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Development of WeBWorK Prelab Problem Sets to Support Student Learning

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Introduction

Prelab assignments are usually developed to support students' learning by providing them with opportunities to build mastery of the relevant concepts prior to the lab sessions where they are required to apply their knowledge. However, in many cases, prelab assignments are poorly completed or copied from peers and therefore of uncertain benefit to students' learning. Moreover, with the changing education landscape and culture, homework practices have evolved and online homework systems are increasingly used due to their potential in improving students' engagement, learning and performance [1], [2]. As such, we developed a set of prelab problems for the course SEE 310: Integrated Energy Solutions II, using the online homework system, WeBWorK, with the goal to enhance student learning, and ensure that students cannot copy directly from their peers. The prelab problems complement the computer-based lab sessions where students create and use energy systems models to deepen their understanding of the models and related sustainability problems as part of their learning experiences for the course. Consequently, we are interested to examine the impact of using WeBWorK prelab problems to support students' learning. Specifically, our study seeks to address the question: What is the impact of the WeBWorK prelab problem sets on students' preparedness for lab sessions, students' learning and students' engagement during lab sessions?

(Due to the COVID-19 pandemic, the course was moved entirely online and the format and the structure of the original lab sessions implemented were affected. Although the shifts in the format and structure may not fully reflect the usual state of the original lab sessions and the corresponding observations, the study was carried out mostly as planned.)

Utilizing Online Homework Systems

One of the key advantages of online homework systems is that students can receive immediate feedback, either through the grading of their responses or the hints provided while attempting the homework, or both. The immediate feedback can motivate students to spend more time on the homework which may increase their performance. Each student can also be given a unique set of problem parameters which encourages them to work with their peers without copying directly. However, research on the impact of online homework on students' actual learning gains is mixed - some studies [2], [3] showed increased performance as compared to traditional paper-and-pencil homework while others showed no significant increments or losses in terms of performance [4], [5]. As such, it is further suggested that certain practices or strategies need to be present for online homework systems to be valuable for teaching and learning (e.g. [1], [2]).

Firstly, the desired learning outcomes need to be clearly determined as they will guide the design of the content and the problem types in the homework. It is also important to decide the purpose of the homework in terms of whether it is meant as a formative or summative assessment. Lunsford and Pendergrass [2] suggested that online homework systems may be more suitable for formative assessment due to the feedback available for both students and teachers. Also, formative assessment views mistakes as part of the learning process which is

supported by online homework systems where students are usually given multiple attempts for each problem. This combination of feedback and multiple attempts can encourage students to persevere till they arrive at the correct solution and thus, spend more time on their homework which may help to enhance their learning and performance.

Secondly, a common practice has been to use online homework systems to promote and assess learning at the basic level, focusing on the definitions, concepts and procedures, rather than at the deeper level due to limitations of the systems. However, this deeper level of understanding, focusing on the relationship between concepts and their applications, can be developed through follow-up in-class-discussions, starting from students' questions or difficulties from the online homework, to reinforce the basic understanding of the concepts before progressing to the connections and applications of these concepts [2]. Thus, it will be beneficial to complement the use of online homework systems, with in-class discussions, to increase students' engagement with the material both inside and outside of the classroom.

Furthermore, even though the focus of the learning through online homework systems tends to reside at the basic level, students' learning experiences need not only constitute memorization of facts and development of procedural fluency. Students' understanding and retention of the concepts may be strengthened by using meaningful narratives in the design of the problems as research has shown that humans have the tendency to form narratives in their experiences to better make sense of them [6]. Consequently, it may be useful to tap on this natural inclination by creating problems around meaningful narratives whenever possible, especially for material that are known to be more complex or challenging for students as it provides a form of scaffolding for them. Five elements are recommended to be included in the narrative, namely, characters, setting, plot, conflict and theme, with the plot being the most important element in order to motivate students to engage with the problem [6]. The narratives can take many forms ranging from real life stories to stories that are situated in a theoretical context where the characters are not people but theoretical objects.

Pre-lab Activities

Pre-lab activities are usually short tasks that students are expected to complete prior to the actual lab sessions. They are developed to better prepare students for the lab sessions by providing the background or context of the lab and asking students to recall or revise the relevant skills and concepts needed. There can be different forms of pre-lab activities including problem sets or quizzes with procedural and/or conceptual questions, group discussions and watching of videos [7], [8]. Past studies have suggested that pre-lab activities can help to facilitate students' learning and understanding of the skills and concepts [9], [10], [11]. It can also help students be more prepared and hence productive during the lab sessions, thus giving more time for students to discuss and reflect on their learning [7].

