Understanding the impact of a general chemistry course on students' transition to organic chemistry

Alexandra Collins-Webb Kathleen A. Jeffery Ryan D. Sweeder
Michigan State University

Abstract

The move from general chemistry to organic chemistry can be a challenge for students as it often involves a transition from quantitatively-oriented to mechanistically-oriented thinking. This study found that the design of the general chemistry course can change the student experience of this transition as assessed by a reflective survey. The general chemistry course design can also increase student confidence during the transition to organic chemistry course and simultaneously help students understand the commonalities that exist between the content of the two courses.

Keywords: First-Year Undergraduate / General, Second-Year Undergraduate, Chemical Education Research, Curriculum, General Chemistry, Organic Chemistry, Student-Centered Learning

Introduction

Atypical of most subjects, in chemistry a natural barrier exists between the traditional first two years of college-level courses. Anderson and Bodner (2008) suggest the progression from quantitatively-oriented general chemistry to a typically mechanisms-oriented organic chemistry is often a challenge because students' study skills, techniques, and methods may not translate smoothly. As a result, students may be discouraged from continuing in the field, leading to fewer quality chemistry majors; in fact, the term "weeder course" is commonly associated with organic chemistry. Pungente and Badger (2003) also point out that waiting for an organic chemist to address the commonalities between the two courses leaves opportunity for students to become cynical and approach organic chemistry from a perspective of memorization rather than understanding. But this kind of dissonant experience is unnecessary: elements of organic chemistry can be introduced as part of the general chemistry curriculum (Gillespie, 1991; Hered, 1941). Such an approach would allow students to build an understanding of organic chemistry atop their existing general chemistry foundation, potentially fostering deeper conceptual connections between the two (Barrow, 1998) and breaking down the traditional, artificial dividing lines between the two courses so that students may begin to see its practical implications. Subsequent reconnections back to general chemistry once students are in organic could then provide an anchor for newly learned concepts while simultaneously strengthening students' comprehension of general chemistry concepts.

This idea of easing the transition by linking the organic and general chemistry curricula to improve students' understanding is a long standing idea (Gillespie, 1991; Hered, 1941). Some have opted to start with organic chemistry and use it to highlight general chemistry concepts (Coppola, Ege, & Lawton, 1997; Reingold, 2001; Scouten, 1992), while other curricula like ChemConnections (Anthony, Ferrett, & Bender, 2003) use real-world problems as part of a context-based approach, often requiring an introduction to organic chemistry. Still others have reported introducing techniques like IR spectroscopy in general chemistry to facilitate student learning of bonding, polymers, and organic functional groups (Spector, 1994). Most general chemistry textbooks now include at least one section of organic chemistry, whether it appears at the end or in the middle of the book to serve as a foundation for continued learning of general chemistry concepts like reaction kinetics and mechanisms. As organic chemistry becomes more commonplace in the general chemistry curriculum as a means of clarifying certain concepts or engaging with practical, real-world issues, its relevance and impact on student performance must be assessed.

To evaluate the impact of including organic chemistry in the general chemistry curriculum, one must investigate students' existing perceptions of the relationship between the two courses, the transitional experience, and affective factors that may influence performance. Lewis et al. (2009) previously found that high levels of student comfort and self-confidence in chemistry is crucial for students' self-concept and is positively related to performance even when controlling for the cognitive domain. Students with a positive attitude toward chemistry have shown a stronger potential for success (Steiner & Sullivan, 1984) and their positive self-efficacy may prevent small obstacles from becoming barriers in their academic and professional pursuits (Gore, 2006). Regressions by Turner and Lindsay (2003) using non-cognitive variables showed that confidence explained 20% of variance in females' organic chemistry performance while anxiety predicted 36% of males' performance. Other non-cognitive variables explored by Turner and Lindsay resulted in only weak or no correlations.

However, the argument that we present here is not what variable most influences success in organic chemistry – as they can easily go hand-in-hand –, but that through design of the general chemistry course we can positively alter the student experience of the transition to organic chemistry. Easing this transition should lessen the "pipeline" effect of organic chemistry (Elaine Seymour & Hewitt, 1997) by instilling confidence in students that would suggest a strong potential for success (Steiner & Sullivan, 1984). Thus this study evaluates how changes to a general chemistry course impacts student perception of the transition to organic chemistry at Michigan State University (MSU).

