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Design, Evolution, and Evaluation of a General Chemistry-Bridging Course

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Abstract: General chemistry I/II courses are important gateway courses for a variety of STEM majors, as poor performance in these courses is often associated with lower rates of student success and retention. Much research has explored preparatory or remedial strategies to improve student outcomes. In this article, we report a different approach, which involved the development of a bridging or intervention course designed to capture students who are not or have not succeeded in general chemistry I and prepare them to retake the course in the following semester or summer. The course was initially developed as an eight-week module in the second half of the fall semester, where students were required to withdraw from general chemistry I prior to enrolling. After three years of this offering modality, with the inception of a winter J-term, the course was redesigned and moved online, where it was taught for another three years. We describe here in detail the design, evolution, and evaluation of this course over the six-year period.

Keywords: first-year undergraduate; retention; self-instruction; Internet; web-based learning

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1. Introduction

General chemistry I/II are critical gateway courses for students enrolled in a variety of Science, Technology, Engineering, and Mathematics (i.e., STEM) disciplines. Lack of success in these courses can lead students to change majors, a problem that is part of the "leaky pipeline" [1–23]. There is much evidence that women [24,25], under-represented minorities [25–27], first-generation students [28], less well-prepared students, and those from low-income backgrounds [25,28] leave STEM majors at higher rates than their counterparts, with a key difference between STEM "leavers" and STEM "persisters" being the number of STEM credits obtained in the first year [29]. This is a "push-pull" effect—i.e., students are pushed out of STEM majors by poor performance in introductory STEM courses while simultaneously being pulled into non-STEM majors by their higher course grades in those subjects [30]. A longitudinal study of attrition in STEM majors found that two root causes were dissatisfaction with the curriculum and student loss (or lack) of self-confidence [31]. A subsequent study of talented students showed that those who dropped out of STEM did so early, prior to declaring a major, with both their academic experiences and STEM self-efficacy found as important predictors [32]. Higher incidences of withdrawn or failed STEM courses are also associated with an increased probability of leaving college [29].

Many solutions to this problem have been explored. In introductory chemistry and biology, much work over the past forty years has focused on the delivery of college-preparatory or remedial courses [33–44]; however, the literature shows a record of mixed success [35,45]. For example, a longitudinal study of a voluntary, online summer preparatory course found that less than 50% of students who registered into the prep course completed it, and while there was a significant increase in the first-term ACS final exam percentile for students who completed more than 50% of the course, this reflected self-selection by more highly motivated students [46]. As another example of this effect, a voluntary, online, self-paced "ChemPrep" program at University of Massachusetts–Amherst showed significant gains for participating students [34]; however, users were primarily classified as

either "students likely to do well but lacking confidence" or "students who will do well and utilize every resource". This illustrates a key problem—such interventions can completely miss the primary group of targeted students, those "underprepared and likely to do poorly without additional help" [34].

A significant body of literature exists on the development of predictive criteria for performance in introductory science courses [33,38,40–42,47]. A recent study evaluated demographic characteristics and early-course cognitive measures in predicting student outcomes in first-term general chemistry [48]. Utilizing a diagnostic exam and adaptive learning pre-assessment, it was found that roughly ~57% of variance in ACS final exam scores and ~60% of variance in final course grades was related to the diagnostic exam score, initial pre-assessment, and predicted first-year quality point average (4 point scale). When these metrics were used in combination, a sizable percentage (~80%) of students with DFW (i.e., grades of D or F and withdrawal) outcomes in the course could be identified, which supports the use of early-term interventions. Such interventions are grounded in the educational literature, as recent work has shown that critical thinking and scientific reasoning ability are perhaps foremost amongst factors correlated with student success in general chemistry [36,37]. However, ultimately, any intervention strategy based upon voluntary student participation will fall prey to the deficiencies identified above.

In this work, we describe a different intervention approach, which attempted to capture students who were at risk of failing general chemistry I and prepare them to retake the course in the following semester. We began these efforts with the thesis that initial assessment (exam, quiz) scores are the best predictor of student success in the course [49]. While this claim may seem self-evident, it is supported by a recent study in general chemistry that found a strong correlation of initial assessment scores with course success, which persisted across multiple institutions, instructors, and course designs [50]. Poor performance in early assessments in introductory courses can lead to feelings of "learned helplessness" [51] and is therefore arguably the best time to intervene. Thus, our initial approach involved, at midterm, voluntarily transferring at-risk students in general chemistry I into a one-credit, eight-week transitional course. As a requirement, students had to withdraw from general chemistry I but were not charged additional tuition. The course design emphasized scientific reasoning and critical thinking, using a variety of active learning and inquiry-based strategies, which have been shown to reduce the achievement gap, lower DFW (i.e., grades of D or F and withdrawal) rates, and improve outcomes for lower-achieving students in both introductory chemistry and biology [52–63].

