Integration of Research-based Strategies and Instructional Design: Creating Significant Learning Experiences in a Chemistry Bridge Course

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Introduction

Bridge courses are often designed to provide undergraduate students with learning experiences to remediate pitfalls in understanding or facilitating the practice of essential skills related to specific content knowledge [1]. The content varies depending on the field of study of students. Still, such bridge courses have a remediation component specifically for mathematics, as many incoming first-year students have difficulties with the content [1-4]. Nonetheless, other science, technology, engineering, and mathematics (STEM) content are also targeted in the bridge course designs [1]. Reported work on bridge courses for college-level presents a variety of secondary objectives besides math remediation, with assessment efforts mainly focused on students' academic success on entry-level STEM courses and dropout rate reduction during the first years of study [5, 6]. Secondary objectives include learning foundations to help participants develop research-based learning frameworks, growth mindset, self-efficacy, and STEM career self-image. These objectives support participants' motivation and passion towards their selected field of study, creating a sense of belonging and community amongst the participants, the faculty, and the university environment [1].

Bridge courses are often concise (ten or fewer days) and highly packed with content. This leads to challenges helping participants sustain their learning gains over time. With the NSF Division of Undergraduate Education's support, the STEM Center at Sam Houston State University (NSF award #1725674) funded the design of a bridge course for entering STEM majors. The bridge course incorporates reported strategies to support students in the short and long term via learning framework sessions and specific content tracks. The work herein presents the design, implementation, and observed results on students learning of the bridge course in chemistry, first implemented in the summer of 2020.

Bridge course design

The bridge course herein uses a backward design model proposed by Fink [7] referred to as the Integrated Course Design. Our instructional design definition is the "systematic and reflective process of translating learning and instruction principles into plans for instructional materials, activities, information resources, and evaluation" [8]. There are two fundamental approaches to design instruction: forward design and backward design. Forward design is typically content-centered and initiated, and characterized by a list of topics that become the centerpiece of the design. Backward design models start with the forward design's final step (the assessment and feedback) and evolve towards the forward design's initial stage, the contents [9]. The components of the chemistry bridge course design are shown in Figure 1.

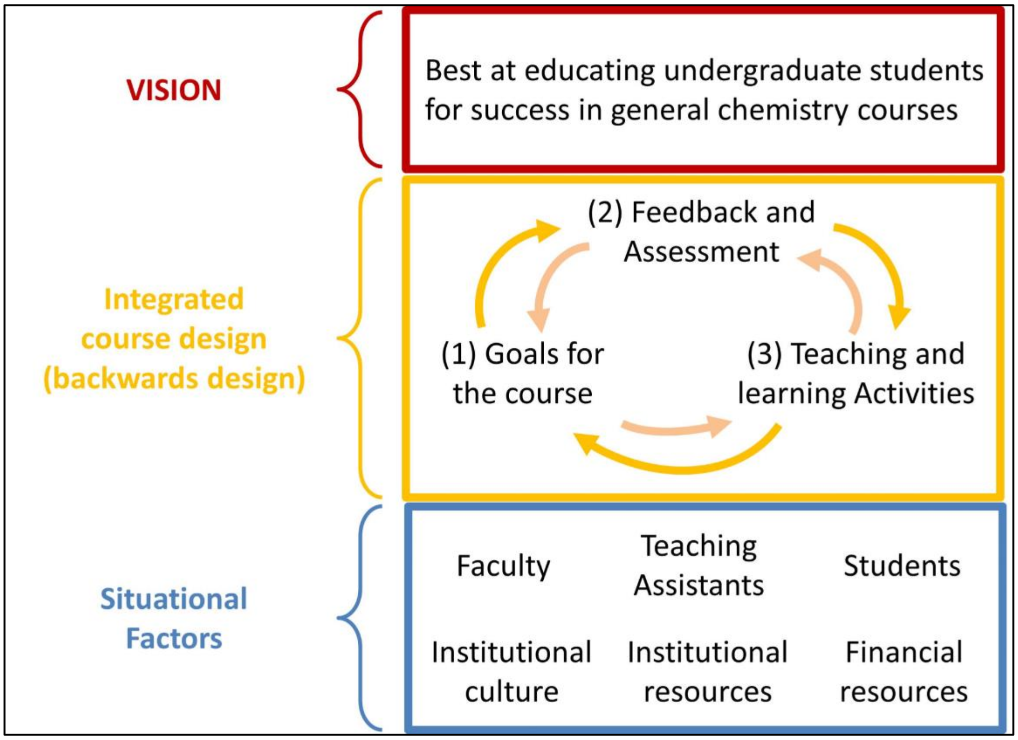


Figure 1: Components of the chemistry bridge course design.

