Strengthening Deep Learning in a Professional Doctorate Pharmaceutics Course: Perceived Impact on Students' Self-Efficacy

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To stimulate and strengthen a culture of deep learning associated with problem-solving, two complementary instructional strategies, productive failure and instructor-designed concept maps, were introduced to pharmacy students in an introductory pharmaceutical course. This study describes the impact of the two instructional deep-learning strategies on pharmacy students' perceptions and beliefs. The analysis of a proposed path model indicated that students' perceived impact of the two instructional strategies were significant predictors of self-efficacy. The results of this study indicated that the combination of the productive failure and instructor-designed concept maps significantly impacted students' perceptions and beliefs on their ability to perform well in the course. The qualitative data related to the perceived strengths and weaknesses provided additional support for these findings and revealed more details regarding the perceived benefits of this instructional strategy. Future research will focus on student-generated concept maps' impact on transfer problems associated with productive failure.

Keywords: problem solving, productive failure, concept mapping, self-efficacy

INTRODUCTION

Pharmacy students enrolled in Doctor of Pharmacy (PharmD) programs are expected to assume diverse roles beyond the traditional responsibilities of dispensing medicines and medication management for patients. Pharmacists are increasingly likely to analyze new information and use the conclusions to solve complex problems related to patient care. Current Accreditation Council for Pharmacy Education (ACPE) accreditation standards emphasize the need for problem-solving competencies to integrate knowledge from foundational sciences into complex clinical skills (Medina et al., 2013). A typical instructional strategy in foundational and applied sciences is scaffolding through worked examples (e.g., Jonassen, 2004, 2011). One of the significant shortcomings of worked examples as an instructional strategy is its tendency to prompt learners to focus on the procedural aspects of the problem-solving process. Consequently, during the worked examples process, students often miss the conceptual integration of foundational knowledge that experts convey as they work through problems (Darabi et al., 2007; van Gog et al., 2015). This shortcoming becomes even more critical for pharmacy education since students often tend to adhere to a micro-culture of shallow learning during their pre-pharmacy coursework.

As these students move into entry-level pharmacy courses, some of the gaps in their problem-solving skills pose challenges that hinder their academic performance.

The major objective of this study was to analyze to what degree two instructional strategies focused on conceptual understanding, concept mapping and productive failure can help pharmacy students build strong problem-solving skills.

INSTRUCTIONAL CONTEXT

As part of the PharmD program at a Midwestern University, "Pharmaceutics I" was a required course that focuses on bridging the foundational chemistry knowledge from the pre-pharm program and the applicative pharmacy clinical skills by building strong analytical and problem-solving skills. The instructor of this course identified some challenging topics where students consistently performed below expectations. An analysis of students' examinations showed that they failed to connect the conceptual aspects of chemical structures and phenomena with the corresponding algebraic equations. The instructor worked with an instructional designer to address this issue by adopting and implementing a productive failure instructional strategy for the identified difficult topics (Kapur, 2008, 2010, 2013). Using a design-based research (DBR) methodology (Cernusca & Ionas, 2014) with two iterative DBR cycles, we found that students in the instructional intervention cohort scored significantly higher on the examination that focused on the productive failure strategy (Cernusca & Mallik, 2018).

However, following the implementation of productive failure, the instructor observed a lack of consistency in students' ability to analyze the structural chemistry concepts for the problem to decide on the appropriate analysis. To address this gap during the Fall 2019 semester, the instructor working with the instructional designer started to integrate a series of designed concepts maps in the instructional process. These concept maps were integrated with the solved examples throughout the course, including the productive failure strategy parts.

