Investigating the Effectiveness of New Geotechnical Engineering Problem-Based Learning Modules for Student Comprehension and Attitude at Two Universities

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Abstract

Two new problem based learning modules have been developed for a required, junior level introduction to geotechnical engineering course. The modules introduce two common topics in introductory geotechnical engineering courses: phase diagrams and two-dimensional flow of water through soil. Both modules were deployed at Lawrence Technological University in Southfield, Michigan and one of the modules was deployed at Oregon Institute of Technology in Klamath Falls, Oregon. The goal of the problem based learning modules was to enhance the cognitive ability of the students and increase student interest and attitude towards geotechnical engineering. The objective of deployment at two institutions was to assess consistency of the observed effects and repeatability of the modules.

Problem based learning has been implemented since the 1960s. The method was first introduced in medical education to enhance the problem solving abilities of students. Despite some mixed results of the effectiveness of problem based learning, the method continues to be employed and is becoming common in civil engineering sub-disciplines such as environmental engineering and geotechnical engineering. These studies however, have been focused only on assessing the effectiveness with regard to cognitive ability and have not addressed student perception and attitude.

The effectiveness of the two problem based learning modules was assessed using targeted exam questions at both universities. In addition to cognitive understanding of the topic, pre and post surveys were given to students in the course to assess their attitude towards geotechnical engineering. A modified Attitude on the Subject of Chemistry Inventory (ASCI) was given to the students at both universities. The modified, eight-objective survey assesses two separate subscales, intellectual accessibility and emotional satisfaction. The results of the attitude survey, as well as the instructors' observations regarding comprehension are presented.

Introduction

Two problem based learning (PBL) modules were developed to introduce common topics in an introductory soil mechanics/geotechnical engineering course. Compared to traditional methods, PBL is used to address five objectives [1] including construction of useful knowledge, development of reasoning strategies, development of effective self-directed learning strategies, increased motivation for learning and becoming effective collaborators. Of particular interest to the authors is the effect of PBL on increasing motivation and attitude towards geotechnical engineering. The effect of this is two-fold, the effect of motivation towards learning the material in an introductory geotechnical engineering course, and the effect of attracting graduate students to geotechnical engineering.

More than 25 years ago Marcuson et al.[2] noted that "today, the entry-level degree to the profession of geotechnical engineering is the master's degree, and this is as it should be." Townsend,[3] in describing the state of geotechnical engineering education noted that we must be attracting the best and brightest students by focusing on design and problem solving, not logging borings and completing foundation reports. Felder et al.,[4] reported the work of several researchers that indicated student attitude towards engineering is a better indicator of completion of a degree in engineering than academic ability. Besterfield-Sacre et al.[5] found that students leaving engineering in good standing (with thus a perceived academic ability) had initially lower attitudes towards engineering than those students that stayed in the program. Lagan and Welsh [6] found that implementing PBL an environmental management and conservation science course increased not only the content knowledge of students, but also the awareness of conservation. To retain the best and brightest students for graduate study in geotechnical engineering, attitude towards subject matter is important.

Attitude and motivation for learning has been studied extensively in general education and engineering education. As described by Ormrod,[7] motivation increases effort and energy, persistence in activities, and enhances performance. Jones et al.[8] found that PBL implemented in capstone engineering courses provides many opportunities to motivate students. In order to investigate the effect of PBL on comprehension and attitude in geotechnical engineering more specifically, the modules were implemented at two separate institutions, Lawrence Technological University (LTU) and Oregon Institute of Technology (OIT) in the same level introductory soil mechanics course. Pre and post surveys were implemented to assess the effect of the modules. The purpose of this paper is to disseminate the modules to the geotechnical engineering community and to present the results and conclusions of the study.

Design and Deployment of PBL Modules

The two basic soil mechanics topics that were chosen to be addressed by the new PBL modules were 1) phase diagrams and volume/weight relationships and 2) permeability and flow through soils. The first module was delivered at LTU and the second module was delivered at both LTU and OIT. Before starting the first module at each respective institution, a pre survey was administered. This was followed by a post survey after the completed of PBL module 2. The following sections describe the objectives and content of the modules and present the pre and post surveys.