The learning goals, feedback and assessment, and teaching and learning activities are the three components representing the critical decisions to address in the design. The model emphasizes integrating the three components; they are intimately related and mutually influenced and supported. The activities must reflect the goals and intended outcomes and lead to consistent feedback and assessment. Thus, the goals of the course must be established before the content and learning activities are selected. The design team then explored the literature on bridge courses for college-level to determine the common goals for bridge courses in science and chemistry in specific. We also asked the department of chemistry at our institution for additional goals for such a course. The goals were then split into three categories: academic, psychosocial, and departmental (see figure 2).

Goals:

Academic Success Goals
- Provide remediation on chemistry-related math skills.
- Increase the retention of STEM majors during the first two years of chemistry education.

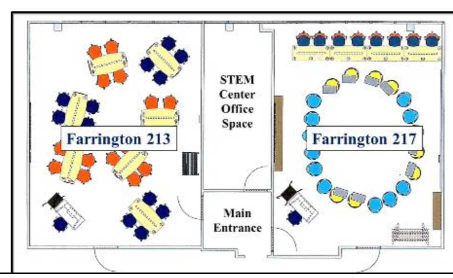
Psychosocial Goals
- Improve sense of preparedness and calibrated-self-efficacy of students.
- Provide an environment to foster networking amongst students.

Departmental Goals - none included

Figure 2: Goals of the chemistry bridge course

With the goals selected, we moved forward to address the situational factors specific to our institution. This was done before the assessment and feedback because the situational factors guide decisions on what best ways to deliver the assessments. The situational factors correspond to relevant information foundational to start the design process (e.g., learners' characteristics, the institution, and the instructor). The situational factors are summarized in table 1. An important feature of the course was the addition of support sessions during the academic semesters for summer participants. In these sessions, teaching assistants will function as tutors or supplemental instructors to the bridge course participants.

Table 1: Situational factors related to the chemistry bridge course.

Factor	Characteristics
Instructors	1) **Faculty** from the Department of Chemistry will be eligible to teach the course. 2) **Teaching assistants:** the Department of Chemistry hire teaching assistants for the laboratory courses, and the TAs are required to hold one office hour per lab section. 3) **General Chemistry Laboratory Coordinator**: the instructor was invited to participate and implement the designed course.
Participants	1) **STEM majors** taking General Chemistry I during fall and spring semesters. 2) **Recruitment**: posting of information on STEM Center website and email incoming students during summertime. 3) **Number of participants**: 30 or fewer students. This supports the fidelity of implementation as instructors and TAs will not be overwhelmed by many students.
Course sessions	Sessions will be managed by faculty with the potential usage of (2-3) teaching assistants (resource made available by the Department of Chemistry). **Summer Sessions** • One week • 4-6 hours per day + **Semester Sessions** • Biweekly meetings • 1-1.5 hours per session
Physical Space	1) **Department of Chemistry** classrooms and laboratory spaces. After regular classes, the classrooms and lab spaces are available to sit 30 or more students. 2) **STEM Center active learning classrooms**. 

The next step in the design was the assessment and feedback component of the integrated course design. For this step, the design team selected research-based strategies and reported instruments to address each goal chosen in the course. It is essential to mention that the assessments were selected before any learning activities were created, and the design was done for a method to be delivered in-person. However, for the first implementation in summer 2020, the course was forced to fit a remote delivery approach, not its original intent. Thus, some of the assessment initiatives could not be fulfilled as the instruments or methodology required in-person contact with the participants or compromised the validity of the responses. The summary of assessments and feedback activities is shown in figure 3.