Setting for the Study

General chemistry at MSU is offered through both the Chemistry Department in the College of Natural Sciences (CNS) and through Lyman Briggs College (LBC), a residential science college (Sweeder, Jeffery, & McCright, 2012). Three different General Chemistry I and II sequences are offered by the CNS: one for chemistry/biochemistry majors (CChem), one for honors [not considered in this study], and one for other majors (GChem) (Table 1). These courses explore traditional general chemistry curriculum, but have different exam formats (Table 1). Topics covered in these courses include atoms, molecules, ions; reactions and stoichiometry; thermodynamics; periodic properties of elements; chemical bonds; states of matter; gas laws; solutions; acids and bases; aqueous reactions and ionic equations; reaction kinetics and mechanisms; gaseous and aqueous equilibria (incl. buffers, hydrolysis, and titrations); heterogeneous equilibria of weakly soluble salts; electrochemistry; coordination chemistry; stereochemistry; and bonding within the transition elements. [These two courses will sometimes be referred to collectively as UChem as we see no significant differences between the student responses in concerns or confidence and they do not contain substantial organic content or response pads.] Alternatively, Lyman Briggs offers one General Chemis-

Course	Intended Student Population	Approx. Class Size	Yearly Enrollment	Exam Style
GChem	Any Major	350-415	2000-2500	Multiple Choice
CChem	Biochemistry/Chemistry Majors	150-240	150-240	MC/Open-Ended
Honors	Chemistry	30	30	(Not in study)
LBChem	Science Majors	80-120	450-490	Open-Ended
Organic				
OLChem	Any Major	275-325	1500-1800	Open-Ended
OCChem	Biochemistry/Chemistry Majors	215-260	215-260	Open-Ended

Table 1. Overview of general and organic chemistry courses at Michigan State University

try I and II sequence (LBChem) that emphasizes most of the same content (excluding coordination chemistry), but adds a significant introduction to organic chemistry in the first semester. In the second semester, organic examples are often used in instruction of the remaining general chemistry concepts (e.g. bond energetics, mechanisms, acid/base reactivity, etc.). Additionally, the LBChem course employs a more active learning approach featuring a student response system (clickers) and regular peer-peer discussion. To fulfill the university's general chemistry requirement, university students are restricted to the UChem courses while LBC students may take either UChem or LBChem. Students with no general chemistry credit from MSU were termed "Non-MSU credit" (likely received credit by transfer, AP, IB, or CLEP).

Students from all general chemistry classes move into one of two versions of organic chemistry taught exclusively through the CNS (Table 1). The more populated sequence (OLChem) serves life science and health science majors, while the other (OCChem) is designed for chemistry/biochemistry majors and students, addressing content at a slightly greater depth. The exams in organic chemistry were open-ended. Students' grades in all of the chemistry courses (general and organic) were mainly generated from performance on three in-class exams and a final exam.

Methodology

This study combined reflective survey data with student demographics and other grade data to examine variables affecting transition to and performance in organic chemistry.

Assessment tool

To evaluate students' experiences in general and organic chemistry, perceived connections between the course sequences, and perceived level of pre- and post-organic confidence, a survey was developed and approved by the MSU Institutional Review Board (IRB# x07-446). This information was then combined with pre-course data obtained through the registrar. The survey included free-response, five-item Likert scale, and limited choice questions (see summary in Table 2). Opportunities for additional comments were provided intermittently. Free-response questions about students' preparation for and transition to organic chemistry were asked before more

Applicability of General Chemistry to Organic
Aspects of Preparation: Which aspect(s) of your general chemistry class (could involve course content, lecture style, class format) most significantly impacted your performance in organic chemistry?
Significant Concerns about Transition: What was your most significant concern(s) about your preparation or transition to the organic chemistry course?
Confidence
Please indicate your level of agreement with the following statement: Going into organic chemistry, I was confident in my ability to understand the course material.
Please indicate your level of agreement with the following statement: Having taken organic chemistry (or at this point in the course) I am confident that I understood the organic chemistry course material.
*Likert scale ratings were strongly agree, agree, undecided, disagree, strongly disagree, not applicable.