Concept mapping proved to be an effective mindtool (e.g., Jonassen, 2000) to support deep learning by helping learners engage in critical thinking (Bilik et al., 2020; Hay, 2007). Concept mapping is also effective for instructors to assess learning (Weinerth et al., 2014). While concept mapping was introduced at a larger scale in education during the 1970's, recent literature shows the potential impact of this tool across various areas of health professions, such as medicine (Daley & Torre, 2010), nursing (Daley et al., 2016), and pharmacy (Hill, 2004; Noble et al., 2011). Finally, concept mapping is particularly effective when integrated with other deep-learning instructional tools and strategies. For example, concept mapping was successfully combined with a photograph association technique (Byrne & Grace, 2010). While this integration elicited children's ideas about a specific science topic, it showed that concept mapping could be useful in pharmacy educational research associated with sensitive topics. For example, adding concept mapping to the photovoice strategy (Werremeyer et al., 2017) proved to enhance the quality of the outcome resulting from the photovoice intervention. At a deeper level, Addae et al. (2012) proposed a modified Problem Based Learning (PBL) strategy where concept mapping was combined with the traditional PBL phases to produce a new 5-phase learning approach in which three of the phases were designed as identifiable concept mapping tasks. In this strategy, the first concept map was developed as a group map focused on the structure of the clinical problem and served as the center of the overall map created in the other two concept mapping tasks.

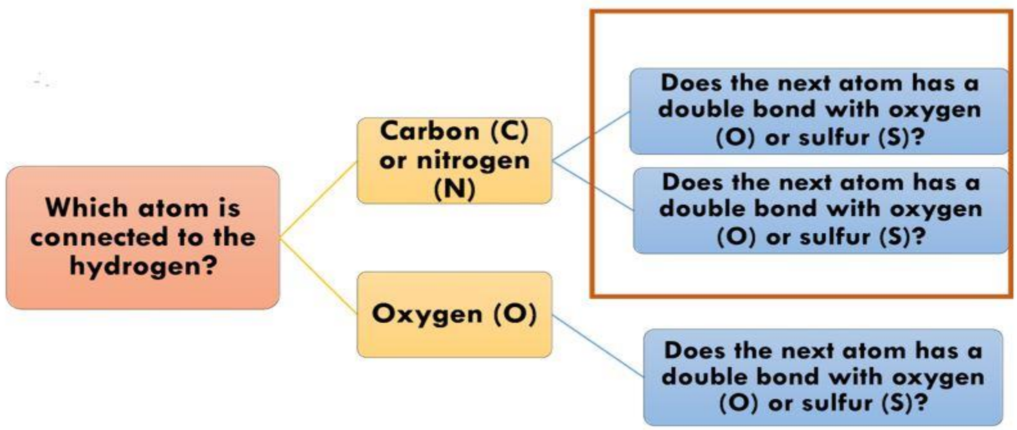
INSTRUCTIONAL INTERVENTION

Considering its potential benefits and flexibility, we decided to integrate the concept mapping strategy with the active learning in-class activities already part of the Pharmaceutics I course. The primary focus of integrating concept mapping into the instructional process was to increase students' ability to solve problems scaffolded with worked examples, including those problems that were augmented with the productive failure strategy. Previous research showed that the fully student-generated and partially student-generated concept maps proved to be more effective than the expert-generated maps (e.g., Lim et al. 2009).

Building on these findings, we decided to use a layered integration process and started with the expert-generated concept maps, with the instructor being the expert in this case. From an instructional impact perspective, instructor-designed maps helped to introduce students to the basic structure of the mental models associated with various stages in the problem-solving process.