Assessment and Feedback:

1) Provide remediation for students on chemistry-related math skills.
- A diagnostic test on math skills with and without a calculator (Math-Up Skill Test)
- In-house questionnaire (targeting the covered concepts)

2) Increase the retention of STEM majors during the first two years of chemistry education.
- Track student performance and their majors over the period (per semester).

3) Improve sense of preparedness and calibrated-self-efficacy of students.
- Surveys – reported instruments (pre and post course) – implement online and physical.
- Student interviews – end of course follow-up interviews

4) Provide an environment to foster networking amongst students.
- Classroom observations by an external evaluator
- Surveys/questionnaires related to their experience with group work during and after the bridge course

Figure 3: Summary of assessment and feedback activities.

In light of the goals and selected assessments, the designed team selected the bridge course's learning experiences. We chose content from the General Chemistry curriculum to frame the activities students will be completing during the bridge course. For example, it was decided that the course will target math remediation. Instead of working out math problems typically encountered in chemistry exercises, we created teaching and learning materials framed within chemistry content that will require math skills to solve. Thus, bridge course participants will be exposed to chemistry activities that could not be solved without math skills. To this end, three anchor chemistry concepts were selected for the summer sessions, and five additional concepts were selected for the academic year support sessions (see figure 4).

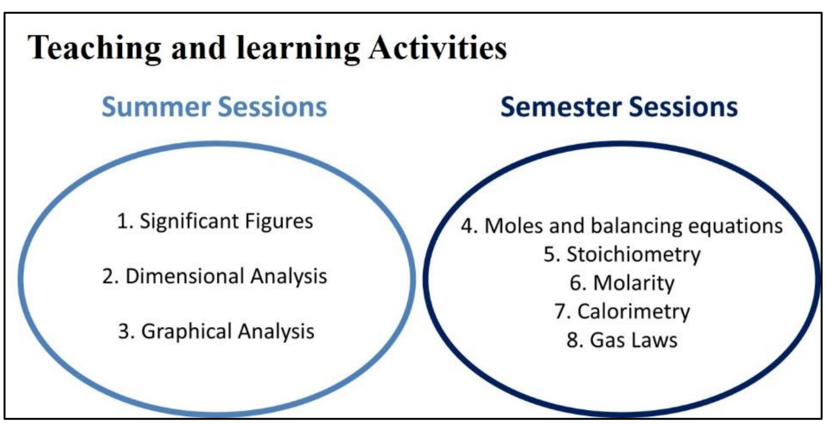


Figure 4: Chemistry content included in the course design.

As previously mentioned, the bridge course was originally designed to be an in-person course, with the activities and sessions for chemistry involving learning spaces like active learning classrooms and laboratories in the Department of Chemistry. However, the first implementation forced us to do the course via remote instruction, impacting our planned activities. The original design included hands-on experimentation, laboratory data collection, group work, cooperative learning projects, and Process Oriented Guided Inquiry Learning (POGIL) activities. The designed team then re-designed some of the original activities and created new ones using freely available online resources. Such resources included PhET simulations [10] and the ChemCollective [11] virtual laboratory program. The revised plan for implementation is summarized in figure 5.

