Brewery and the Ithaca Beer Company. The breweries were a better match for student projects than the environmental data firm. Although the brewers were busy, their schedules were flexible. Additionally, the breweries were very open to experimentation with their beer.

Several lessons in dealing with these breweries may be applicable to other brewery collaborations. First, establishing connections with the breweries required persistence. The breweries were occasionally difficult to reach by phone or e-mail. Fortunately, breweries are easy to approach in person. Both breweries serve beer on-site and offer brewery tours open to the public. Establishing the pattern of meeting the brewers in person helped when students urgently needed input and e-mails were not answered quickly.

Second, the brewers had personal connections to the university. The owners of both brewers knew chemistry and food science professors personally. It is likely that breweries near other colleges also have personal connections to the local school that would facilitate establishment of collaboration. At a minimum, the cachet of the college in the local community can be very helpful for establishing the partnership.

Third, the breweries had problems that could be solved with undergraduate science. Hopshire is a very small brewery (7 barrels/week) that lacks the microbiological tools to identify bacterial contamination early in the fermentation process. Students could use microscopy and selective growth media to detect contamination. The Ithaca Beer Company is about one hundred times larger than Hopshire, but had many protocols that were products of tradition and not scientifically based. An example is the three day dry hopping time discussed in Case Study 1.

Other tips for establishing a partnership include emphasizing the potential benefits of the student work while not promising or requesting too much. Chemistry departments have equipment and expertise that are useful but too expensive for craft breweries. However, the brewer's expectations need to be managed as the undergraduate students may not produce actionable results. The author offered student work in return for access to the breweries and supplies for research such as hops and finished or unfinished beer. The breweries gladly agreed to these terms. Requests for money, however, were rejected. Since no money was exchanged, the brewers understood well that the primary goal of the course is student learning and the secondary goal is results for the brewery.

In the first two years covered in this manuscript, twenty-one undergraduate chemistry and food science students carried out six research projects. Projects in the first two years were exclusively at the Ithaca Beer Company. Several of the projects are highlighted in the two case studies below. Complete descriptions of each project are available in the Supporting Information. The titles and techniques used for the first two years' projects are shown in Table 1.

Table 1. Synopsis of Course Project Titles and Lab Techniques Used

Project Title	Techniques[a]
Sniffing the Aroma Profile of Beer during Fermentation	HS-SPME/GC–MS
Carbohydrate Content of Beer during Fermentation	HPLC–RID, GC–MS
Temperature Dependence of Oil Expression in Dry Hopping	HS-SPME/GC–MS
Bitter Acid Retention in Spent Dry Hops	UV–vis
Supercritical CO_2 Extraction of Spent Dry Hops	SFE, UV–vis
Establishing Scientifically Sound Sensory Analysis in the Brewery	Triangle tests

[a]Technique abbreviations are HS-SPME/GC–MS (headspace solid phase microextraction/gas chromatography mass spectrometry); HPLC–RID (high performance liquid chromatography refractive index detection); GC–MS (gas chromatography mass spectrometry); UV–vis (UV–visible spectroscopy); SFE (supercritical fluid extraction).

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CASE STUDIES

Case Study 1: Aroma Profile of Beer during Fermentation

Technique: HS-SPME/GC−MS. Hops (*Humulus lupulus*) have historically been added to beer for preservation. In modern beer, hops are added for bitterness, flavor, and aroma as shown in Figure 2. Bitterness and flavor hops are added before and during the boiling of the wort (the liquid carbohydrate mash before fermentation). The heat of the wort boil isomerizes insoluble alpha acids into the very bitter and soluble iso-alpha acids.[15] The heat also drives off volatile compounds. Aroma hops are added after the boil. Adding aroma hops—also known as dry hopping—retains volatile aroma compounds.[16] Bitterness and flavor hopping primarily adds taste, while dry hopping primarily adds aroma.

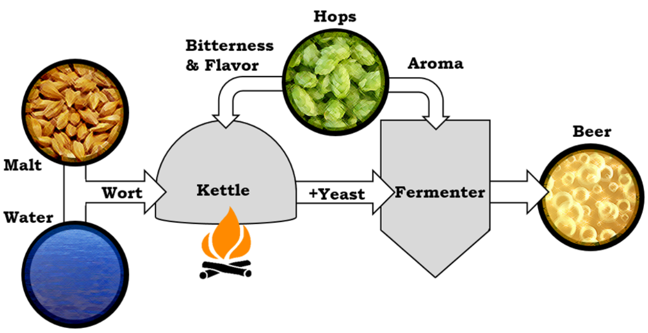

Figure 2. Simplified brewing diagram. The wort is the malt and water mix. At the wort boil in the kettle, bitterness and flavor hops are added. After removing heat and moving the wort to the fermenter, yeast is added. The fermenter is also the location of dry hopping: the addition of aroma hops. After fermentation is complete, the beer is processed and prepared for sale.