After three years of running the intervention course in this fashion, the university began a 4-week winter J-term, where all courses were taught online. In an effort to increase the number of students served by including all students with a DFW in fall general chemistry I, we transitioned the bridge course into a fully online J-term course. The course was thus cast into four one-week modules, using the elements of earth, air, fire, and water to examine fundamental chemical principles that are critical for success in general chemistry and beyond. In this article, we describe in detail the in-person and online implementations of the course and examine data on student outcomes.

2. Theoretical Framework

A key theoretical framework underpinning this effort is Dweck's growth mindset theory [64–69], which at its core centers on an individual's response to (here, academic) difficulties and impediments. It is based upon the premise that intellectual ability is not fixed but rather is changeable and can be developed. Significant research to date has demonstrated that a growth mindset can lead to more positive outcomes and resiliency for students faced with academic difficulties [70,71]. For example, a recent large study of 9th graders in the U.S. that evaluated the use of an online growth mindset intervention demonstrated both increased grades for at-risk students and increased retention in subsequent, more difficult math courses [72]. While other studies of mindset have shown mixed [73] or even negative results [74], a recent meta-analysis suggested that an association between

mindset and achievement is both reproducible and significant [75]. Notably, there, it was emphasized that this association will be strongest for students facing academic difficulties, which can introduce a heterogeneity in effect size. With respect to the present effort, we hypothesize that students exhibiting a growth mindset will be more likely to participate in the offered intervention. Viewed through that lens, the entire bridge course can be considered as a type of growth mindset intervention.

3. Guiding Research Question

The central question guiding this effort is the following: To what degree does participation in a voluntary bridging course impact student success in a retake of first-semester general chemistry? While many other aspects (e.g., retention in STEM majors and performance in subsequent chemistry courses, including general chemistry II and organic chemistry) can be examined, these were not considered as a part of the current study, which examined only the immediate initial impact of the bridging course.

4. Initial Course Design, Student Recruitment Strategy, and Capture Rate

Recognizing that student success in general chemistry goes beyond chemistry content to the fostering of critical academic skills, our initial design of the one-credit intervention course incorporated both specific chemistry content and academic skill development. The course outline, shown in Table 1, reflects a course design developed to emphasize important learning outcomes in the first-term course, including dimensional analysis, use of the periodic table, chemical bonding and intermolecular forces, and stoichiometry and limiting reagent. Interspersed with these topics were academic skill development activities, which included concept mapping, note taking, and formulating questions. Detailed examples of these activities are provided in the supporting information.

Table 1. Initial Course Design.

Week	*Class Topics and Activities*
1	• *Structure of the Atom* • *Concept Maps: Construction and Use*
2	• *Thinking like a Chemist: What Element Am I?* • *Scientific Reasoning and the Art of Deduction: Periodic Trends*
3	• *Dimensional Analysis* • *Case Study in Dimensional Analysis*
4	• *Bonding over Questions* • *Formulating Good Questions in Science*
5	• *Sticking Together in Chemistry* • *Electronegativity and Intermolecular Forces*
6	• *Limitations in Chemistry: What is a Limiting Reactant?* • *Strategies for Success in General Chemistry: Taking Notes*

The course met for six weeks, 75 min per week, and was implemented in a "flipped" format, with a video lecture and associated homework set posted each week, which students were asked to complete prior to coming to class. Each class session then focused on interactive activities centered around the weekly topics. Grading was on an S/U (Satisfactory/Unsatisfactory) scale based upon activity completion, attendance, and classroom participation.

In the in-semester implementation, students were recruited into the course following the second assessment (exam) in general chemistry I. A flyer (Figure S1; note that the prefix S indicates material in the supporting information) was prepared for publicizing the course, and all general chemistry I instructors were asked to disseminate information about the course. The course enrollment occurred via permission, but the course was open to any student who began the semester in general chemistry I. To gain entry into the course,

students were required to withdraw from general chemistry I. As this essentially swapped four credits for one credit, additional tuition was not charged.

The course was run in this format for three years. Considering the capture rate, during this period, a total of 2193 students enrolled in the fall-semester general chemistry I course across all sections, taught by various instructors. Of these students, a total of 183 (8.3%) withdrew from the course, and 38 of these (20.8%) enrolled in the bridge course.