Table 2. Examples of questions included on survey. Applicability were free response questions; confidence questions were Likert scale*;.

directed items to reduce prompted bias.

Data collection and analysis

Students were solicited for participation via email if they had taken Organic Chemistry I in one of four semesters (N=2852). Data was gathered via an online course management tool (ANGEL, 2008). Students had four weeks to complete the survey, at the end of which 39% (N=1103) students (UChem N=639, 35.6%; LBChem N=292, 54%; Non-MSU N=159) responded with informed consent. The respondents were representative of the overall population with respect to grades and incoming ACT scores. Female students were more likely to respond to the survey for both UChem and LBChem, consistent with previous literature (Sax, Gilmartin, & Bryant, 2003). Students who took both UChem and LBChem classes (N=13) were not included in any category. All students had completed Organic Chemistry I prior to the survey and N=430 (39%) of the respondents were actively enrolled in Organic Chemistry II.

Using the constant comparison method, two raters evaluated the free-response items to create categories from the recurrent themes and developed a rubric for each free-response question (Merriam, 2009). Responses were then re-evaluated and coded into the appropriate categories. A Cohen's kappa inter-rater reliability of 0.794 was obtained for the "Aspects of Preparation" question and 0.822 for the "Significant Concerns about Transition" question.

Survey data was combined with additional student information including general chemistry grades, organic chemistry grades, GPA, ACT scores, and gender obtained through the Registrar's Office. Survey results and student information data were analyzed using SPSS version 20 (SPSS, 2012). Pearson Chi Square tests were used to evaluate differences in reported pre- and post-organic confidence between LBChem and UChem students in matched triads by ACT score. Multiple linear regressions were used to evaluate factors that explained confidence.

Results and Discussion

The gamut of responses to the question of what aspect of general chemistry most impacted students in organic chemistry was strikingly similar regardless of general chemistry experience (Table 3). Overall students most frequently cited class format and course content as having impacted their performance in organic chemistry (58.8%) with 28.3% of students citing specific general chemistry concepts (excluding an introduction to organic). The most frequently cited concerns about taking organic chemistry included feeling ill-prepared (26.0%), being worried about memorization (14.4%), and their course load (14.0%). Students who took LBChem, with an introduction to organic chemistry, cited it positively 51.0% of the time in free-response questions while also expressing few or no concerns about the transition between the courses (Table 3). Only 1.9% of UChem students made similar comments. LBChem students also expressed higher pre-organic confidence across the range of ACT scores (Figure 1).

Student thoughts on transition to and preparation for organic chemistry

In order to elicit relatively unbiased responses about students' perceptions of the transition to organic chemistry, students completed the two-question free-response portion of the survey first (see "Applicability" section of Table 2). Examples of students' responses and their frequency can be found in Table 3. In response to the *Aspects of Preparation* question, 58.8% of all students indicated that class structure/format of general chemistry helped them prepare for organic (Table 3). Interestingly, 28.3% of all students indicated that general chemistry content (e.g. "electronegativity", "molecular orbital theory" or simply "course content") helped them prepare for organic chemistry, indicating that some students made conceptual connections between the courses. Students from all groups also indicated that class format (high-enrollment lectures) prepared them for organic chemistry, though UChem students cited it more frequently (64.7% v. 43.2%, $p \leq 0.001$).

In response to the *Significant Concerns about Transition* question, 26.0% of all students felt ill-prepared or had specific content concerns upon entering organic chemistry (Table 3), indicating that both version of the curricula left one in four students anxious about transitioning to organic chemistry. Additionally, 19.6% of all students had heard rumors of its difficulty and 14.4% were worried about memorization (Table 3). The similarity in response rates between UChem and LBChem highlight that the introduction organic chemistry did not appear to allay students' worries about an organic chemistry class.

