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Using Low-to-High Structured Learning Sequence with Peer-Based Learning in Advanced Engineering

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ABSTRACT

CONTEXT

In the post-pandemic era, the Australian government recently changed the policy to encourage international students to come to Australia to study and work, which led to a significant increase in student enrolment in universities. This development has added tremendous pressure on academic staff and made traditional teaching practices (e.g., teacher-centred, lecturing, etc.) less effective.

PURPOSE OR GOAL

In this study, we proposed to tweak the original problem-based learning a bit in our study design. First, providing problem-based activities during tutorials, followed by lectures to consolidate the targeted concepts used to solve the problems in tutorials. We call this approach a *tutorial-lecture* (Low-to-High) approach, starting with a low-structured tutorial and following a high-structured lecture. It is the opposite of the conventional sequence. The purpose of this study is to examine the effectiveness and impact of using the tutorial-lecture (Low-to-High structured) approach (Jacobson et al., 2013; Jacobson et al., 2016) with peer-based learning (Kennedy, 2020; Penprase, 2020) to redesign the Reservoir Engineering course.

APPROACH OR METHODOLOGY/METHODS

Ninety-eight students participated in the study during a 13-week teaching period in an Reservoir Engineering course. Data sources include students' scores of Assessment 1 in Week 5, Assessment 2 in Week 9, final assessment in Week 13 and an anonymous survey at the end of the study period.

OUTCOMES

The findings revealed that the tutorial-lecture (LH) approach with PBL: (1) significantly reduced the achievement gap between the undergraduates and postgraduates, (2) achieved 90% student satisfaction, and (3) helped students logically articulate their understanding and confirm it with peers leading to increase student engagement.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Overall, we believe these approaches should be introduced gradually across the course's curriculum and as part of a well-resourced course redevelopment.

KEYWORDS

Engineering Education; Sequences of Pedagogical Structure, Peer-Based Learning, Achievement gap

Introduction

During 2020 and 2021, the outbreak of COVID-19 across the globe created many barriers for international students, for example, the uncertainty of international travel options, recognition of vaccinations and visa approvals. It resulted in the number of international students dramatically shrinking. However, in the post-pandemic era, the Australian government recently changed the policy to encourage international students to come to Australia to study and work, which led to a significant increase in student enrolment in universities. This development has added tremendous pressure on academic staff and made traditional teaching practices (e.g., teacher-centred, lecturing, etc.) less effective. Furthermore, the prior knowledge gap between undergraduate and postgraduate students in the same course is another challenge for teaching academics. In a large class, traditional teaching approaches generally result in low engagement, more passive learning and no time for feedback on student progress and personal needs. Therefore, the academic staff was required to redesign courses in order to promote student engagement and learning.

These challenges have been found in Reservoir Engineering, a core petroleum engineering course at an Australian university. The course content extends students' understanding of fluid flow in rocks beyond the more idealised cases covered in Reservoir Engineering. Students are expected to have advanced mathematical skills and a deep understanding of well-drilling knowledge to solve authentic problems.

In order to overcome these challenges, the purpose of this study is to examine the effectiveness and impact of using the Low-to-High (LH) structured learning approach (Jacobson et al., 2013; Jacobson et al., 2016) with peer-based learning (Kennedy, 2020; Penprase, 2020) to redesign the Reservoir Engineering course. In the following sections, we provide an overview of the relevant literature that has informed our pedagogical strategies, followed by the methods, results and discussion sections. The paper concludes with the implications and limitations of this study.