5. Online Course Design, Student Recruitment Strategy, and Capture Rate

In 2019, the university instituted an online 4-week J-term during the break between fall and spring semesters. With the goal of capturing a larger fraction of students with DFW outcomes in general chemistry I, the decision was made to switch the course to a J-term course. This involved a restructuring of the course and the development of online content. The decision was made to reorganize the chemistry content along four themes aligned with the four ancient elements of air, earth, fire, and water. The modules and their detailed learning objectives are shown in Table 2, while detailed worksheets for each module are provided in the supporting information.

Table 2. Online Course Modules and Learning Objectives.

Module 1: The Air that We Breathe
• Define the important classifications of matter, distinguishing between mixtures and pure substances and between physical and chemical properties; • Use developed guidelines to determine significant figures in numerical measurements and in calculations; • Demonstrate use of dimensional analysis to solve problems; • Describe Lewis dot symbols, write symbols for main group elements, and draw Lewis structures for simple molecules.
Module 2: Of Elements and Earth
• Discuss periodic trends in properties among the main group elements and their ions using trends in atomic radii, ionization energy, and electron affinity; • Differentiate between ionic, covalent, and metallic bonding, comparing and contrasting properties of each; • Describe periodic trends in ionization energy and electron affinity; • Compare and contrast properties of metals and non-metals.
Module 3: Fire and Flame
• Write and balance equations for simple chemical reactions, including the physical state of reactant and product; • Differentiate endothermic and exothermic processes connecting to the first law of thermodynamics; • Define enthalpy and discuss why it is a useful variable for heat transferred in reaction; • Calculate enthalpy changes for reactions using different approaches.
Module 4: Water is the Solvent of Life
• Define intermolecular forces, classify into different types, and rank intermolecular forces in terms of strength; • Describe the uniqueness of the phase diagram for water and connect to the physical and chemical properties of water; • Discuss properties of aqueous solutions and measures of concentration; • Identify important reactions occurring in aqueous solution.

For each module, a series of short (~5 min) lecture videos were filmed using lightboard technology. Students were tasked to watch the videos, take notes in the Cornell note structure [76], and post these for review. Each module had an associated quiz, and for each module, participants were also asked to develop a concept map of the topic and submit for review by the instructor and other participants. The peer review resulted in a summary statement about how the conceptual associations were different and similar with other

students. Finally, modules 1 and 2 featured case studies, which the participants analyzed. The course assessment equally weighted the quizzes, notes, mind maps/peer reviews, and case studies, with an overall grade of 80% required for a satisfactory rating on an S/U scale.

The course was run in this format for three years, and we note that, here, students were charged additional tuition to take the course. Thus, while the move to the online J-term was designed to increase capture rates, the opposite trend was observed. During the three-year period a total of 1328 students enrolled in the fall-semester general chemistry I course across all sections. Of these students, a total of 103 (7.8%) withdrew from the course, and 2 of these (1.5%) enrolled in the bridge course. Considering the full six years of data then, a total of 4021 students enrolled in the fall general chemistry I course; of these, 286 (7%) withdrew, and 40 (14%) of these were captured into the bridge course.

6. Results and Discussion

To consider the impact of this course, we first consider the general chemistry I retake rate for students who completed the bridge course. Here, the full six-year cohort is examined. Of the 286 students who withdrew from all sections of general chemistry I, 91 (32%) enrolled again in general chemistry I in the following spring. The general chemistry I retake rate for students completing the bridge course was markedly higher, 60% vs. 27%. This is not surprising from a growth mindset perspective, as it can be anticipated that students enrolling in the bridge course would be more highly motivated to retake the course.

The key question we now address is whether students who completed the bridge course had improved outcomes upon retake. Of the 87 students during this period who withdrew from general chemistry I in the fall and retook the course in spring, the median grade was a 2.50 on a 4.0 scale. For the 23 students who took the bridge course, the median grade upon retake was higher, 3.0 on a 4.0 scale. More interesting, however, are the grade distributions and DFW rates for the two groups. In Figure 1, we compare the grade distributions for the two groups. A chi-square test of the distributions was statistically significant (p = 0.042). We note that 58% of students who completed the bridge course received at least a 3.0 (B) upon retake compared to 25% of students who did not complete the bridge course. Also significant are the differences in DFW rates, which were a factor of two smaller (12.5% vs. 25.8%) for the cohort completing the bridge course. The failure rate upon retake was particularly distinct: 4.2% for students who completed the bridge course and 20.9% for those who did not.