PBL Module 1 – Building an Arena

The first problem-based learning module (PBL 1) was designed to introduce students to the elementary soil mechanics concepts of phase relationships. The module was focused on cut and fill operations associated with a deep excavation that was in progress near LTU, for the construction of a sports venue. The deployment timeline of PBL 1, discussed below, was arranged such that the problem could be used to present students to the need for phase relationships and a three phase soil model. The problem was then returned to throughout the broader unit on phase relationships and weight/volume measures (approximately 4 lectures) to provide context for the concepts. The module was designed to address some of the soil mechanics course objectives, which propose that at the end of the soil mechanics course (not necessarily at the end of the module), students should be able to:

- Estimate values of basic soil index properties (e.g. unit weight, specific gravity, void ratio, etc.) when provided with a standard soil description.
- Use basic definitions and phase diagrams to derive various weight-volume relationships.
- Use weight-volume relationships to compute soil quantities for cut and fill operations.
- Communicate geotechnical engineering recommendations by composing professional written and graphical documents.

The PBL began with students being introduced to the arena construction project with pictures of the site prior to construction, pictures of the current state of the excavation (at the time of the PBL), and renderings of the complete facility. The primary purpose of the introductory presentation was to provide students with an understanding of the magnitude of the excavation. The students were then shown a demonstration where moist sand was transferred from one cup to another of identical size. Despite fitting perfectly into the first cup, the soil overflows from the second cup, due to particle rearrangement and a change in void space. Students were asked to consider how this would translate into the field and what the implications might be for excavation, transport and placement of soils. This demonstration, in conjunction with the presentation on the excavation project, was used to make the point that we need a set of quantitative soil measures that account for the multi-phase nature of soil.

Before presenting the traditional three-phase model of soil and the associated weight and volume measures, students completed a Think-Pair-Share activity in which they were asked to brainstorm quantitative measures that could be used in a model to address the problem at hand. Students were then introduced to the three-phase (air-water-solids) model of soil and the associated volume and weight measures through traditional lecture. The example calculations shown during the lecture were related back to the excavation project.

Towards the end of the unit, the problem associated with the PBL was formally posed to the students and the first portion of the assignment was presented. The problem at hand (for the purpose of the course) is that the desired volume of the excavation is known, but an engineer must estimate the volume of the *excavated* soil, as well as the volume of borrow material required to construct an access ramp for the excavation. Students were asked to define the problem (outside of class, in pairs) by brainstorming a list of the information they would need (e.g. geometry, soil information, etc.) in order to complete the problem. During the following class session, a gallery walk type activity was done where each group put their list of required information on the board. A discussion followed and any missing items were added to the list. By having the students define what information they need, the assignment takes on a more open-ended nature than a traditional homework assignment.

The second portion of the assignment was then assigned. The information required to solve the problem was provided to the students in the form of a boring log from the site. While providing the required information, this still left the problem open-ended through the interpretation of the boring logs, as well as some geometry considerations and equipment sizes. The deliverable for the assignment was a calculation package that addressed the following items:

- The volume of excavated soil
- Approximate number of haul trucks required to transport the soil away from the site
- The volume of borrow fill required to construct an access ramp.

PBL 2 – Holding Back a Hurricane

The second module (PBL 2) was designed to introduce students to the basic concepts associated with flow of water through soils, including permeability, Darcy's Law, and flownet construction. PBL 2 was based on the flooding events in New Orleans, LA that followed Hurricane Katrina in the summer of 2005. As with the PBL 1, the module was used to introduce students to the broader unit on flow through soils and to provide context throughout the unit. The following soil mechanics course objectives were the motivation for the module:

At the end of the course students should be able to:

- Use flownet techniques to solve two-dimensional seepage problems for steady-state conditions (including flow estimates, hydraulic gradient estimates, and factor of safety against piping).
- Calculate total and effective vertical stresses in a soil mass due to overburden stress, the presence of groundwater, and seepage.
- Communicate geotechnical engineering recommendations by composing professional written and graphical documents.