Sequences of Pedagogical Structure in STEM Education

The issue of how pedagogical guidance should be provided to learners has been a practical debate in the educational literature for decades (Jacobson et al., 2013; Jacobson et al., 2016; Kirschner et al., 2006; Mayer, 2004). Jacobson and colleagues (2013) proposed the sequences of pedagogical structure framework to distinguish learning designs based on if and when low and high-structured activities occur. The four sequences of the pedagogical structure included in this framework are high-to-high (HH), high-to-low (HL), low-to-low (LL) and low-to-high (LH). For example, an HH sequence could consist of direct instruction followed by a worked example (e.g., traditional teaching approach). On the other hand, an HL sequence starts with direct instruction and is followed by a discussion section (e.g., a flipped classroom). LL sequences, on the other hand, encompass minimally guided approaches like discovery learning, experiential learning, and problem-based learning (Jacobson et al., 2013; Kirschner et al., 2006). Problem-based approach has been dramatically reported its beneficial to student learning and engagement in STEM education for decades (De Graaff, 2003; Hmelo-Silver, 2004; Hmelo-Silver et al., 2007; Ribeiro & Mizukami, 2005). Problem-based activities could be categorised as LL sequences, as the activities are ill-defined. Problem scenarios are used to encourage students to acquire knowledge and develop critical thinking and problem-solving skills. Psychological and educational research suggests that by having students learn through problem-solving experience, they can learn both the targeted concepts and critical thinking strategies (Hmelo-Silver, 2004; Ribeiro & Mizukami, 2005). Implementing a problem-based approach depends on well-designed problems and the sequence of pedagogical structure (Hmelo-Silver et al., 2007). Furthermore, in a student cohort with diverse cultures and prior knowledge levels, the problem-based approach can significantly reduce the achievement gap between academically advantaged and disadvantaged students (Haak et al., 2011). This argument is especially relevant because the student body is becoming more international in Australian universities. In contrast, Kirschner et al. (2006) have provided evidence to suggest the overall limitation of learning effectiveness when implementing minimally (LL) guided approaches.

Although LL approaches may not be effective for learning, a group of educational researchers suggests that combination approaches, such as LH approaches, might be more beneficial than HH approaches (e.g., traditional teaching approaches) alone in science and engineering education (Cao et al., 2023; Jacobson et al., 2020; Jacobson et al., 2013; Kapur & Bielaczyc, 2012; Lai et al., 2017; Portolese, 2021). Therefore, we proposed to tweak the original problem-based learning a bit in our study design. First, providing problem-based activities during tutorials, followed by lectures to consolidate the targeted concepts used to solve the problems in tutorials. We call this approach a *tutorial-lecture* (Low-to-High) approach, starting with a low-structured tutorial and following a high-structured lecture. It is the opposite of the conventional sequence. The tutorial problems help students identify aspects of the new material that they find unclear or confusing. Lectures can then be used to deepen students' knowledge of the topic and to address common misunderstandings. The tutorial-lecture (LH) approach guides the students through a problem-solving process consisting of four steps below:

1. *Motivation*: This sets up the problem's context and importance and motivates the students to engage with the topic.
2. *Strengthen*: Students review and strengthen their prior knowledge.
3. *Build*: Students employ prior knowledge to build new skills and understanding.
4. *Consolidate*: The academic staff summarises the outcomes from the tutorial and outlines how these outcomes form the basis of the following lecture.

Employing the tutorial-lecture approach helps students to bridge the gap between the simplified concepts they have learnt in their previous year and a more realistic approach that incorporates a much more nuanced understanding of the complex behaviour of how fluids are distributed and flow through porous media. This approach allows an opportunity for students to discover the limitations of their current knowledge and provides an intrinsic drive to understand more complex systems encountered in professional environments. Further, embedding more complex theories in a real-world context immediately shows students the benefit and significance of mastering this new content. Another tweak in the study design is including a Peer-Based Learning (PBL) component to promote peer discussions and learning.

Peer-Based Learning (PBL)

The peer-based learning (PBL) approach means asking students to engage in tasks requiring peer-based collaboration (Kennedy, 2020). PBL activities generally are student-led and directed. The academic staff acts as a facilitator to provide guidance, monitor students' progress, and provide feedback while students work together on a specific problem, scenario or issue in a social learning environment. To extend student interaction from the tutorials to lectures, we employed PBL during lectures.

Generally, students seem reluctant to ask clarifying questions in class because of a fear of looking ignorant in front of their peers. PBL provides peer-to-peer and informal student-to-teacher interactions, which helps students realise they are not alone with misunderstandings or only partially comprehending key concepts (Mercer & Howe, 2012). This encourages them to ask more questions. PBL also allows students to clarify their own understanding in a context that is less intimidating than having to directly answer questions from the academic staff in front of the whole class. This process also provides feedback to the academic staff on the class's comprehension.