The Ithaca Beer Company uses a three day dry hopping procedure on their most popular India Pale Ale (IPA). Students hypothesized that the logarithmic nature of solid−liquid extraction meant that almost all of the extracted hops compounds are extracted in the first few hours of dry hopping. Therefore, a shorter dry hopping schedule could be used without affecting the beer. A shorter dry hopping process would allow the brewery to increase output and revenue. To monitor aroma compounds added by dry hopping, students implemented Headspace Solid-Phase Microextraction Gas Chromatography Mass Spectrometry (HS-SPME/GC−MS). Students developed methods from published work monitoring the deterioration of beer in storage,[17] developing fingerprinting for different beers,[18] and verifying hop varieties.[19] Students produced results for hops-derived aroma compounds that indicated that hops aroma compounds generally reached maximum solubility after just 1 day of dry hopping (as seen in Figure 3). Students also tracked yeast-produced compounds. More results are shown in the Supporting Information.

Students used samples pulled from the production line by the brewer, which limited them to six time points and only one time point during dry hopping. More time points during dry hopping would help trace the logarithmic nature of the solid−liquid extraction. More replicates would also help improve the signal-to-noise ratio, although high variance is characteristic for food analysis. The quality of the student work was not publication quality, but it was sufficient to support the potential of shorter dry hopping.

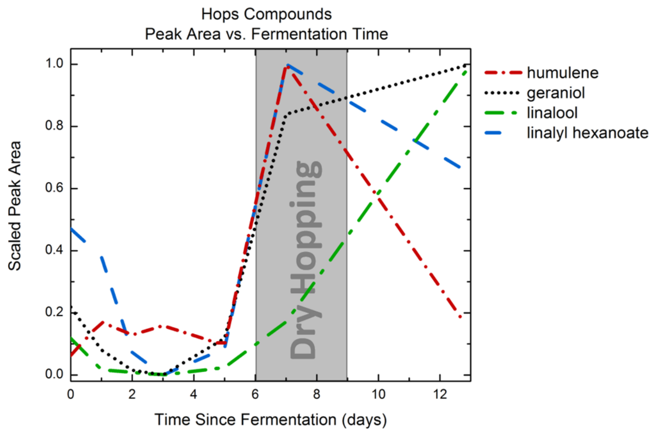

Figure 3. Scaled peak areas vs fermentation time for compounds originating in hops for *Flower Power IPA*. Dry hopping commenced on day 6 of fermentation. Tracked compounds are a terpene, two terpene alcohols, and a terpene ester.

Therefore, a student group continued the project the next year by using triangle sensory tests to evaluate beer dry hopped for only 1 day. Test panelists tasted no significant difference between the differently dry-hopped beers. A more detailed description of the sensory tests is available in the Supporting Information. The two projects' results demonstrated that the Ithaca Beer Company could safely reduce dry hopping times without affecting consumers. Considering that the tested IPA is brewed many times per month, the reduction of brewing time and corresponding increase in brewery throughput could have enormous financial implications for the small brewery.

Case Study 2: Temperature Dependence of Bitter Acid Retention in Spent Dry Hops

Technique: UV−Visible Spectroscopy. Hops provide beer's bitterness and floral aroma. The bitterness originates from alpha and beta acids that isomerize in the heat of bitterness and flavor hopping. Pale Ales and certain other beers incorporate dry hopping that adds aroma through essential oils. Figure 4 shows the base structures of alpha and beta acids and two essential oils.

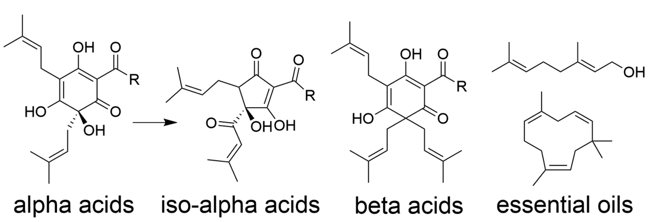

Figure 4. Primary hops-derived chemicals in beer. Alpha acids contribute bitterness when converted to iso-alpha acids at high heat (humulone and isohumulone shown). Beta acids increase shelf life, but do not isomerize or solubilize as well as alpha acids (lupulone shown). The R groups for the alpha and beta acids are short alkyl chains that determine the specific acid. Essential oils add aroma to beers (geraniol and humulene shown).

Hops are already the most expensive ingredients in craft beer and cause concern with price volatility. A drought in the Yakima Valley has driven this year's hops prices up to 50% higher. Additionally, hops agriculture is environmentally intensive. Despite being a perennial vine, hops are often planted like an annual, which leads to soil acidification and

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erosion. High pesticide and water use are additional causes for environmental concern.