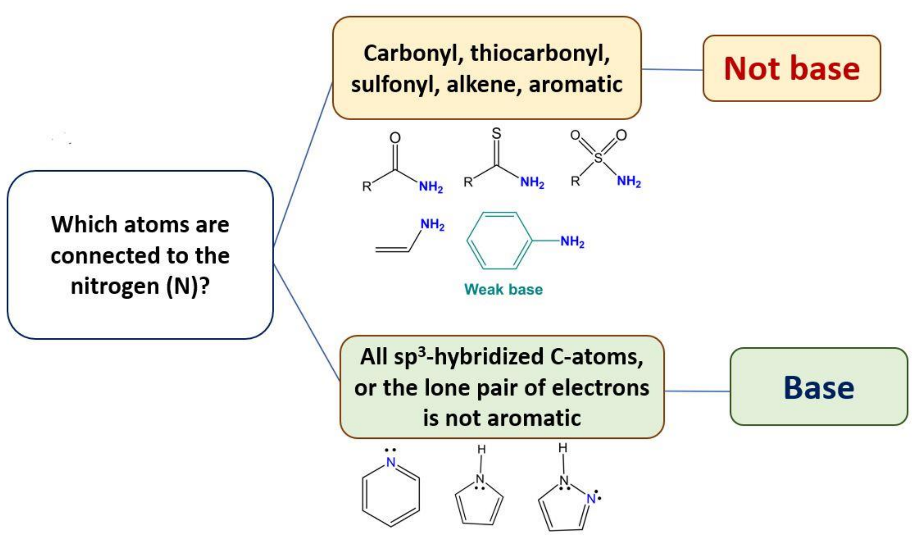
In addition, this strategy was not expected to significantly increase the anxiety associated with the changes in the instructional process, reducing the chances of student resistance to the change. The instructor observed that the students lack the foundational concepts to determine if a drug is an acid or a base and the effect of resonance on acidity and basicity. Consequently, the pH calculations for aqueous drug solutions were particularly challenging for the pharmacy students. The instructor created three linked concept maps to address these issues to calculate the pH of dilute aqueous drug solutions. The first concept map focuses on identifying resonance and acidic hydrogen atoms (see Figure 1).

FIGURE 1
RESONANCE AND ACIDIC HYDROGEN ATOMS CONCEPT MAP



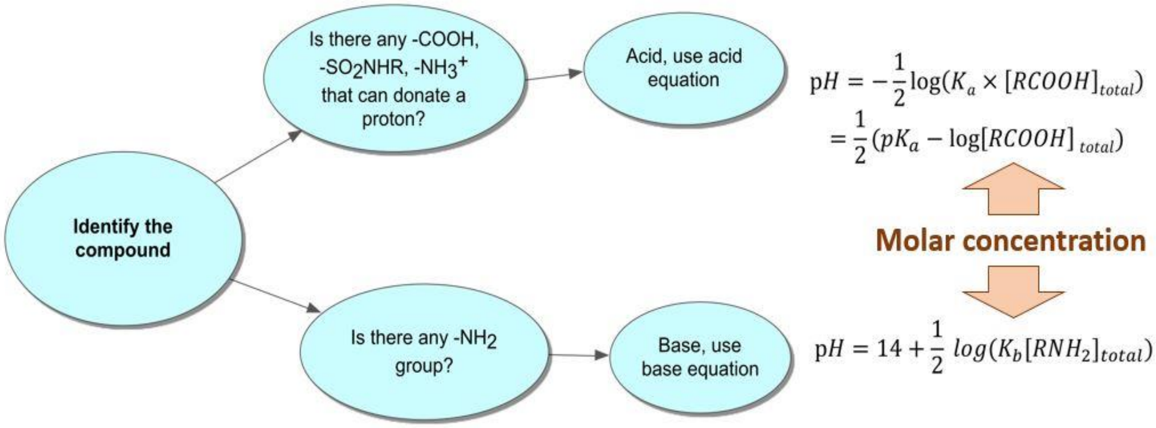
The second concept map guided the students in identifying organic structural fragments that render a drug molecule basic (see Figure 2).