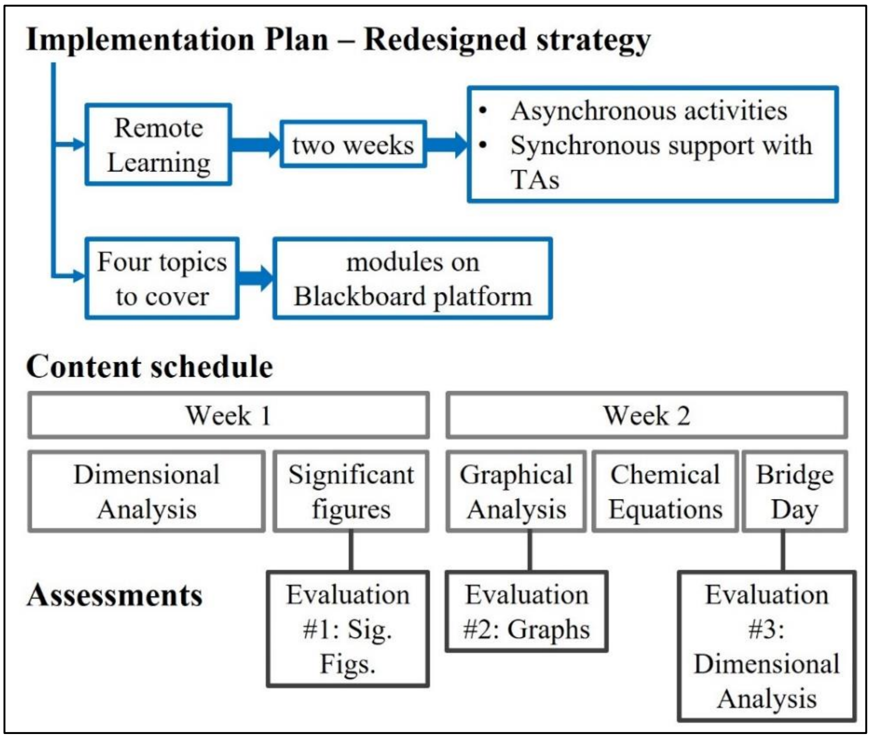


Figure 5: Implementation plan for learning activities and assessments.

Learning materials

The online implementation was completed during the planned two-week. Additional learning activities were also delivered online during the following academic year. The design team created a total of eight modules for the Blackboard platform used at the institution. The learning experiences were all original products of the designed team, and two teaching assistants revised it and provided their student perspective on how to improve it. The end products were then implemented, and participant's feedback further guided its constant development. The activities varied from video recordings of content knowledge, digital worksheets, virtual laboratories, data collection from pre-recorded laboratory experiments, and data analysis using Microsoft Excel. Figure 6 presents an overview of learning activity using the ChemCollective virtual laboratory to collect data. Students input the data into a Microsoft Excel worksheet to analyze it in graphical form.

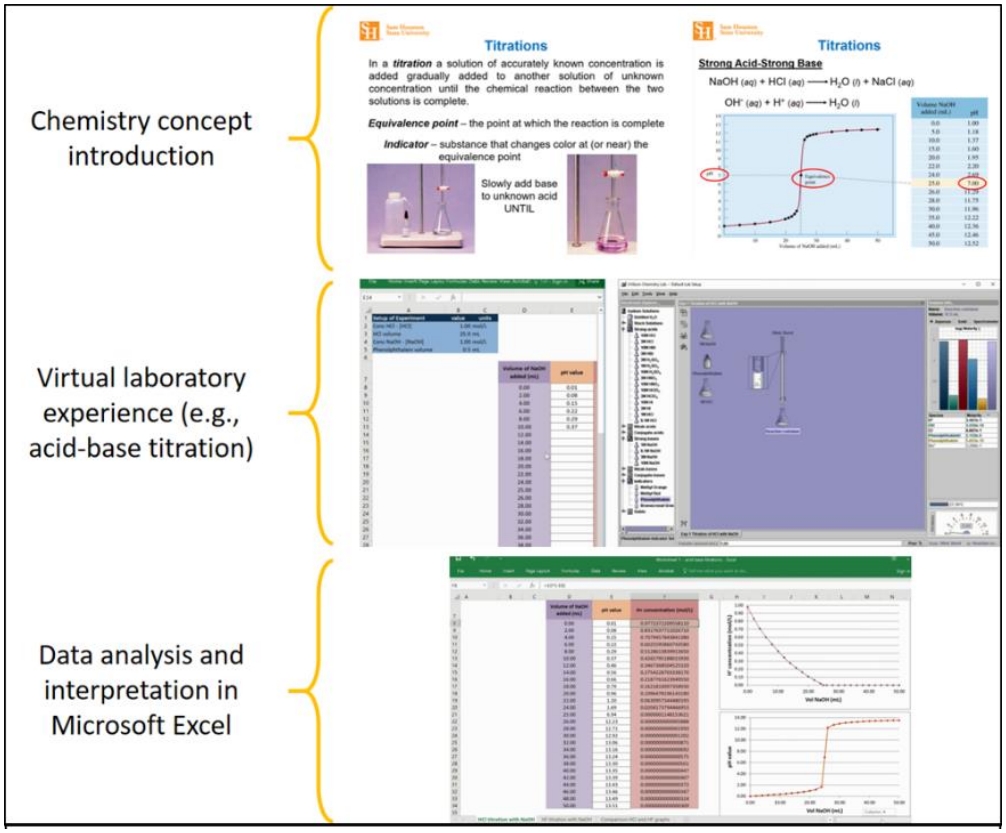


Figure 6. Overview of designed learning activity in the chemistry bridge course.