Therefore, one student group proposed recycling spent aroma hops as bitterness or flavor hops. Recycling used hops would provide significant financial and environmental benefits. Dry hopping at room temperature leaves many alpha and beta acids in the hop material. Students used UV−visible spectroscopy to quantify the alpha and beta acids in fresh and spent Amarillo, Simcoe, and Centennial hops following standard American Society of Brewing Chemists methods.[20] Dry hopping was simulated by adding fresh hops pellets to unhopped green beer from the brewery for 3 days. The hops were then filtered and dried. Temperature was controlled during the simulated dry hopping with water baths at 18, 19, 20, and 21 °C. Samples were prepared in triplicate for a total of 36 samples.

Averaging across the four temperatures and three hops types, alpha and beta acids were present in spent dry hops at 38% of their corresponding concentration in fresh hops. Students hypothesized that spent hops with 38% residual alpha and beta acids are worthwhile to recycle. In order to recycle the spent hops into a usable format, a project the following year extracted the alpha and beta acids using supercritical carbon dioxide extraction. The third year's project has commenced sensory testing of beer brewed with the recycled hop extracts.

The first year's students were able to use UV−vis spectroscopy to determine that spent hops from dry hopping are a promising source of recycled alpha and beta acids. The second year's students used supercritical CO_2 to extract spent dry hops and evaluated the extracts using UV−vis spectroscopy. The combined work demonstrated recycled dry hops as an environmentally conscious and inexpensive source of alpha and beta acids.

■ DISCUSSION

Reaching Nonresearching Students

According to the National Science Foundation, 28% of chemistry majors graduate without any research experience.[5] The four most common reasons for not participating in research are lack of time, interest, opportunity, and information.[5−7] To counteract these common obstacles to research, the projects here required moderate time commitments, offered a provocative research topic, and recruited students actively.

First, students were able to experience undergraduate research within one semester, which is much shorter than the average 11.8 month duration of undergraduate research.[5] Although each student spent a fraction of the average lab time of an individual undergraduate research project, the students still participated in many of the key features of research culture: mentoring other students, presenting at poster sessions, and seeking out expert collaborators. While individual research in a lab would be more rewarding, these group research projects were invaluable for students who would not otherwise have researched. For example, several second-semester seniors who participated in these projects had never researched before. They likely would not have been accepted into research laboratories for only one semester.

Second, many students expressed that beer was a significant motivation to participate, as seen in other work.[21] Students have enough common knowledge about beer to propose interesting hypotheses and are able to appreciate the applicability of their work.[22−24]

Third, students were recruited by an e-mail sent to the chemistry and food science departments. These students have many opportunities competing for their time and attention. For students to invest time and energy, they must reap meaningful and compelling personal outcomes. Therefore, the recruitment e-mail was titled "Free Beer" and emphasized the fun, autonomy, and camaraderie of the projects. The recruited student demographics are shown in the Supporting Information. Institutional review board approval based on student consent was obtained for all demographic data and student work within this manuscript.

These strategies succeeded in reaching students who were not engaged in research. For nine of the 12 students (75%) who have graduated, the projects were their sole undergraduate research experience. Additionally, only 6 of the 21 students (29%) had previous research experience: 3 had done other on-campus research; 3 had done research in off-campus internships.

Budget Considerations

At the large research university where this work was completed, the students had a large budget. However, similar courses could be accomplished on much smaller budgets. The majority of costs were buying lab supplies and chemicals in the first year and paying for instrument time on the GC−MS. The incremental costs to the department were about $100/project. UV−vis spectrometry was an extremely cheap technique as cuvettes and an instrument were freely available. Several research laboratories also made expensive instruments available for students to use free of charge. For example, research laboratories allowed use of the supercritical fluid extractor and the HPLC−RID spectrometer. Sensory science was another inexpensive technique that required only cups and paper for the testing panel. Participants were incentivized with coupons provided by the Ithaca Beer Company. The one exception to the small budgets is HS-SPME/GC−MS. Expensive SPME fibers and GC−MS instrument time caused each sample run to cost about $20. For instructors without large budgets or expensive equipment available, there are a variety of less expensive techniques that would still be useful to breweries.[21,24]

Affecting Students

Academics often view undergraduate research as part of professional socialization into the sciences. Clearly, students gained professional research skills such as reading scientific journals, designing experiments, analyzing data, and presenting research. However, students also developed personally through the research experience. Therefore, the student reflection essays were examined for six types of gains following the work of Seymour et al.: (1) personal and professional gains; (2) skills; (3) becoming a professional; (4) thinking and working like a scientist; (5) enhanced career preparation; and (6) career clarification.[25] These results represent the first such coding of chemistry or food science students working with an outside industry. Previous work categorized gains from students who had worked with outside industry through the Harvey Mudd College clinic program, which is limited to engineering, computer science, physics, and math.[25] Figure 5 summarizes the total number of occurrences in each gain category. Career clarification was not mentioned by any students and is not shown.