FIGURE 2
IDENTIFICATION OF RESONANCE AND BASES CONCEPT MAP



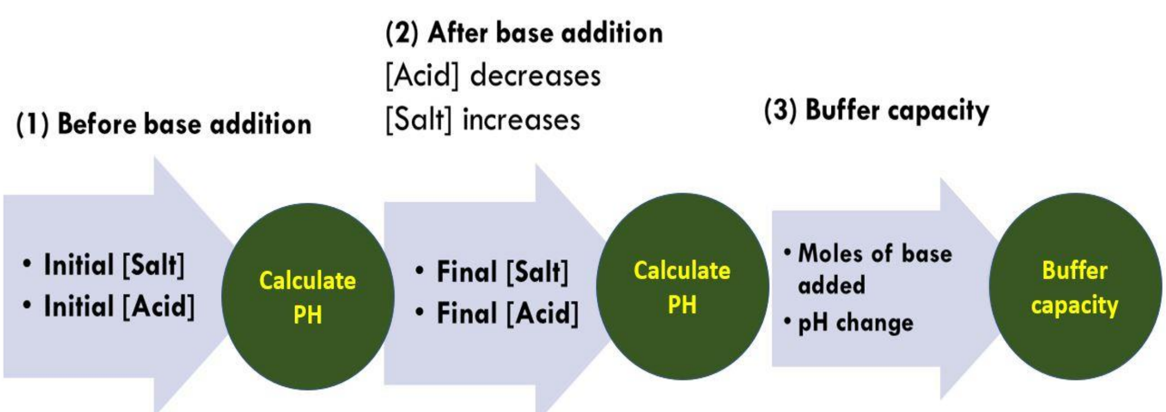
Finally, the last linked concept map used in calculating the pH of dilute aqueous drug solutions focused on correlating the structure with the corresponding equations (see Figure 3).

FIGURE 3
CORRELATION OF THE STRUCTURE WITH THE EQUATIONS CONCEPT MAP



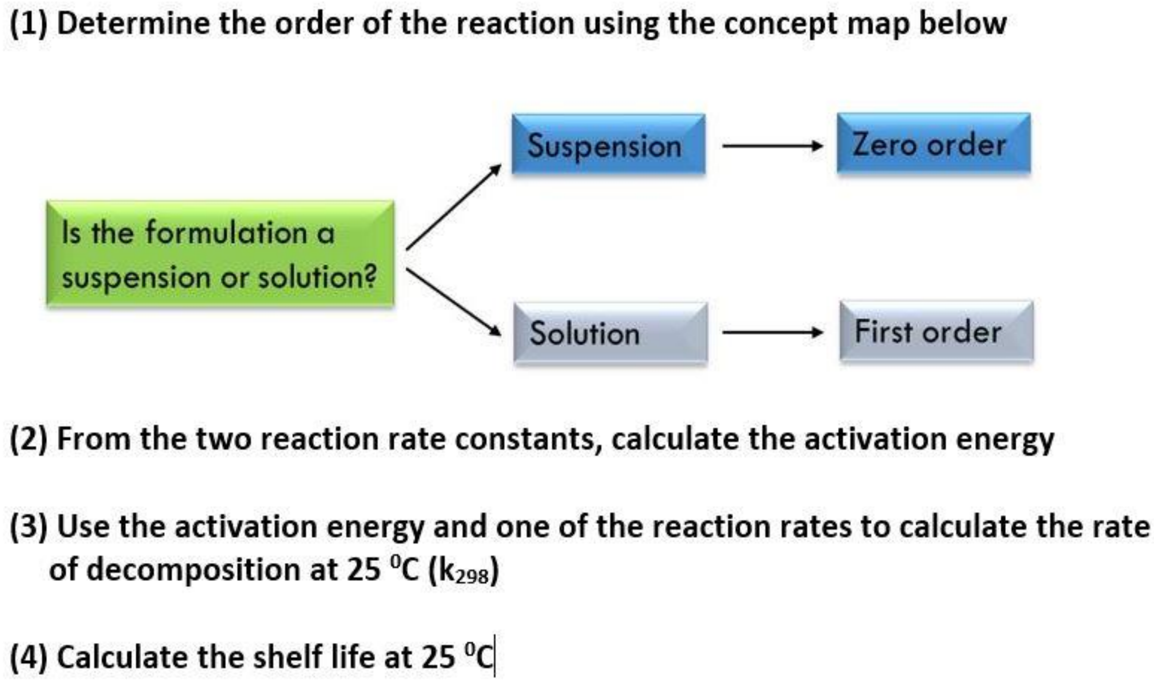
Another challenging topic was the buffer capacity calculation, possibly due to several sequential analyses. In collaboration with the instructional designer, the instructor introduced the productive failure strategy on this topic. However, the class participation was not optimal. Hence, the instructor prepared a concept map delineating the steps (see Figure 4).