The data presented thus far are promising in showing (a) an increased retake rate for students completing the bridge course and (b) improved outcomes for students upon retake. Considering the bridge course as a growth mindset intervention, it may very well be that students taking and completing the bridge course were more likely to demonstrate a growth rather than fixed mindset. The very small numbers in the online implementation prevent a comparison of the different bridge course modalities. To obtain additional information, then, we examined student evaluations from the on-semester implementations. Our standard evaluation instrument features a set of Likert-scale questions followed by open commentary. The results of the Likert-scale questions are shown in Table 3.

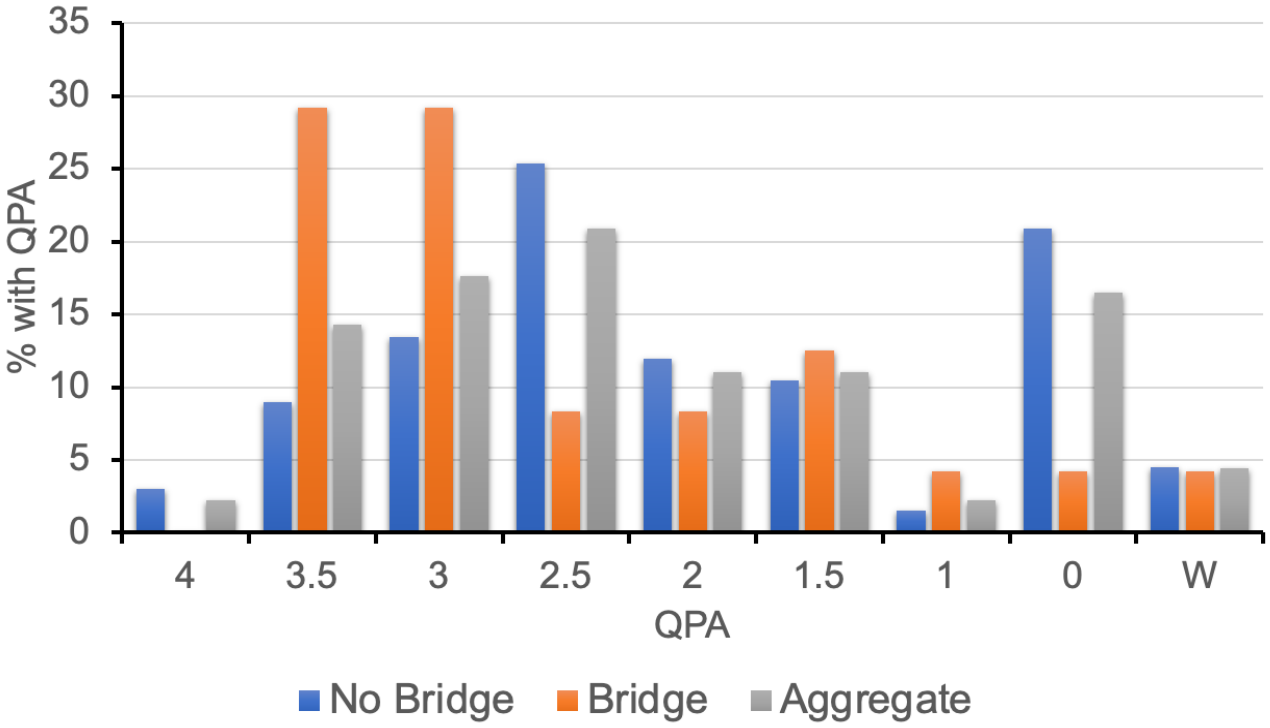


Figure 1. Course outcomes for students withdrawing from fall general chemistry I course and retaking in the following spring, 2016–2021. Outcomes are compared for students who took the bridge course vs. those who did not.

Table 3. Summary of student evaluations (group median) from the fall implementations.

Question	Key [(a)]	Fall 2016	Fall 2017	Fall 2018
How was this class as a whole?	1	4.3	5.8	4.0
How was the content of this class?	1	5.0	5.7	3.8
This class positively impacted my problem-solving abilities.	2	5.0	5.8	4.3
This class was intellectually challenging.	2	4.8	5.3	3.6
Evaluations were consistent with course objectives.	2	5.6	5.7	4.8
Response Rate		70%	81%	64%

[(a)] Key 1: 6 = excellent, 5 = very good, 4 = good, 3 = fair, 2 = poor, 1 = very poor. Key 2: 6 = strongly agree, 5 = agree, 4 = agree somewhat, 3 = neither agree nor disagree, 2 = disagree somewhat, 1 = strongly disagree.