Method

The course SEE 310: Integrated Energy Solutions II is a third-year course for students in the School of Sustainable Energy Engineering program. Its focus is on the integrated design methodology for sustainable engineering problems. Students are introduced to modelling, simulation and optimization of energy systems, and global and local regulatory and policy frameworks. They are expected to demonstrate their learning through a sustainable energy system design project. It is the first time that the course is offered and hence only six students were enrolled but all six students took part in this study.

To take advantage of both the benefits of pre-lab activities and online homework systems, we decided to design our pre-lab activities as problem sets on the online homework system, WeBWorK. WeBWorK, used as an instructional tool by several institutions, was chosen for its features such as giving students multiple attempts to solve each problem and providing students with immediate feedback on the accuracy of their solutions. Consequently, students will be able to reflect on their mistakes and make timely corrections as they build mastery of the concepts. Another important feature of WeBWorK was the multi-part problems which can be coded such that the subsequent parts are revealed only if the preceding part was answered correctly. This will help to provide scaffolding for the students to build their mastery progressively. Moreover, as WeBWorK allows problem parameters in similar problem sets to be randomized for different students, students are more likely to discuss and work together to understand the problems and share approaches rather than solutions before solving the problem themselves for their unique set of parameters. The option of integrating R into WeBWorK further broadens and enhances the types of problem sets that can be developed within the tool.

The design and development of the prelab problem sets were guided by some of the effective online homework design practices mentioned earlier. The specific concepts and skills that students need to acquire for each lab session were identified and split into those that are suitable to be developed through WeBWorK (e.g., basic concepts and numerical skills) and those that will be developed during the lab session. The concepts and skills that can be addressed through WeBWorK were associated with questions that allowed students to gain mastery of them. The problems were also created around meaningful narratives with theoretical objects as the characters, adapted from relevant contextual-based problems from previous courses as a form of scaffolding for the students. These problems were then coded into the WeBWorK interface. Considering the appropriateness of the content for each lab session, coupled with limited time available for implementation, only three out of seven lab sessions in the entire course had prelab WeBWorK problem sets. The corresponding problem sets for these actual lab sessions were similarly designed and implemented on WeBWorK, for the continuity in the use of the tool for learning. In all, a total of six problem sets were built on WeBWorK and implemented across the span of the course. Students were given unlimited attempts to complete these problem sets prior to each lab session.

In evaluating the effectiveness of the WeBWorK prelab problem sets on student learning and engagement in the course, data was collected and analysed using a mixed method approach. Quantitative data such as the amount of time students spent on the problems, number of attempts per problem, completion rate and grades were collected from the WebWorK system. A survey (see Appendix A) was designed and implemented at the end of the course to gather students' feedback on the effectiveness of the WeBWorK prelab problem sets in helping them master the required materials. A half-hour long focus group discussion (see Appendix B) was further conducted to gather feedback from the students, as a follow-up to the preliminary findings from the survey. Students' responses to both the survey and focus group discussion; and students' solutions to problem sets, were analysed qualitatively and quantitatively (using descriptive statistics). Other than the impact on students' acquisition of the materials, we were interested to examine students' engagement during the lab sessions and how the prelab problem sets have helped to prepare them for the lab sessions. Lab observations were conducted to gauge the impact of the prelab problems on the students' engagement during the lab sessions. Lab sessions without prelab problem sets were observed in a similar manner for comparison purposes. (Refer to Table 1 for the sequence of lab

observations). With the shift to remote learning due to COVID-19, remote lab sessions, lab observations and focus group discussion were conducted virtually through Blackboard Collaborate on Canvas.

	Prelab problem set
Lab 4 – I-O Modelling	Yes
Lab 6 – Building Energy	No
Lab 8 – Linear Programming Model I	Yes
Lab 9 – Linear Programming Model II	Yes
Lab 10 – Power System Modelling	No

Table 1. Sequence of lab sessions observed.

Findings and Discussion

We organized the findings from the analysis according to the three categories in our research question – impact on students' preparedness for lab sessions; students' learning; and students' engagement during lab sessions. We will also discuss some possible reasons for the findings made.

1. Impact of prelab problem sets on students' preparedness for lab sessions.

The students valued the multiple attempts given as they all took as many attempts as needed (Refer to Table 2) to be successful in solving the problem sets. Consequently, the students spent substantial amount of time engaging with the material required for each lab. Eventually, all the students completed the prelab problem sets prior to the lab sessions and the respective lab problem sets successfully.