Methods

This study is in relation to the viability and feasibility of implementing active learning strategies in an engineering curriculum in an Australian university. Freeman et al. (2014) reported that average failure rates reduced from 33.8% under passive learning to 21.8% under active learning. The study aims to examine the effectiveness and impact of using the tutorial-lecture (LH structured) approach in an Reservoir Engineering course.

Nighty-eight students participated in this study, of which 58 were undergraduate students, and 40 were postgraduate students. Eighty-eight out of 98 were international students with the background of English as a second language. The study took a whole teaching period of 13 weeks. Table 1 shows the tutorial-lecture approach in the weekly learning sequence of the pedagogical structure of the course, which started from Week 2 of the teaching period. First, during the *low-structured tutorial*, the problem scenario was presented and subdivided into small-scale questions to guide students toward the solutions. Students were asked to form a group of 4 at the beginning of the tutorial, and then the academic staff provided the problem scenario with small-scale questions to each group. Students were asked to discuss the questions and concluded with group responses in their groups. Academic staff and two tutors monitored students' discussions and progress and provided guidance if any of them was off-track. Moreover, during the monitoring, academic staff and two tutors would identify students' misunderstandings based on their discussions.

Table 1: Tutorial-lecture approach: weekly learning sequence of pedagogical structure of Advance Reservoir Engineering course

Pedagogical Structure	Duration (mins)	Class types	Peer-Based Learning	What academic staff does	What students do
Low-structured	60	Tutorial	√	· Provide the problem scenario with small-scale questions · Monitor students discussions and progresses · Identify students' misunderstandings from discussions	Discuss the questions provided and conclude with group responses
High-structured	30	Tutorial		· Collect groups' responses and lead a class discussion · Discuss the plausibility of different solutions and address the identified misunderstandings. · Consolidate and summarise the discussion and set up for the next question	Discuss with the academic staff and listen to the conclusion
	60	Lecture	√	· Introduction to complex and advanced concepts · Conclude the outcomes from discussions	· Explain the new concepts to their neighbours and discuss how the explanation could be refined · Share the group ideas to the class

The second half of the tutorial was a *high-structured consolidation* phase. Academic staff gathered groups' responses and led a class discussion. From discussing the plausibility of different solutions, the academic addressed the identified misunderstandings and consolidated the knowledge gap students had. Finally, academic staff introduced more complex materials with advanced concepts during the high-structured lecture. Students were asked to explain the new concepts to their neighbours and discuss how the explanation could be refined. Academic staff concluded the outcomes from discussions.

Assessment 1, Assessment 2 and the final assessment were conducted in week 5, week 9 and week 13 individually, respectively, to test students' understanding of the targeted concepts and applications for problem-solving tasks. The weight of Assessments 1 and 2 are both 20% of the overall mark, including ten online questions, respectively. Assessment 3 was the end-of-semester face-to-face exam, weighted 60% of the final mark. In addition, students were given an anonymous survey to evaluate their learning experience with the tutorial-lecture (LH structured) approach and peer-based learning. The survey consisted of four rating questions with a 5-point Likert scale (1= strongly disagree; 5= strongly agree), and two open-ended questions to gain a deep understanding of students' learning experience (see Table 2).

Table 2: Anonymous survey questionnaire

	Rating Questions
Q1	I found the tutorial-lecture (low-to-high) approach to help me learn deeply.
Q2	I found the tutorial-lecture (low-to-high) approach increased my engagement.
Q3	I found that peer-based learning helps me learn deeply.
Q4	I found that peer-based learning helped me understand complicated concepts easily.
	Open-ended Questions
Q5	What do you like about these approaches the most?
Q6	What do you like about these approaches the least?