The module started by introducing students to the widespread levee failures in New Orleans with a presentation on the overview of the storm and the resulting levee breaches. Following a general overview, two breaches in particular, the London Avenue Canal South breach and the Inner Harbor Navigation Canal North breach, were focused on. These breaches were selected because they were well documented cases of piping failures [9, 10]. Students were shown photographs of the breaches as well as geotechnical cross sections at the locations of the breaches and were then asked to do a Think-Pair-Share activity in which they proposed failure mechanisms for the levee. During this activity, more emphasis was placed on the London Avenue breach, as the failure investigations more conclusive in support of a single failure mechanism and the mechanism was slightly more straight-forward.

Following the brainstorming activity, the proposed failure mechanisms were discussed and it was first explained why the incorrect mechanisms (e.g. overtopping, wave erosion, sliding, etc.) were not the case. The actual mechanism, internal erosion/piping was then qualitatively described and used as a transition to the lecture material; in order to understand the failure mechanism we must first investigate how water flows through soil. Lectures on permeability, Darcy's law, seepage, and flow nets followed, with the in-class examples being related back to the scenario in New Orleans. At the end of the unit on flow through soils, the deliverable was presented to the students. After being provided with the geotechnical cross section of the London Avenue breach, the students were asked to prepare a calculation package that included the following items:

- A 2D flownet analysis showing that the probable failure mechanism was indeed internal erosion and piping.
- A 2D flownet analysis proposing a mitigation technique that would have prevented this failure mechanism.

Pre and Post Surveys

To assess the effects of implementing PBL modules on attitude and motivation in the course, a modified Attitude on the Subject of Chemistry Inventory (ASCI) was given to the students at both universities. The surveys were optional and anonymous. The modified, eight-objective survey assesses two separate subscales, intellectual accessibility and emotional satisfaction [11, 12]. The attitude survey is used to measure, as described by Bauer [12], the tendency to approach or avoid and react positively or negatively to a subject. In this case, the subject is geotechnical engineering and the research question is whether PBL has a positive or negative effect on attitude. Because the concept of attitude is broad, its assessment requires a carefully researched and planned survey which is why the ASCI survey was used. This survey has been vetted for reliability and validity, [11, 12].

The two subscales measured by the modified ASCI are intellectual accessibility and emotional satisfaction. These broad subscales are necessary to capture many of the mental constructs related to attitude. As described by Bauer [12, 13], many behavioral aspects need to be addressed to understand the effect of 'attitude.' The survey is based on a seven point scale. The survey was given to students prior to and after the PBL modules. The survey is shown in Figure 1. Intellectual accessibility is assessed with questions 1, 3, 6 and 8 while emotional satisfaction is assessed with questions 2, 4, 5 and 7. For consistency and to reduce bias, questions 1, 4, 5 and 7 must have their scores reversed before averaging.

Soil Mechanics/Geotechnical Engineering is:			
1	easy	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	hard
2	chaotic	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	organized
3	confusing	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	clear
4	comfortable	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	uncomfortable
5	satisfying	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	frustrating
6	challenging	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	not challenging
7	pleasant	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	unpleasant
8	complicated	| 1 | 2 | 3 | 4 | 5 | 6 | 7 |	simple

Figure 1 – Pre and post survey to measure attitude of students (After Xu 2010 and Bauer 2008)

In addition to the ASCI survey, students completed a survey specific to PBL 2 after completing the module. The survey was a series of statements intended to directly ask the students' opinions on the module. Students ranked the statements on a 5-point scale with 1 indicating strong disagreement and 5 indicating strong agreement. The survey was preceded by the following prompt:

> The following statements are intended to assess the impact of the Hurricane Katrina module (in-class activities, lectures, and calculation package assignment) on your perception of geotechnical engineering. Consider these statements as compared to a traditional lecture and homework assignment course delivery method. Rank the following statements on a scale of 1 to 5 with 1 indicating that you *strongly agree* with the statement and 5 indicating that you *strongly disagree* with the statement.

The statements were as follows:

1. Solving open-ended problems in geotechnical engineering has led me to explore/investigate items beyond the scope of the problem.
2. Solving geotechnical problems with real applications has led me to appreciate the contribution of geotechnical engineering to the broader discipline of civil engineering.
3. Observing the potential consequence of failure in geotechnical engineering problems has increased my appreciation of the societal value and importance of geotechnical engineering.