	Average score per pre-lab (%)	Average number of attempts per pre-lab	Average time spent per pre-lab (min)
Lab 4 – I-O Modelling	100	12.8	25.8
Lab 8 – Linear Programming Model I	100	9.7	14.8
Lab 9 – Linear Programming Model II	100	12.3	23.3

Table 2. Data on students' completion of pre-lab problem sets.

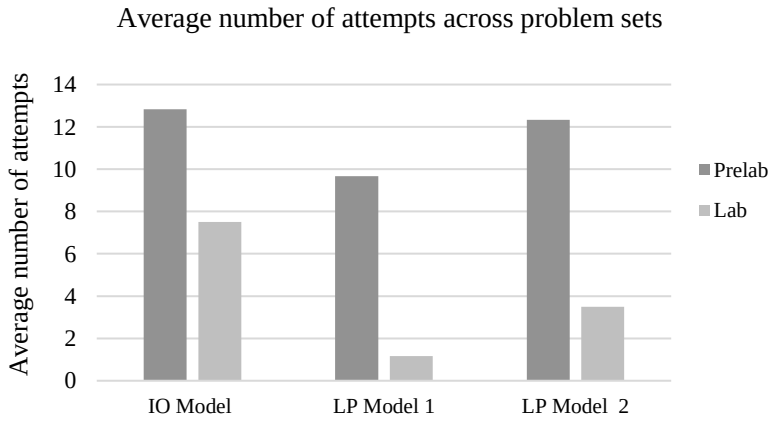

Figure 1. This bar graph shows the average number of attempts students took to complete each of the problem sets.

Moreover, an interesting relationship is observed between the average number of attempts taken by the students to complete the prelab problem sets and the corresponding lab problem sets. The average number of attempts for each lab problem set was always less than that for the corresponding prelab problem set (Refer to Figure 1). This difference may be a reflection of the impact of the prelab problem sets on the students' preparedness for the lab session. Of course, it may also be due to the availability of help from the teaching assistant during the lab sessions.

From the survey results (Refer to Figure 2), all six students agreed or strongly agreed that the WeBWorK prelab problems were useful to help them prepare for the actual lab sessions.

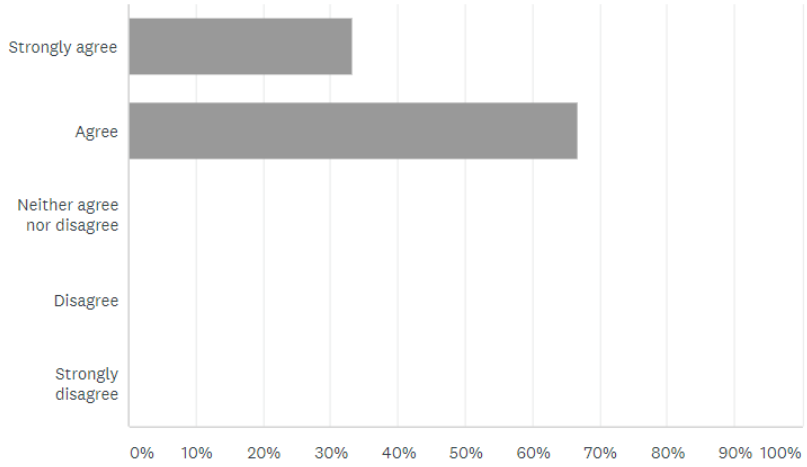

Figure 2. This bar graph shows the students' responses to the survey Q2: The WeBWorK prelab problems helped me to prepare for the labs.

They also agreed that the prelab problems and the lab problems complemented each other in their learning (Refer to Figure 3). During the focus group discussion, a student mentioned that the prelab problems were like "teasers" to the actual lab as the problems gave them a glimpse of what to expect in the actual lab. However, one student felt that the prelab problems and the lab problems were rather similar, where "the prelab was like the lab except without the time constraints".