FIGURE 4
CONCEPT MAP FOR BUFFER CAPACITY CALCULATIONS



In the last topic for the semester, the students need to calculate the shelf-life of drugs using the equations for accelerated stability testing. To complete this task, students need to analyze and determine the order of the drug decomposition reaction, follow several sequential steps, and use complex equations. Initially, the instructor implemented the productive failure strategy. Then, to further enhance students' comprehension, he introduced a concept map to support the calculations (see Figure 5).

FIGURE 5
CONCEPT MAP FOR CALCULATING THE SHELF-LIFE OF DRUGS



The instructor-generated concept maps' structures were dependent on the context of the problem to be solved. Therefore, the instructor encouraged students to adapt the maps for the worked example problems discussed during the classroom activities as part of the assigned homework and when they were preparing for the exams and quizzes.

RESEARCH FOCUS AND METHODOLOGY

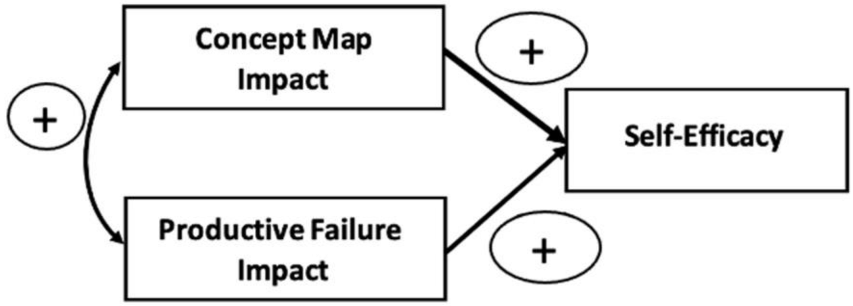
Due to the expected relatively low impact of the instructor-driven concept maps on students' overall performance (e.g., Jonassen, 2000), the primary goal of this study was to explore the perceived impact of the integration of productive failure and instructor-driven concept maps on pharmacy students' self-efficacy. Self-efficacy was used as a proxy for students' future performance as it reflects the nature and quality and feedback received by the learner as part of an instructional process.

Research Design

An exploratory quantitative design research was used to analyze if the perceived impact of concept mapping and productive failure were significant predictors of student perceived self-efficacy. For triangulation purposes, students' answers to an open-ended question on the strengths and weaknesses of concept maps used in this course were analyzed from a qualitative perspective (e.g., Cernusca & Price, 2013).

The proposed structural model used for the quantitative analysis is presented in Figure 6. As shown in Figure 6 the expectation was that both the perceived impact of concept mapping and productive failure tasks on own learning will increase student self-efficacy beliefs, while students' perceptions related to the two types of strategies will interact with each other.

FIGURE 6
CONCEPTUAL MODEL RELATED TO THE INSTRUCTIONAL INTERVENTION



For the data collection, the instructor collaborated with an instructional designer to develop and administer online, using Qualtrics®, an end-of-course survey with items adapted for three constructs validated in the literature and one open-ended essay question. The *perceived impact of productive failure on own learning* and the *perceived impact of concept maps on own learning* constructs were adapted from Grasman & Cernusca (2015) with minor changes related to the course name and focal topic (see Appendix 1). The self-efficacy construct was adapted from Cernusca & Price (2013). All three constructs used a 9-point Likert evaluation scale ranging from 1 for "Strongly Disagree" to 9 for "Strongly Agree". Each construct was evaluated as the average of the scores of its individual items, resulting in a continuous value ranging from 1 to 9. The open-ended question focused on students' overall perception of the strengths and weaknesses of concept maps in the course. The online survey was administered during the last two weeks, and students had 10 days to complete the survey. No bonus points were given for those that participated in this research study. The local Institutional Review Board approved this study. The informed consent form was posted at the onset of the survey indicating the voluntary participation in the research and the alternative task available for those interested in earning the bonus points but not participating in this study.