Student recognition of benefit of organic chemistry introduction

The responses to these two open-response questions suggest that the introduction to organic chemistry was key difference between LBChem and UChem students' experience. First, LBChem students reported less frequently that there was no application of concepts between general and organic chemistry (4.5% v. 19.8% $p \leq 0.001$). Second, approximately half of LBChem students indicated that the organic unit was significant in preparing them for organic chemistry (51.0% v. 2.3%, $p \leq 0.001$) providing responses such as the example in Table 3. Third, LBChem students reported significantly more frequently that they were not concerned about the transition to organic chemistry (15.1% v. 7.4%, $p \leq 0.001$). Lastly, LBChem students also were significantly less concerned about the less quantitative nature of organic chemistry (4.5% v. 8.1%, $p \leq 0.05$). This was further highlighted in the closed response section of the survey where 85.5% of LBChem students agreed that the organic introduction in general chemistry had a positive impact on their understanding of organic chemistry. 29.4% of GChem students and 34.8% of CChem students responded similarly. The surprisingly high rate of response for the GChem and CChem students may arise from a survey bias with the students giving answers they thought were desired. Alternatively, it may be the result of a short organic segment was unofficially added in some UChem classes or that a few examples of organic molecules were provided by the textbook or professor which were then interpreted as an introduction.

Additionally, some students (N=252) opted to provide free-response comments on the survey. 53.8% of those mentioning the inclusion of organic were favorable with 12.1% unfavorable, yet even the negative comments frequently supported the reasons behind including organic chemistry:

> I do not think that an intro to organic chemistry is necessary because everyone is not going to be taking organic chemistry in the future.

> I failed to see how organic chemistry often related to everyday life. To me, it was just a bunch of shapes joining other shapes.

These responses (from LBChem students) indicate that even when science-oriented students are introduced to organic in general chemistry, some still struggle to see its practical applications in areas such as medicines and polymers, not recognizing that its prevalence in the real world is precisely the reason it should be included in the curriculum and applicability addressed explicitly, especially for students that do not continue to organic chemistry. This sentiment was echoed by UChem students:

> It seems to me that at least for [OLChem], most all the students are some sort of biology or pre professional. For this reason... you (you being chemistry department) should consider incorporating more relevant material, such as Organic chemistry in biological systems, or Organic chemistry in relation to human physiology. I'm sure all the current material is relevant and I am sure I will see it in Med school, etc., but at least make it more apparent to us pre professional kids now, so organic chemistry doesn't seem so abstract.

> You are giving us examples here of how organic and general chemistry relate and that makes sense to me now. When I was taking the organic chemistry course it did not seem as if they pointed out that connection. That would have definitely helped.

Such responses are actually encouraging because even students that respond to organic chemistry neutrally or unfavorably state or allude to the importance of being shown its applicability. These responses are further evidence of the perceived disconnect described by Anderson and Bodner (2008). In order to retain more high-achieving students in the scientific disciplines – and especially in the physical sciences – it is necessary to recognize and