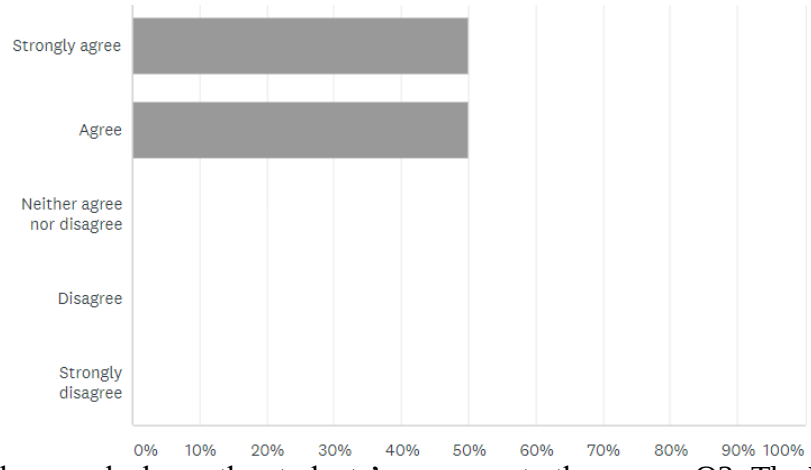

Figure 3. This bar graph shows the students' responses to the survey Q3: The WeBWorK prelab problems and lab problems complement each other.

When comparing lab sessions with and without the prelab problem sets, all the students also agreed or strongly agreed that they felt more prepared for labs that had prelab problems (Refer to Figure 4). In particular, during Lab 9 - Linear Programming Model (which had a prelab problem set), numerous students commented that the lab problem was relatively easier after having completed the prelab problem set. The positive effect of the prelab problem sets was also evident when a student suggested adding a prelab problem set for Lab 10 - Power System Modelling on the sensitivity analysis as it was a little overwhelming during the lab session, as concurred by a couple of other students.

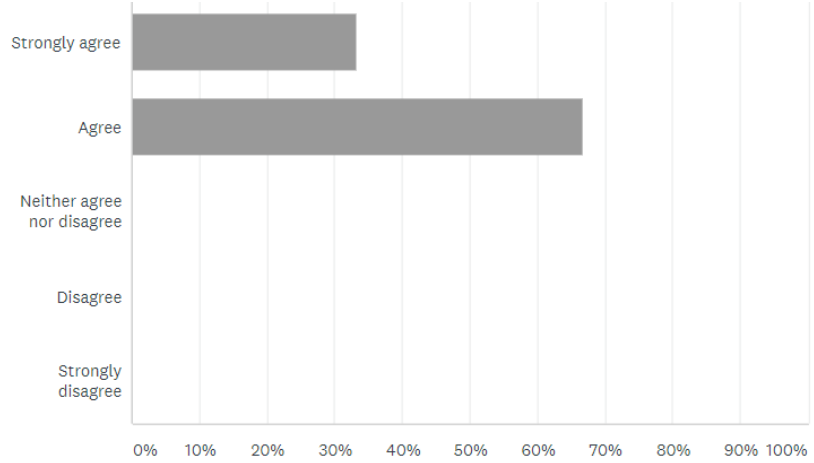

Figure 4. This bar graph shows the students' responses to the survey Q10: I felt more prepared during labs that had WeBWorK prelab problems.

Overall, both the qualitative and the quantitative data suggest that the students felt more prepared for the lab sessions which had prelab problems designed as compared to those without. One possible reason may be the complementary nature of the prelab problem sets and the problems in the actual lab session, in terms of their content, structure and format. The prelab problems probably helped the students build the knowledge needed for the lab problems and provided a glimpse of what to expect for the actual lab session. The prelab problems also created opportunities for the students to check their understanding through making mistakes and reflecting on them prior to the lab. Another reason may be due to the increase in time spent engaging with the content that increased that preparedness for the lab session.

2. Impact of prelab problem sets on students' learning.

For each lab session, students were graded based on their lab work and a short reflection component. Based on the average grade of the class, the students generally performed better in the labs with prelab problem sets (Refer to Table 3). Though in comparison, the lab without prelab on Power System Modelling may have seen the highest average grade, this may be due to factors, such as it being the final lab for the course, and students have become more familiar with the course content.

	Labs with prelab			Labs without prelab	
	I-O Modelling	LP Model I	LP Model II	Building Energy	Power System Modelling
Average grade (%)	81.2	87.1	85.7	75	94.9

Table 3. Comparison of average grades across labs

From the survey results (Refer to Figure 5), a majority of the students felt that the WeBWorK prelab problems helped them master the concepts and materials. The students were asked to elaborate on how the prelab problem sets helped in their learning during the focus group. Most of the students agreed that the prelab problems helped them to have a better understanding of the materials (especially the different models covered in the prelab). They shared that they were able to make connections to the materials covered or methods demonstrated during the lectures and apply what they have learnt as they worked on the problems. It also allowed them to learn through practice and check their understanding. A couple of students added that the prelab problems "forced" them to revisit the lectures which was good for their learning. They also liked and were able to relate to the practical examples used in the problems.