4. Observing the potential consequences of failure in geotechnical engineering problems has led me to consider the ethical implications of geotechnical engineering assumptions and decisions.
5. Solving problems with real applications in geotechnical engineering has helped me to better comprehend the technical content of the course material.
6. Solving open-ended problems in geotechnical engineering has allowed me to exercise my engineering judgement.

Observations and Survey Results

General Observations of Instructors

Initial observations by the instructor, of the student reactions to and performance following the first PBL at LTU generally indicated a positive response to implementation of the PBL. During the introductory activity, students did a great job of coming up with a list of measures for soil, such as moisture content, saturation, unit weight, etc. (although they of course did not know these terms). Their attention levels and interest also seemed relatively high during the introductory presentation and activities. The author surmised this was due to the fact that it was a currently ongoing project that they could relate to and were perhaps even excited about. Once the calculation package assignment was given, it was evident from the students' questions that the assignment invoked the curiosity of some (about half) of the students to explore beyond the scope of the assignment. Without being asked to, they researched items such as typical access ramp grades, haul truck capacities, and even regulatory loading limits for roads surrounding the site. Despite these positive reactions, students did initially express some frustration at the open-ended nature of the problem. They had to be repeatedly reassured that it was okay (and necessary) to make assumptions and educated guesses about values.

The second module, which was delivered at both LTU and OIT, had observations similar to PBL 1 by both instructors. Both instructors noted that the general interest and attention was good during the introduction of the problem, as students generally describe enjoying failure case studies. During the introductory activities, the students did a good job of arriving at the correct failure mechanism and quickly acknowledged that permeability, water levels, and geometry were key elements of the problem (although this was prior to being introduced to these concepts). Once the calculation package was assigned, it became apparent to both instructors that the geotechnical cross section of the levee failure made the flownet too difficult for students to solve at an introductory level. Due to the layered nature of the profile, solving the problem with a hand-drawn flownet requires some simplifying assumptions that the students were not able to arrive at on their own. At LTU, even after being told what assumptions they could make, the students still seemed to struggle with understanding the flownet. The instructor felt that they needed more practice with simple flownets before being expected to make simplifying assumptions. At OIT, the instructor simplified the cross section for the students, to have them correctly answer the problem. However, the instructor still noted that it was difficult to convey the boundary conditions to students.

Despite these difficulties with the assignment, the students at LTU responded in a manner that the instructor found noteworthy. Several of the students came together to work on the calculation package and submitted a single assignment, without asking for permission. They explained that they felt they needed each other to test their judgement since the problem was so open-ended. They also researched and referenced peer-reviewed literature on the failures in their calculation package, without being asked to.

Pre and Post Survey Part I (ASCI Survey)

While both instructors felt the PBL modules seemed to have a generally positive effect, the results of the ASCI pre and post surveys indicated otherwise. The authors acknowledge that the sample sizes of the surveys were not large enough to make statistically significant comparisons and conclusions. However, they were used to observe general trends. The results from LTU (N=6) and OIT (N=26) of the survey pre and post implementation of the PBL modules are shown in Figures 2 and 3, respectively. Higher scores mean that students feel soil mechanics/geotechnical engineering is intellectually accessible and emotionally satisfying. The average of all of the responses for the emotional satisfaction word pairs was 5.21 prior to the modules and 4.80 after. For intellectual accessibility, the combined averaged decreased from 3.84 before to 3.62 after. These results suggest that overall the students' attitudes were negatively impacted by the implementation of the PBL modules. A significant literature review by Albanese and Mitchell [14] indicates the opposite, that PBL environments in the medical field significantly improved student satisfaction about the topic almost uniformly. A significant review of literature by Thomas [15] also indicated that PBL increase student attitudes towards learning.