Results and Discussion

Student academic outcomes

An independent-sample *t*-test was conducted to compare the students' grades on assessment tasks from the undergraduate and postgraduate groups. There was no significant difference in students' grades for Assessment 1 between the undergraduate and postgraduate groups (t = .51, df = 96, p = .612, two-tailed) (see Table 3 and Figure 1). In addition, the difference was not significant between the undergraduate and postgraduate groups on Assessment 2 conducted in week 9 (t = .83, df = 96, p = .408, two-tailed), even though the postgraduates scored slightly higher than the undergraduates. In contrast, the undergraduates scored marginally higher than the postgraduates on the final assessment, but there was no significant difference between the two groups (t = .88, df = 96, p = .385, two-tailed).

The results suggested that the tutorial-lecture (LH) approach with PBL significantly reduced the academic achievement gap between undergraduate and postgraduate students, since they had different levels of prior knowledge in reservoir engineering. This suggestion is in line with Haak and colleagues' (2011) argument that low-structured active learning that promotes peer interaction allows disadvantaged students to articulate their logic and consider other perspectives when solving problems, leading to learning gains, and decreasing the gap in academic outcomes.

Similarly, Hmelo-Silver and colleagues (2004; 2007) claim that small group discussion and debate in low-structured problem-based learning sessions enhances higher-order thinking and promotes shared knowledge construction because the student interaction help distribute the cognitive load among group members by allowing the whole group to tackle problems that would generally be too difficult for each student alone.

Table 3: Means and standard deviations of students' grades on each assessment task

Assessment	Time	UG group (n = 58)	PG group (n = 40)
Assessment 1	Week 5	2.72 (.35)	2.76 (.31)
Assessment 2	Week 9	1.72 (.60)	1.83 (.59)
Final Assessment	Week 13	2.19 (.43)	2.12 (.35)
Sum		6.63	6.71

Note. The total score for each assessment task is 3 points.

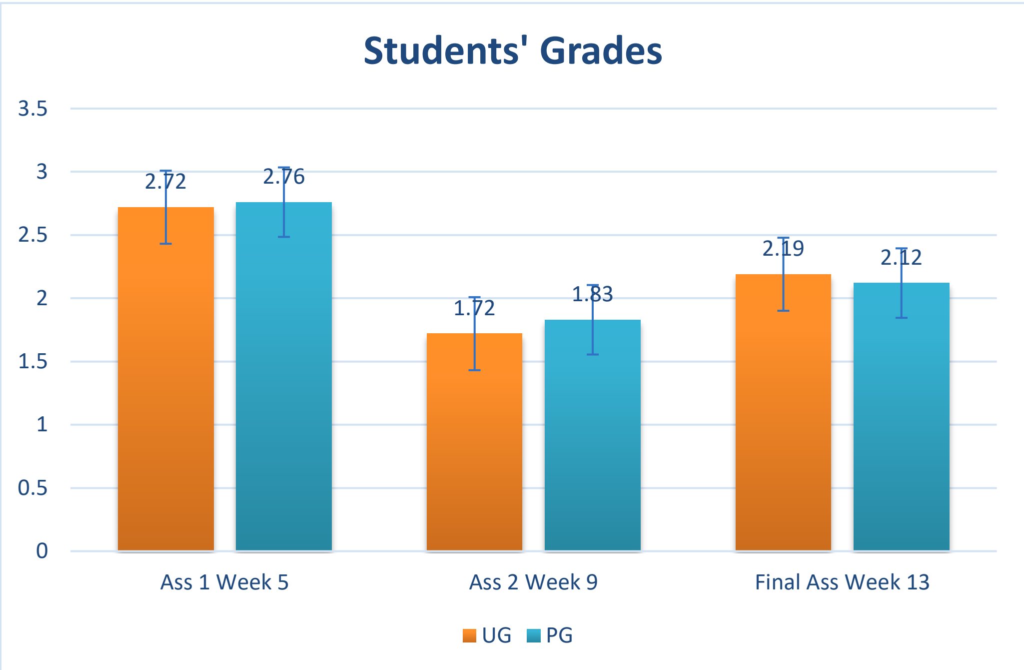

Figure 1: Differences between the undergraduate and postgraduate groups in assessment scores

Student evaluation outcomes

The survey results revealed that approximately 90% of students were satisfied with the tutorial-lecture (LH structured) approach and peer-based learning (see Figure 2). However, 4% of students were strongly dissatisfied with the peer-based learning (PBL) that was embedded in tutorials and lectures.