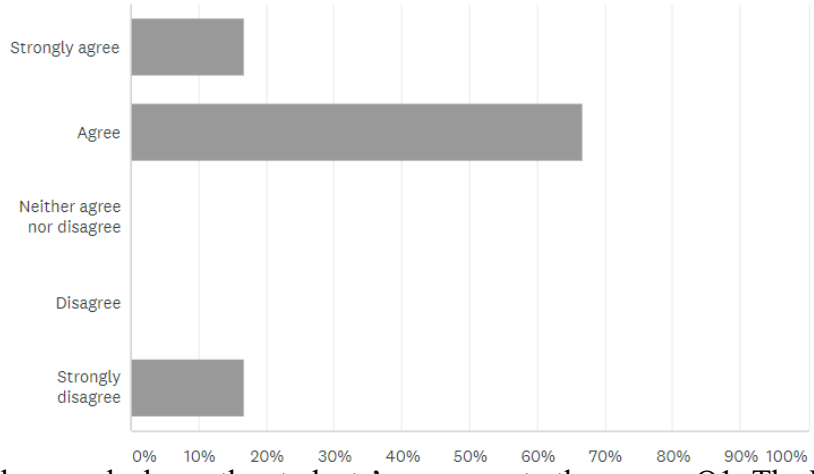

Figure 5. This bar graph shows the students' responses to the survey Q1: The WeBWorK prelab problems helped me to master the concepts/materials.

Moreover, all students appreciated having multiple attempts to solve the problem sets as that provided them a safe learning environment to make and learn from mistakes. The majority of the students also liked the immediate grading of their solutions as it boosted their confidence when they obtained the correct answer.

In general, the prelab problems seem to have enhanced students' learning where they gained a better understanding and mastery of the materials. By working through the prelab problems, the students were able to apply and check their understanding from the lectures. Another possible factor may be due to the immediate feedback received on the accuracy of their solutions which allowed them to reflect on their mistakes and make timely corrections as they build mastery.

3. Impact of prelab problem sets on students' engagement in the lab.

Broadly, students were able to make better progress for the lab sessions with prelab problem sets as compared to those without. Specifically, it was observed that students faced more difficulties during Lab 6 (Building Energy Calculations) and Lab 10 (Power System Modelling) - both had no prelab problem sets. For these lab sessions, the students required more time to complete the problems and sought more help from the teaching assistant regarding the expectation of the problems and the approach to solve them. They also looked and sounded more uncertain while discussing the problems. Despite the greater difficulties faced in these lab sessions without prelab problem sets, the students did not give up and were

still committed to complete them. Thus, there were no significant differences in the level of attention or perseverance observed among the students across the various lab sessions.

Notably, more clarification questions such as “What do we need to do...?”, “Are we supposed to do/use this…” and “Do we use…?” surfaced during group discussions for these two lab sessions. This seems to suggest that the students were learning at the comprehension level of the Bloom’s Taxonomy and had yet to advance to the higher levels of application, analysis, and synthesis during these sessions. In comparison, in the lab sessions with prelab problems, the students appeared to be learning with at a deeper level of the taxonomy as their discussions revolved around the applications, analysis of the advantages and disadvantages, and comparisons across models.

Therefore, from the observation of the actual lab sessions, it seems like the students were more engaged in their learning and made better progress for the lab sessions that had prelab problem sets. They were better prepared to apply and extend their understanding and participate in discussions about the material at a deeper level, possibly due to time and effort spent to work through the prelab problems that were designed to complement the lab problems.

Limitations and Recommendations

Due to the small enrolment for the course, our findings may not be statistically sufficient in generalising the positive impact of WeBWorK prelab problem sets in supporting student learning for future cohorts of students enrolled in the SEE 310 course. Moreover, as the course was offered for the first time, it was not possible to compare with the results from previous editions of the course. However, we are optimistic in the potential of this tool and intend to conduct further studies with more students to validate the current set of findings.

Also, as WeBWorK was not used for all the lab sessions in this project, further validation in terms of the greater difficulties faced and the increased frequency of students’ clarification questions observed during lab sessions without prelab problem sets will be necessary. This will help to ascertain that these observations are consequences of the absence of prelab sessions, rather than due to the differences in the labs themselves. One consideration in our future studies will hence be the use of WeBWorK as a common tool for all lab sessions in the course.