Data Analysis

Quantitative data collected were analyzed for basic statistics and correlations among proposed variables using SPSS v25. Analysis of raw data did not reveal outliers, and the analysis of z- scores ($< \pm 2.5$), skewness, and kurtosis ($< \pm 0.5$) indicated an acceptable level for the normality of the dataset. All three constructs adapted from the literature showed robust internal reliability with Cronbach's Alpha values of 0.98 for the *perceived impact of productive failure* on own learning and 0.95 for *self-efficacy* and *perceived impact of concept mapping* on own learning. A path analysis model for the three proposed variables, perceived impact of productive failure on own learning, perceived impact of concept mapping on own learning, and self-efficacy, were tested using IBM SPSS Amos v25 software. Qualitative data used for triangulation purposes were organized manually in significant themes.

FINDINGS

For the quantitative analysis, Table 1 presents the basic statistics for each of the measured continuous variables at the exit point in the course. The proposed conceptual model was supported by the statistically significant ($p < 0.001$) correlations among these variables with a moderate to high strength ranging from 0.58 to 0.64 (see Table 1). The results of the path analysis as resulted from the data generated with AMOS are summarized in Figure 7.

The path analysis indicated that both perception variables were significant predictors of self-efficacy, with the perceived impact of productive failure standardized coefficient of $\beta = 0.32$, $p < 0.01$ and the perceived impact of concept maps standardized coefficient of β = 0.47, $p < 0.001$. The covariance between the perception variables had a standardized coefficient of β = 0.58, $p < 0.001$ (see Figure 7).

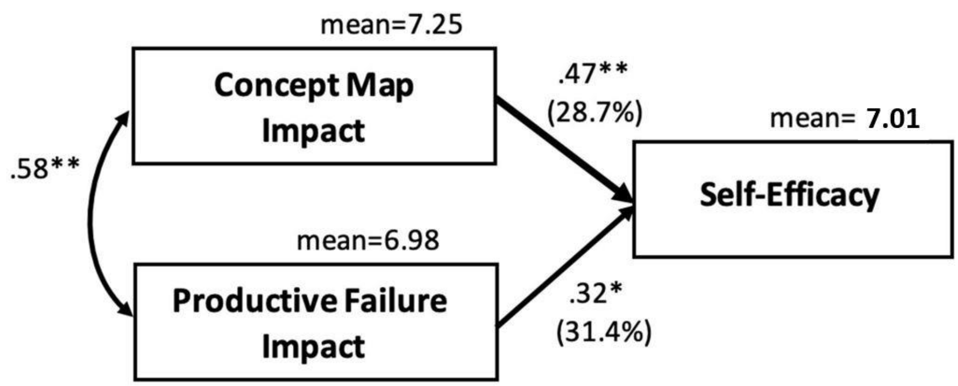
TABLE 1
MEANS, STANDARD DEVIATIONS, AND PEARSON CORRELATIONS FOR CONTINUOUS VARIABLES (N = 53)

	M	SD	1	2	3
1. Perceived impact of concept maps	7.24	1.69	-	0.58**	0.64**
2. Perceived impact of productive failure	6.98	1.79		-	0.59**
3. Self-efficacy	7.04	1.44			-

Note: **p < 0.01 (2-tailed)

The overall model had a good fit (NFI = 0.99; CFI = 0.99), and the two perception variables explained 49% of the variance in students' self-efficacy, an acceptable level considering the low-impact nature of the concept mapping instructional intervention. Because the exams in this course are open-notes, anecdotal data based on the instructor's observation indicated that students used the instructor-developed concept maps when they worked on the problems during the exam.