When observing results from the two institutions and individual word pairs separately, the same conclusion can generally be reached. Students at both institutions rated soil mechanics/geotechnical engineering as being more complicated, confusing, and hard after the PBL modules. They also rated it as being more frustrating and uncomfortable after the modules. The dimensions that did have instances of improvement with the PBL (unpleasant-pleasant and challenging-not challenging) were inconsistent between schools with improvement only at one institution, LTU and OIT, respectively. Students at both institutions ranked the organization level (chaotic-organized) of soil mechanics essentially the same before the modules as after.

The underlying reason for the apparently negative effect of the PBL modules, from student surveys, cannot be definitively discerned, but the authors surmise it is due to the open-ended nature of the problems. Students are likely not comfortable with making assumptions and simplifications regarding values and parameters to which they have just been introduced. This could explain why they feel the associated assignments to be more frustrating, uncomfortable, and unpleasant, which in turn makes them feel that the subject is more complicated, confusing, and hard. This may indicate that the instructors placed too high of expectations on the students, with regard to their ability to make assumptions. However, what is perceived as a negative impact on the students' attitude (lower emotional satisfaction and intellectual accessibility) may actually be a positive indication that the students are being exposed to situations that required them to exercise their engineering judgment. The classroom is an ideal safe environment for this to take place and exposing students to these feelings is a critical part of their engineering education.

Table 1 – Summary results of the pre and post surveys shown in Figure 2 and 3

Pre and Post Survey Averages			
Lawrence Technological University			
	Pre	Post	Percent Difference
Intellectual Accessibility	3.63	2.83	-25%
Emotional Satisfaction	4.83	4.54	-6%
Oregon Institute of Technology			
	Pre	Post	Percent Difference
Intellectual Accessibility	3.90	3.81	-2%
Emotional Satisfaction	5.28	4.88	-8%
Both Universities Combined			
	Pre	Post	Percent Difference
Intellectual Accessibility	3.84	3.62	-6%
Emotional Satisfaction	5.21	4.80	-8%

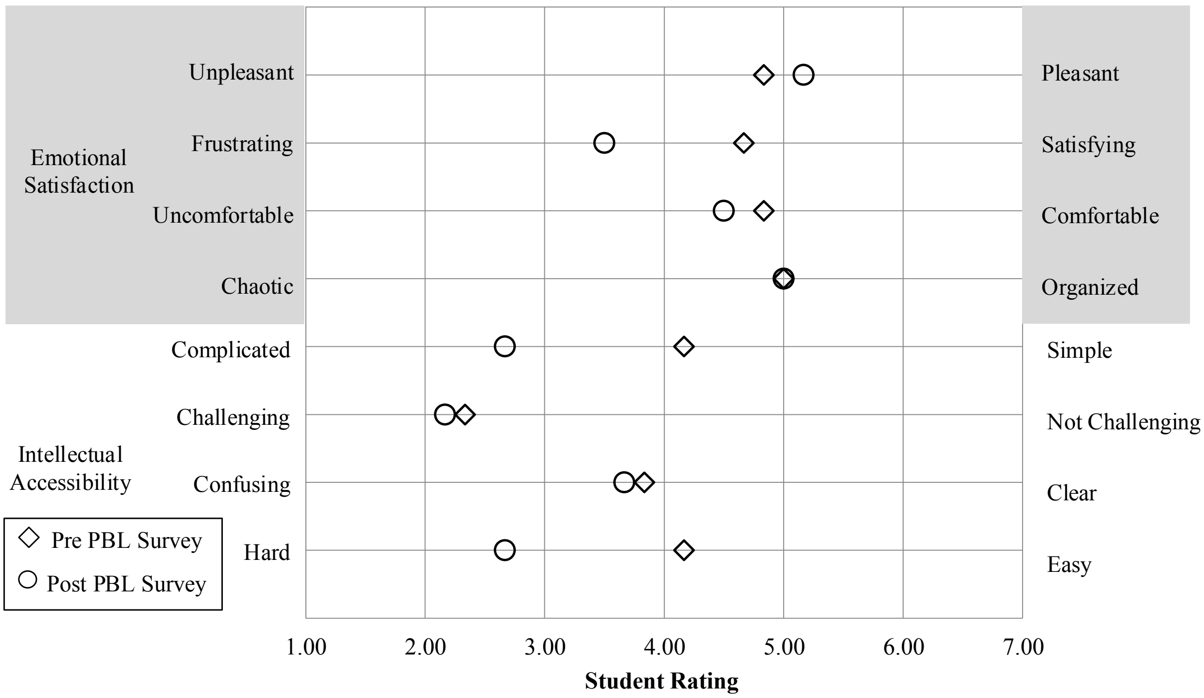

Figure 2 – Results of Part I pre and post survey at Lawrence Technological University (N=6, 100% Participation)