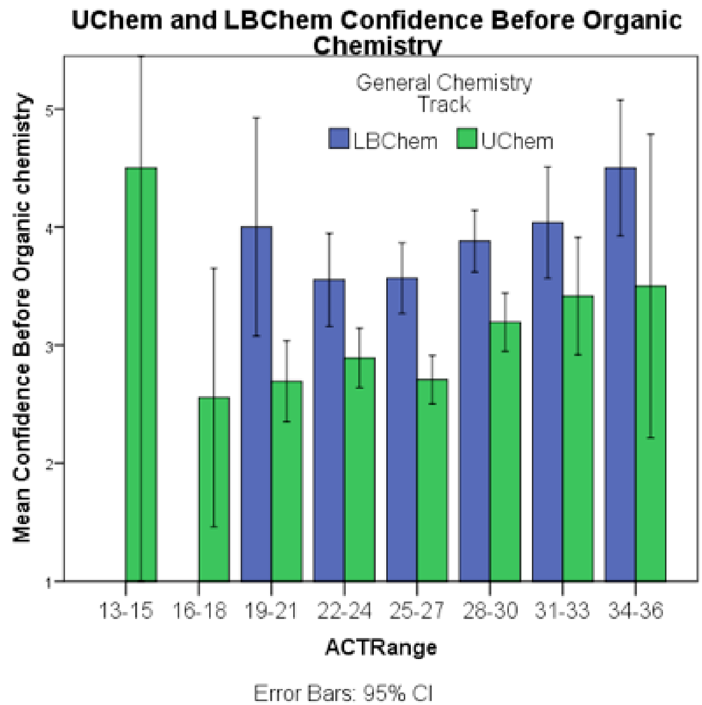
Categories	Illustrative Quotes	Frequency			
Which aspect(s) of your general chemistry class (could involve course content, lecture style, class format) most significantly impacted your performance in organic chemistry?		**All (N=1103)**	**UChem (N=639)**	**LBChem (N=292)**	**Non-MSU Credit (N=129)**
No answer*		6.9	7.4	3.1	
No application of concepts †	"…None of the content of [GChem] or [OLChem] overlapped, I believe. I could have taken either one first." (UChem)	14.4	19.9	4.5	11.3
Course content (excluding organic)	"I believe that the course content that was presented to me that most helped me within organic chemistry was the acid-base chemistry, Lewis dot structures, electro negativity and quantum mechanics. I did well in general chemistry and understood all of those concepts and ideas, which later helped me with organic chemistry." (Non-MSU Credit)	28.3	27.9	27.7	30.8
Organic unit†	"Most definitely the chapter we did in [LBChem] on organic chemistry. It was extremely frustrating at the time, and was one of the most challenging exams we had during the semester but it prepared me for Organic Chemistry. I felt like I had all of the basics down in Orgo I and can concentrate on learning the new more difficult material." (LBChem)	16.4	1.9	51.0	8.8
Class format/lecture style/recitation†	"The lecture style that I had in [the CChem sequence] prepared me better for [the OCChem sequence] because there was more of an emphasis on concepts rather than just solving problems like it seems to be in [both CChem courses]... The format of our exams also seemed to help because there were no purely multiple choice tests and partial credit was given for answers, unlike in [both CChem Courses]." (UChem)	58.8	65.1	43.2	63.5
Class size	"My general chemistry class was much smaller and it was much easier to get to know my professor. In organic chemistry classes at MSU I felt like a number rather than a student." (LBChem)	5.2	5.2	5.8	4.4
Other	"Not attending class regularly because the course is offered at extremely poor times of the day and this lead [sic] to extreme overcrowding." (UChem)	1.4	1.6	0.7	1.9

Table 3a. Categories for student free-responses and frequency of response (percent) by general chemistry sequence

Categories	Illustrative Quotes	All (N=1129)	UChem (N=665)	LBChem (N=292)	Non-MSU Credit (N=129)
What was your most significant concern(s) about your preparation for or transition to the organic chemistry course?					
No answer*		10.3	12.8	7.4	5.0
Was not concerned†	"I was actually pretty excited to take organic chemistry. I took the higher level organics just for the heck of it and so far have been very successful at it." (LBChem)	9.2	7.0	15.1	6.9
Vague expectation*	"I didn't know what it was before I took it. I didn't know what to expect." (UChem)	2.8	3.9	1.0	1.9
Heard course was difficult	Most of my concerns stemmed from fear of the course itself, not from preparation. " (UChem)	19.5	21.0	16.4	19.5
Felt ill-prepared/ content concerns	"Main concern was that I felt that I didn't learn enough to actually move over to Orgo." (UChem)	26.0	25.0	28.1	25.2
Less quantitative nature of organic*	"The visual aspect of the material. It was no longer numbers that were used to determine structures, you had to learn to see the molecules to understand what was taking place." (UChem)	7.3	8.5	4.5	7.5
Memorization	"…I was worried about having to memorize a whole set of unrelated reactions and molecules and then having to recall that information verbatim on an exam…" (LBChem)	14.1	13.0	17.1	11.9
Course load/ amount of time	"Too much material too fast at first. Exams covered way more novel information than inorganic ever did. If you're going to jam-pack a lecture schedule, you need more exams or less cumulative questions." (UChem)	14.1	15.3	10.6	15.1
Course style differences*	"The different format of exams (going from multiple choice in gen chemistry) to short answer in organic." (UChem)	8.9	7.5	12.7	8.8
Class size*	"The class size being too big." (LBChem)	2.5	0.3	7.2	3.1
Other	"That I would fail and have to take it over again." (LBChem)	6.9	5.3	4.8	17.6