FIGURE 7
RESULTS FOR THE PROPOSED PATH ANALYSIS MODEL



The qualitative analysis focused on the input from 46 participants (82%) who answered the open-ended question on the strengths and weaknesses of concept maps. Students' answers were grouped into four major themes: concept maps useful for my learning, concept maps somewhat helpful, the need for more details, and the need to expand the use of concept maps for additional topics in the course. Most students found concept maps useful (33, 72%) or somewhat helpful (6, 13%). Students' input for these two themes ranged from short, more generic answers such as "good" or "I loved them. They were a huge help" to more elaborated details on the nature of the learning-related benefits of concept maps as follows.

Helped summarize the information in a visual way

> "I like the concept maps because it summarizes the information into more basic pathways." (S7)

> "I personally found the concept maps to be helpful for the most part. I am a visual learner so having the concepts laid out in the way that the concept maps were helped me to put all of the pieces together." (S39)

> "Made it slightly easier to visualize concepts and how to differentiate multiple concepts" (S51)

> "I like the concept mapping a lot. It visualized the thinking/judging process, helps me to understand the process in just one page of graph." (S55)

Helped when dealing with complex concepts and topics

> "I really enjoyed the concept maps. If I was struggling with a concept or problem I could go through a step by step process to find where something wasn't connecting with me." (S2)

> "Concept maps are helpful especially when the material is challenging. Sometimes we go through things quickly in class, but going back and looking at the concept map helps me figure out each step of the problem." (S19)

Support for problem-solving process

> "I love the concept maps, they help me to initialize where to start when faced with a problem" (S6)

> "In particular, I liked the one [concept map] that helped us tell if something was water soluble." (S23)

> "I think they were very beneficial and easy to follow. They were a quick tool to use when solving problems." (S27)

> "I thought the concept maps helped very much. It was a good way to see the process of solving problems and understanding concepts." (S48)

The remaining answers focused on the need for more details (3, 7%) and the benefit of expanding concept maps for additional topics in the course (3, 7%). Only one student specifically indicated that they "rarely referred back to the concept maps because I don't think they summarized the content as well the slides themselves and my own notes" (S54).

DISCUSSIONS AND FURTHER RESEARCH

The results of this study indicate that the combination of the two strategies, productive failure and instructor-designed concept maps, can significantly impact students' perceptions and beliefs on their ability to perform well in the course. The acceptance of the two strategies is also a potential indicator of students' willingness to use deep learning problem-solving strategies as part of this course. The qualitative data related to the perceived strengths and weaknesses provided additional support for these findings and revealed more details regarding the perceived benefits of this instructional strategy. Considering the piloting nature of this study, the research team intends to explore the identified trends further by expanding the use of instructor-driven concept maps and introducing instructional tasks that will require students to generate their concept maps for transfer problems associated with the worked examples integrated into the productive failure activities.

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APPENDIX: INSTRUCTIONAL ENGAGEMENT CONSTRUCTS

The *use of Concept Maps in PCSI xxx helped me to…*	**Strongly Disagree**				**Strongly Agree**
***…better retain* the material taught in lectures**	1	2…	5	…8	9
***…better prepare* for the exams**	1	2…	5	…8	9
***…develop a better* understanding of the concepts introduced in lectures**	1	2…	5	…8	9
***…feel more confident* in my ability to learn the material**	1	2…	5	…8	9
***…make the time studying* for exams and quizzes more effective**	1	2…	5	…8	9

The *use of Productive Failure in PSCI xxx helped me to…*	**Strongly Disagree**	**Column 1**	**Column 2**	**Column 3**	**Strongly Agree**
***…better retain* the material taught in Buffered Solution lectures**	1	2…	5	…8	9
***…better prepare* for the exam 2**	1	2…	5	…8	9
***…develop a better* understanding of the concepts introduced in lectures**	1	2…	5	…8	9
***…feel more confident* in my ability to learn the material for Buffered Solutions**	1	2…	5	…8	9
***…make the time studying* for Buffered Solutions exam more**	1	2…	5	…8	9