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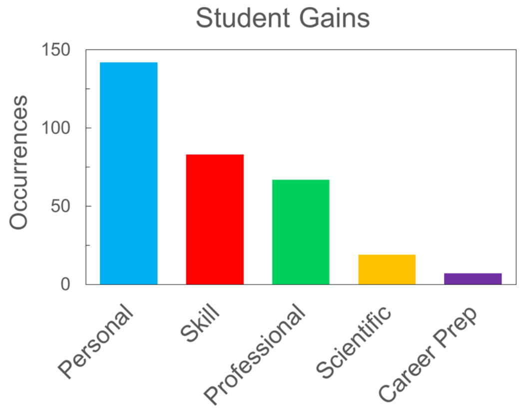

Figure 5. Number of occurrences in each gain category. A total of 318 specific gains were coded from student reflection essays. The full category names are (1) personal and professional gains; (2) skills; (3) becoming a professional; (4) thinking and working like a scientist; (5) enhanced career preparation; and (6) career clarification. Career clarification is not shown as no occurrences were coded. The percentage of students reporting gain types is reported in the text and also follows this ordering. More information on the coding is available in the Supporting Information.

While students view research as a learning experience, the most commonly reported gain category was personal and professional gains. All 21 students (100%) reported personal and professional gains. Students invariably described the course in personal terms. A student who had not previously researched wrote that "the project was shockingly daunting at the beginning but equally rewarding now that we have finally worked out the kinks." Indeed, many students wrote about personal growth during the course. Common themes were the highs and lows of group work, the wonder of chemistry, and the challenges and satisfaction of autonomy. For example, one student wrote "this project reminded me of the childish wonders of the chemistry of materials and foods that got me interested in chemistry in the first place."

Skills gains were the second most commonly reported gain type. All 21 students (100%) reported skills gains. One student described learning to design an experiment by writing that "the meetings in which we attempted to determine exactly what we would be able to use and what information we would be able to gain—chipping away at our proposed ideas and finally coming up with a concrete experimental design—were among the most rewarding experiences I have had at Cornell. They were applied science in a way I was unable to achieve in any of the classroom labs or in working with a professor's research group."

Student gains also included becoming professionals. Eighteen of 21 students (86%) reported gains in becoming professionals. One student wrote that "the scientific independence that was gained in this experience was helpful in gaining contacts and knowledge across the Cornell scientific community. I now feel more comfortable reaching out to particular professors and using the contacts I have made both at Cornell and at Ithaca Beer Company in future projects."

Students also became more comfortable thinking and working like scientists. Eleven of 21 students (52%) reported gains in becoming professionals. One reflection essay wrote that "although reading journal articles is slow, I have found that the result is not only a better understanding of the subject matter, but also a better understanding of how science works. Although I could find a lot of the necessary background information on sites like Wikipedia, reading the journal articles that actually determined those facts was much more interesting and valuable."

Enhanced career preparation was reported by graduating students. Six of 21 students (29%) reported enhanced career preparation from the course. One graduating senior wrote that "coming out of the chemistry major, there is little we can put on our CV/resume that says we are capable of independent scientific pursuit. This project, however, allows us free reign to demonstrate just that!"

Overall, the reflection essays indicated that the course was a significant professional, cognitive, and personal experience for the students, but not an experience that directly benefited future career preparation or clarification. A more complete summary of reported student gains is available in the Supporting Information.

■ CONCLUSION

In summary, a one-semester research course for chemistry and food science undergraduates introduced analytical chemistry research experiences in collaboration with a local brewery. Craft breweries are an excellent local partner for analytical chemistry instructors. Brewers have interesting problems, but lack the expertise or resources to find scientific solutions. The course design overcomes the most common reasons that students do not participate in research: lack of time, interest, opportunity, and awareness. Specifically, real-world research topics with broad appeal, reasonable time commitments within group projects, and active recruitment reached students who likely would not have researched otherwise. Only 25% of graduated students had other research experience and only 29% of all participating students had previous research experience. The student groups chose research topics, designed and executed analytical chemistry or sensory science experiments, and presented results to academic and industrial audiences. Students were challenged by the autonomy of their work and reported impressive scientific, leadership, and personal growth. Undergraduate research is perhaps the best learning opportunity that chemistry departments offer. Industry-collaborative course-based undergraduate research experiences with local breweries can help instructors recruit and motivate more students to research.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00875.

Synopses of student projects, breakdown of student demographics, and detailed categorization of self-reported student gains (PDF, DOCX)

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Notes

The author declares no competing financial interest.

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