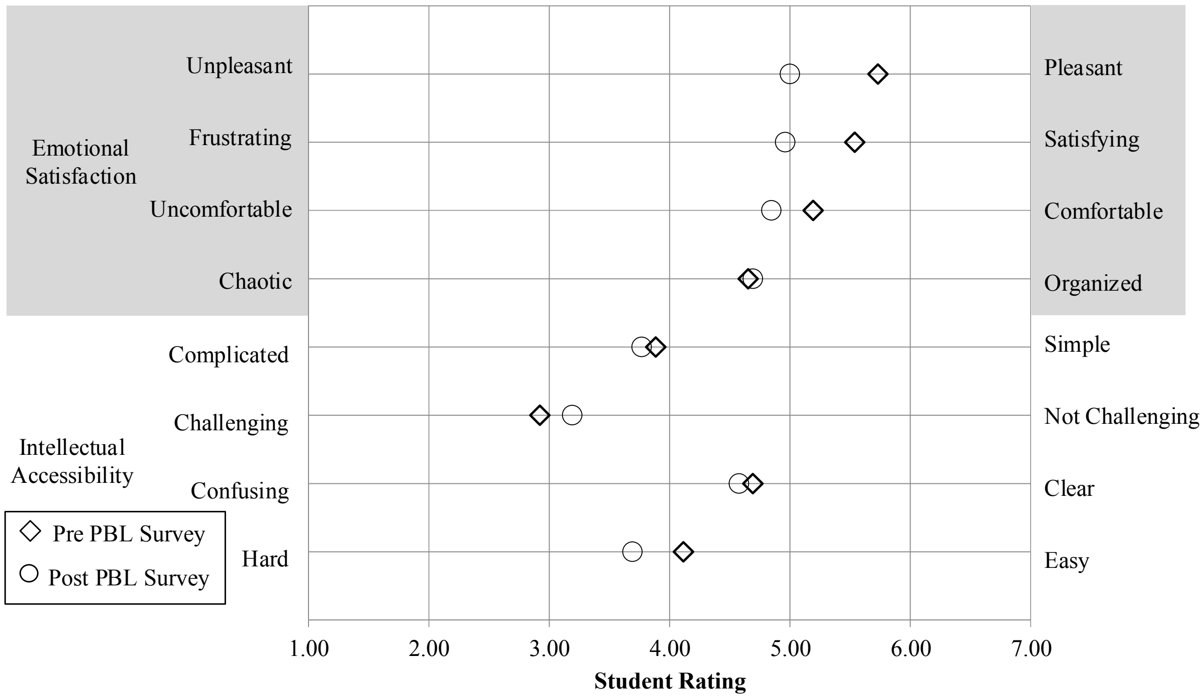

Figure 3 – Results of Part I pre and post survey at Oregon Institute of Technology (N=26, 100% Participation)

Post Survey Part II

The results of the second part of the post survey, in which students ranked their level of agreement with a set of statements regarding PBL 2, indicate a more positive effect of the PBL module. The results for both institutions are shown in Figure 4. The survey results were remarkably similar at the two institutions. Although the Part II survey is not as rigorous as the ASCI survey, the results suggest that students generally felt the PBL increased their appreciation of the importance of geotechnical engineering (statements 2, 3, and 4). Overall students also generally agreed that the PBL increased the technical value of their work (statements 1, 5, and 6), although to a slightly lesser degree than the other statements.

It is of interest that the results of Part II of the survey seem to disagree with Part I of the survey. When asked directly about the PBL (Part II) the students gave a generally positive response, but when indirectly surveyed about their attitude (Part I), students indicated that the PBL had a negative effect.