Differences in UChem and LBChem are significant at the $p \leq 0.05$ level (*) or $p \leq 0.001$ level (†) as determined by a Pearson Chi Square

Table 3b. Categories for student free-responses and frequency of response (percent) by general chemistry sequence



ACT Composite Score/Score Range	Pearson Chi Square	p-value	Sample Size (N)
19-21	7.02	.071	56
22-24	10.03	.018	148
25-27	23.77	≤0.001	228
28-30	13.70	≤0.01	167
31-33	6.82	.078	51
34-36	3.00	.223	12

Figure 1. Comparison of UChem and LBChem students by composite ACT scores

address this disconnect by illustrating how concepts and skills from general chemistry are related and can transfer to the study of organic chemistry.

Confidence

As previous literature has indicated, affective variables can impact students' performance in chemistry (Gore, 2006; Steiner & Sullivan, 1984; Turner & Lindsay, 2003). Since our student populations may differ from each other, direct comparisons of students' reported pre- and post-organic confidence make little sense. Instead we must evaluate the confidence relative to pre-course indicators. A significant positive confidence difference was found in LBChem students with ACT composite scores between 22 and 30 (Figure 1). Above and below these ranges, the sample size was too small to show statistical differences or no difference existed. Significant Pearson correlations were found between student pre-organic I confidence and general chemistry I grade (0.345, p≤0.001), general chemistry II grade (0.289, p≤0.001), and organic chemistry I grade (0.354, p≤0.001). Post-organic confidence correlated with organic chemistry I (0.508, p≤0.001) and organic chemistry II grades (0.463, p≤0.001). This data shows that confidence tracks more closely to the student's first grade in the course series rather than the second. This is consistent with Barrow's insistence that students must be able to graft new material onto their existing cognitive framework (1998). It should be noted that pre-organic confidence was asked after students had begun or taken organic chemistry, so responses may have been altered according to self-efficacy theory: that changes in self-efficacy expectation occur based on success or failure (Campbell & Hackett, 1986).

Given the large number of written responses indicating the organic unit of general chemistry was important to their subsequent performance in organic chemistry (Table 3), it is arguable that the LBChem students' higher confidence may have arisen from their organic chemistry introduction. This confidence likely has a positive impact on their performance (Steiner & Sullivan, 1984), possibly providing comfort and reassurance to students as the following student quote seems to indicate:

> We were given an introduction to organic chemistry which included nomenclature and a few reactions, which ultimately gave me an idea as to what organic chemistry was all about so that I was not intimidated going into it. (LBChem)

Response pads and class size

As mentioned previous the course differences involved not only the introduction to organic chemistry, but also the use of response pads and smaller class sizes. Although not directly cited by the students, these variables may have contributed to some of the observed differences in LBChem. Response pads have been shown to raise students' confidence in and develop a working knowledge of course material by facilitating professor-student interaction (Addison, Wright, & Milner, 2009; Fies & Marshall, 2006; Gauci, Dantas, Williams, & Kemm, 2009). Over three years of LBChem end of semester surveys, 93-97% of students have indicated response pads helped improve their learning, and 85-87% indicated they helped improve their confidence. 73.2% of LBChem students indicated positively that class size had an effect on their general chemistry performance compared to 9.1% and 9.2% in GChem and CChem, respectively, perhaps it provided a more solid basis on which organic chemistry could be built. Response pads as well as a small class size are components of fostering an encouraging class environment, a factor that affects whether students remain in the sciences irrespective of their level of achievement (Astin, 1993; E. Seymour, 1995). While reducing class size may be difficult at the university level, institution of response pads may still be one method of improving student confidence prior to organic chemistry and thus smoothing the transition to create a better introductory chemistry experience for students.