Looking deeper, the qualitative data on what students liked the most about the learning approaches, the responses were very encouraging. Students repeatedly indicated their preference for the peer-based learning approach, as PBL allowed them to share their points of view with each other with simplified explanations and develop teamwork skills. One of the students' comments expressed:

> *Peer discussion approach gives the students an insight or a perspective to new ideas from their peers, hence exposing the students to a broad range of ideas and this brings about strong team work.*

They also emphasised the tutorial-lecture (LH structured) approach with PBL helps them understand the targeted concepts better and the authenticity of the problem scenarios. Another student's comment typified this sentiment:

> *The tutorials and discussions allowed me to properly understand the concepts by applying it to questions. It also helped me stay focused and interact. It gives purpose to what we study and the application to real life reservoir engineering problems.*

However, the data revealed students liked the least of these approaches were that the problem questions were unclear and peer discussion was not enough. For example, a comment was: "peer discussion is only a few minutes". In addition to this, another comment on unclear questions was: "Sometimes we just misunderstand the question and move on the wrong direction."

Overall, the qualitative data add to quantitative findings by providing explanations for why students value the tutorial-lecture (LH structured) approach with PBL and also what to justify and improve for the next delivery.

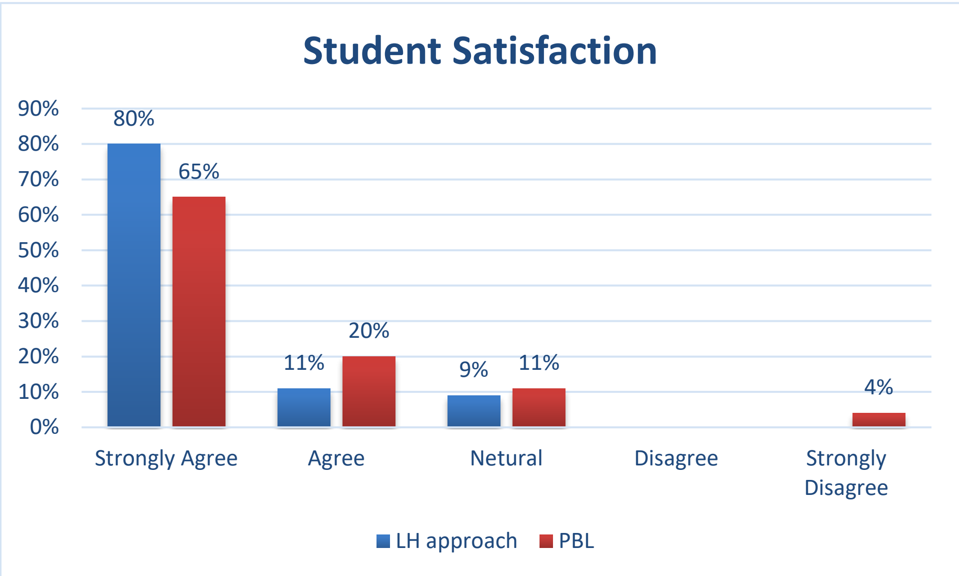

Figure 2. Anonymous survey results

Conclusion

This paper reported the findings of employing a low-to-high structured (tutorial-lecture) approach with peer-based learning to enhance students' academic outcomes and learning experience in an Reservoir Engineering course. The findings included the tutorial-lecture (LH) approach with PBL: (1) significantly reduced the achievement gap between the undergraduates and postgraduates,

(2) was satisfied with 90 % of students, and (3) helped students logically articulate their understanding and confirm it with peers leading to increase student engagement.

Shifting from the traditional teaching approach to the tutorial-lecture (LH structured) approach with peer-based learning requires redesigning the tutorial questions based on students' prior knowledge. The absence of the pre-test for students' prior knowledge of reservoir engineering is one of the limitations of this study. In future direction, we tend to carefully design the study with a pre-test of students' prior knowledge and look at student learning performance in different types of knowledge and problem-solving applications. Overall, we believe these approaches should be introduced across the course's curriculum and as part of a well-resourced course redevelopment.

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