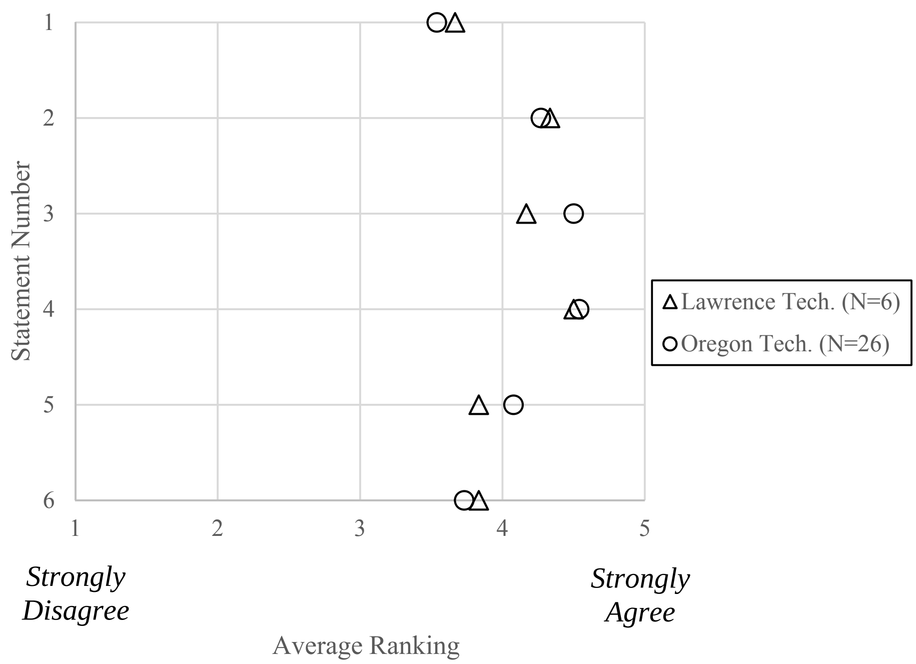

Figure 4 – Results of Part II post survey at both institutions

Conclusions

Two problem-based learning modules were developed for an introductory, junior level soil mechanics/geotechnical engineering course. The first module was delivered at one institution, and the second module was delivered at two institutions. The instructors made general observations to assess the effectiveness of the modules with regard to comprehension and used a series of pre and post surveys to assess the effect of the modules on student attitude towards soil mechanics and geotechnical engineering. The following conclusions are drawn from the instructors' reflections on the PBL delivery and from the results of the surveys:

- In preparing the PBL modules, the tendency was to overestimate students' abilities to work with open-ended problems. This became evident after giving the assignments associated with the PBL's and highlighted to the instructors, the importance of being able and ready to quickly modify and/or simplify the assignments.
- Observation of and interactions with the students led the instructors to perceive a generally positive effect of the PBL on student comprehension and interest. Interest and participation during implementation of the modules was high at both institutions. Part II of the survey, in which students ranked their agreement with a set of statements about the PBL appeared to confirm this.
- The results of Part I (ASCI survey) of the pre and post survey, indicated an overall negative effect of the PBL modules on students' attitude toward soil

mechanics/geotechnical engineering, with regard to both emotional satisfaction and intellectual accessibility.

- A junior level soil mechanics/geotechnical engineering course is generally the first course related to geotechnical engineering for civil engineering students. The authors' general perception is that while giving the PBL modules, student interest and attitude was high but the ASCI survey results indicate that the modules may have had a negative impact on student attitude towards soil mechanics/geotechnical engineering.
- The similarity in survey results and instructor observations at LTU and OIT indicate that the effect of PBL course modules on student attitude and comprehension is very repeatable between institutions.
- Attempts were made to measure comprehension with exam questions, but interpretation of results was difficult as concepts from PBL 1 and PBL 2 were also reinforced with additional assignments and lectures.

The conclusions made based on this study are limited by the small sample size, in terms of number of students, number of course offerings, and number of institutions. However, the results presented in this paper offer insight into general trends. This work can be improved in the future by comparison of the results to a control set, as well as a larger data set.

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