The Likert-scale items generally followed trends observed for our general chemistry courses, with some variability, which might be expected from the relatively small cohorts. Some additional insights come from specific student comments, which are summarized here as examples of positive comments and criticisms:

Positive Comments

- This class really helped in my understanding of chemistry. I feel more prepared to retake general chemistry I because of this class;
- Really got me prepared for general chemistry I and helped me become more familiar with periodic table;
- It gave many tips on how to study and take notes and how to really be a better student;
- Overall, the class was very helpful because everything was broken down and taught in a manner in which students could understand;
- The class created a great foundation;
- I really like the creativity of the class and the way the professor went into depth with everything;

- I understood everything and just, overall, below my level; it felt super nice to really slow things down and feel like I had an even deeper understanding of things.

Criticisms

- There were some particular areas that I would have liked to have been discussed more in this class, such as the math/equation aspect of chemistry;
- This was the first time that this class was offered, so it could use a little tweaking, but all in all, it was definitely helpful;
- I feel the notes on how to become a better student were great, but I think if the class was more focused on taking an extensive look at the criteria we would be learning in the next chem class and really delving into doing chem problems and understanding how all the parts in chemistry work, it would make it an even more beneficial class;
- That class should not be an hour and 15 min. I hate going there.

Qualitatively, these comments suggest that students did benefit from and appreciated the course. Similar comments were found from the very small cohort taking the online offering. Considering the criticisms, it was very clear from the course inception that students appreciated the chemistry content over the study skills components. Therefore, as the course evolved, we made concerted efforts to blend these activities together. Tables S1–S3 show the evolution in course structure from the initial in-person to initial online offerings.

As noted in the introduction, studies of attrition in STEM majors have found that student self-efficacy and self-concept in STEM are both significant factors, amongst others [31,32]. This connection helps to explain the impact of failed or withdrawn STEM courses on student retention in STEM majors, as described above. Additional evidence comes from a six-year study on the benefits of a chemistry preparatory or remedial course, which found that (1) at the 95% confidence level, there was not a statistically significant difference in grades for students who had completed the remedial course or not, and (2) the remedial course decreased the number of students successfully completing general chemistry, as 44% of students who successfully completed the remedial course (i.e., with a grade of C or better) did not subsequently enroll in the targeted chemistry course [35,45]. Importantly, through post-course surveys, the authors found that the attrition rate stemmed largely from a change in choice of major and/or career goal, which did not appear to be directly attributable to the remedial course [45]. An important factor here could be the loss of self-efficacy, as an outcome of C, for example, in a remedial course may be considered on the one hand a success but on the other hand lead to a loss of self-efficacy for the student. Recognizing this, we attempted here through an intervention strategy to build student skills and self-efficacy in preparation for a retake of general chemistry I. Despite the limitations of this study, the results presented here are promising in showing potential for improved outcomes for students completing the intervention.

Moving forward, we plan to keep offering the course with the following modifications: (1) we will add an in-person offering into the second 8-week term of the fall semester, following the format of our initial implementation; (2) we will add a 0-credit option for the winter J-term course in order to capture students for whom the additional tuition was an issue. Given that the J-term begins immediately after the fall semester and ends just before the spring semester, we suspect that student "burnout" may also be an important factor in limiting the enrollment in the J-term course.

7. Limitations

The primary limitation of this work is the size of the cohort of students in the intervention course, particularly in the online offering. This makes it difficult to evaluate the efficacy of the course and certainly to compare the different course modalities in any meaningful way. While there is some evidence for improved outcomes for students completing the intervention course, the role of student mindset, motivation, and self-efficacy in contributing to these outcomes has not been examined.

8. Conclusions

We have reported here on the design, implementation, and evaluation of a chemistry intervention course designed to capture students at risk of failing general chemistry I and prepare them to retake the course in the following semester. The course was initially conceived as an eight-week in-person offering in the second half of the semester, where students were required to withdraw from general chemistry I prior to admission, thus effectively swapping four credits for one credit. After three years of running in this format, the course was transitioned to the online J-term between fall and spring semesters, which led to a drastic reduction in the students completing the course. An analysis of outcomes showed a much higher retake rate for students completing the intervention course and improved outcomes upon retake. Overall, this study provides preliminary data that an intervention course may be a useful addition to the toolkit for improving student outcomes and retention in gateway general chemistry courses.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci13090891/s1, Figure S1: Announcement flyer for the Bridge Course. Table S1: Schedule of activities for the bridge course, Fall 2016 implementation. Table S2: Schedule of activities for the bridge course, Fall 2018 implementation. Table S3: Schedule of activities for the online version of the bridge course. Examples: detailed examples of activities. Module Worksheets: detailed worksheets used in the online implementation.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The author declares no conflict of interest.

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