Study limitations

As with all survey-based studies, there is the potential for self-selection bias in the respondents. The 39% of respondent appear to be representative of the entire sample, however some experiences might have been missed. There is also potential for bias in the background characteristic between the LBC and other MSU students that must be acknowledged. Although LBC has no additional requirements beyond acceptance to MSU, students must indicate interest in the residential college during application, thus students are not randomly assigned into the different pathways and motivational or academic differences may exist. However, since some LBC students opt to enroll in UChem, this subset afforded an opportunity to separate the difference from the students and the chemistry course. Regression analysis of LBC students enrolled in LBC chemistry compared to university chemistry showed that, in the prior eight years, Lyman Briggs students who took any of the UChem classes were statistically equivalent to other UChem students in their grades earned in Organic Chemistry.

It is also important to recognize the students' involvement in Organic Chemistry when completing the survey may result in differences. However, analysis of confidence variation in populations of students who had completed, were currently enrolled, or opted not to take organic chemistry II (i.e. students in different cohorts) found few significant differences. The only difference found was that students in the midst of the course had higher confidence than those who had completed it, perhaps showing extra optimism since they had not yet received their final grade for the class.

Another concern of this study is variation due to instructor differences. However, multiple linear regressions using dummy variables to represent the specific professors indicated that differences in student confidence were only slightly due to differences in professors: organic chemistry I professors indicated about only 1.4% of the variance in confidence, and organic chemistry II professors, only 3.9%, to yield a combined 5.3% of the total variance explained. Because student variation due to instructor difference in organic chemistry has been recognized and is small, the authors believe this limitation has minimal impact on the results of the study.

Conclusions and Implications for Undergraduate Chemistry Curriculum

From these data it appears that multiple factors affect students' perceptions of and transition to organic chemistry. Our surveys showed that 19.5% of all students had heard rumors of difficulty, 14.1% were worried about time demands, 26.0% were concerned about being ill-prepared, and 14.1% were concerned about memorization. This implies that the majority of all our students are anxious about transitioning to organic chemistry. Yet a course that included organic chemistry, along with smaller class size and response pads, yielded a significantly lower percent of students that report no application of concepts between general and organic chemistry (19.8% v. 4.5%, $p \leq 0.001$). Further 51.0% of its responding students indicate that the organic unit was significant in their preparation ($p \leq 0.001$). These changes also resulted in higher reported student confidence when entering organic chemistry. Additional favorable and unfavorable student comments about incorporation of organic chemistry in the curriculum further support its inclusion: generally it appears that students need (and sometimes even want) to be explicitly shown the connections between general and organic chemistry, as well as its applicability to the world. Overall, addressing students' perceptions and incorporating organic into the general chemistry curriculum has the potential to increase either actual preparedness or confidence both of which can improve retention of students in the sciences.

Acknowledgements

The authors would like to thank the Lyman Briggs Research Fund for financial support. This material is based upon work supported by the National Science Foundation under Grant No. 1022754.

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Alex G Collins-Webb is a veterinary student at Michigan State University, interested in small animal medicine. She received an undergraduate degree in Zoology from Michigan State University with an interdisciplinary minor in Bioethics, Humanities, and Society. She is currently finishing her clinical studies at MSU and is interested in pursuing advanced post-graduate training. Her particular interest is behavior medicine and clicker training: her dog, Raisin, frequently volunteers as a subject. Her other clinical interests include anesthesia and pain management, ultrasound, and orthopedic surgery.

Kathleen A. Jeffery is a graduate student at Purdue University in Chemical Education. She received an undergraduate degree in Biological Sciences for Secondary Education from Michigan State University with minors in Chemistry and Integrated Science. After a fantastic experience doing STEM education research at Michigan State, she briefly taught English abroad in South Korea before returning for graduate school to pursue a PhD. Although interested in almost everything related to science education, she has particularly soft spots for science teacher education, authentic context-based learning environments, and curriculum development.

Ryan D. Sweeder is an Associate Professor of chemistry in the Lyman Briggs College (a residential science program) and the CREATE for STEM research institute at Michigan State University. He received his Ph.D. at the University of Michigan in inorganic chemistry and chemistry education and completed his postdoctoral studies at Cornell University. He and his research group study the undergraduate science student experience in an effort to understand student retention and the impact of curricular interventions promoting either chemistry or interdisciplinary learning.