Participants

In summer 2020, the bridge course had 110 participants enrolled (see table 2). The STEM Center bridge course subdivides all participants into three tracks depending on their target preparation course. The three tracks include calculus, pre-calculus or trigonometry, and general chemistry I. Table 2 presents enrollment information for summer 2020. Due to the remote delivery and extraordinary circumstances of summer 2020 (i.e., world pandemic due to COVID-19), the bridge course's designed team saw a significant drop in engagement during the two weeks of the course. In the prior two years of implementing math bridge courses, the dropout rate was low, as students were part of in-person work sessions, and the program was run with residential support for the participants. However, online connectivity and time restrictions for the participants lead to lower completion rates for summer 2020.

Table 2: Participants in summer 2020 STEM Center bridge course series.

Bridge Course Track	Total Enrollment	Completed the Course
Calculus	21	62%
Pre-Calculus or Trigonometry	29	31%
General Chemistry I	60	40%
Total	110	42%

Results of the bridge course for the General Chemistry I track

For this work, we will focus on academic performance during the subsequent academic semester, fall 2020, of the chemistry bridge course participants. We collected the participants' grades in the chemistry courses taken during the semester (see table 3) and contrasted them against all students' performance. We found that the bridge course participants had a 46% passing rate (ABC letter grades) in General Chemistry I. This result doubles the observed 27.1% passing rate of all students for that course in fall 2020. Thus the bridge course participants seem to have a higher chance to pass the intended course. Although not all students enrolled in the bridge course completed it, even the students that did not finish it had a better performance (41% passing rate) in the General Chemistry I course during fall 2020. We acknowledge that the results might be affected by the participants' self-selection to enroll in the summer course. Thus, it could be that the participants were proficient in the content knowledge. Still, at the moment, we have not finalized the data analysis of all evaluations and assessments done during the summer course to determine potential differences in prior knowledge on our participants. Also, not all intended assessments were deployed, as the remote delivery hindered our ability to perform them.

Table 3: Academic performance of chemistry bridge course participants in their fall 2020 chemistry courses. Total participants n=60.

Completed the bridge course	Grade	CHEM1411 General Chemistry I Totals (%)	CHEM1412 General Chemistry II	CHEM1406 Inorganic and Environmental Chemistry	No chemistry course was taken in fall 2020
YES n=24	ABC	11 (46%)			
	DF	8 (33%)			
	Q	5 (21%)			
	N/A				
NO n=36	ABC	11 (41%)		1 (100%)	
	DF	12 (44%)			
	QW	4 (15%)	2 (100%)		
	N/A				6

Conclusions

The results of student academic performance presented in this work provide an optimistic view of the designed chemistry bridge course's impact. The participants that fully engaged in the course were motivated and engaged with the content and the learning experiences. At our institution, courses were delivered in a hybrid fashion with classes help in-person and remotely for most of the 2020 academic year. The bridge course participants experienced first-hand what remote instruction was before the academic year started. Thus, they had an excellent opportunity to develop remote learning strategies, which help them benefit from this instruction method. Therefore, the summertime experience could explain the observed performance results in the General Chemistry I course of the bridge course participants.

Future Plans

Summer 2020 was the first implementation of the chemistry bridge course. The STEM Center and the design team are confident the bridge courses are a beneficial experience to the participants and will continue to implement the courses in the upcoming years. As many of the materials are now available online for remote instruction, we plan to provide them yearlong for all General Chemistry students in our courses. In summer 2021, we will implement a new track for the bridge course to target the General Chemistry II course. This course will follow the integrated course design presented in this work for the General Chemistry I track.

Acknowledgements

The authors wish to acknowledge the National Science Foundation under grant No. 1725674 for supporting this work. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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