Moreover, with the shift to remote learning due to COVID-19, the format and the structure of the original lab sessions had been affected and limited to remote lab observations through Blackboard Collaborate on Canvas. Such shifts in terms of the format and structure may not fully reflect the usual state of the original lab sessions and the corresponding observations. Thus, we may need to re-assess the impact of the prelab problem sets in supporting student learning within the original context when the situation permits.

Based on the students’ feedback and suggestions, there are a few areas that can be improved in the next iteration. The majority of students recommended having a greater number of problems (different examples) in the prelab problem sets as they would like to acquire a greater mastery and fluency of the concepts before the actual lab sessions. Some students also requested for theoretical problems to be included to complement the calculation-based problems. We will consider assessing students’ theoretical knowledge of the course content through multiple-choice questions, with alternative plausible responses or distractors to

uncover student misconceptions. Similarly, students will be able to receive immediate feedback on the accuracy of their answer for such questions via WeBWorK.

Surprisingly, even with the shift to an online format for the lab sessions, the students enjoyed doing the labs in groups (via breakout rooms in Blackboard Collaborate) as they could discuss their ideas and approaches, seek help or clarifications from their peers. Thus, it may be helpful to include more collaborative activities for students to work together even within an online learning context.

Conclusion

Although there were some unprecedented challenges with the implementation of the project intervention and the data collection process due to the course moving entirely online as a result of COVID-19, both the qualitative and quantitative data gathered suggest that the prelab problem sets helped the students to be better prepared for the lab sessions due to the complementary nature of the prelab problems and the lab problems. Coupled with the features of WeBWorK, the prelab problem sets provided better support for the students' learning and also deepened their understanding of the concepts during the actual lab sessions.

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Appendix A: Survey Questions

Question	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
Q1. The WeBWorK prelab problems helped me to master the concepts/materials.					
Q2. The WeBWorK prelab problems helped me to prepare for the labs.					
Q3. The WeBWorK prelab problems and lab problems complement each other.					
Q4. The WeBWorK prelab problems are worded clearly.					
Q5. It was easy to follow the instructions to complete the WeBWorK prelab problems.					
Q6. The WeBWorK prelab problems are too difficult.					
Q7. The WeBWorK prelab problems are too easy.					
Q8. The workload of the WeBWorK prelab problems is too much.					
Q9. The workload of the WeBWorK prelab problems is too little.					
Q10. I felt more prepared during labs that had WeBWorK prelab problems.					
Q11. The WeBWorK platform is user-friendly.					

Q12. What aspect(s) of WeBWorK do you like? Choose all that apply.
Answer Choices:

- I am given unlimited attempts.
- I can receive immediate feedback on the accuracy of my answer.
- I can enter formulas/equations.
- It is easy to use.
- It is integrated into Canvas.
- It is online.
- I can use the answer preview feature to check the format of expression entered.
- The numbers/parameters are different for every student.
- Nothing.
- Other (please specify)

Q13. What aspect(s) of WeBWorK do you dislike? Choose all that apply.
Answer Choices:

- I am given unlimited attempts.
- I can receive immediate feedback on the accuracy of my answer.
- I can enter formulas/equations.
- It is easy to use.
- It is integrated into Canvas.
- It is online.
- I can use the answer preview feature to check the format of expression entered.
- The numbers/parameters are different for every student.
- Nothing.
- Other (please specify)

Q14. What difficulties (if any) did you face while using WeBWorK?

Q15. What, if anything, could be improved to make the WeBWorK problems more effective for the course?

Appendix B: Focus group discussion script and questions

Introduction

Good morning and welcome to our focus group discussion today. Thank you very much for your time. The aim of today's discussion is to gather your views on the WeBWorK prelab problems for this course.

There are no right or wrong answers but rather different points of view. Please feel free to share your views even if it differs from what others have said. You don't need to agree with others, but do listen respectfully. Keep in mind that we are interested in both positive and negative comments as they are both helpful to make this course better.

We will be recording our discussion because we don't want to miss any of your valuable comments. You may be assured of complete confidentiality and we would not use any names in our reports.

If it is possible, could we get all of you to start your video so that we could see everyone's faces. But keep your mics muted except when you are sharing your views.

Key Questions

1. Impact on learning
    - How did the WeBWorK prelab problems help you to master the concepts/materials?
    - What were some features of the prelab problems that helped you in your learning?
2. Preparation for Labs
    - How did the WeBWorK problems help you to prepare for the labs?
    - Would you prefer to have a prelab for all labs or any labs in particular?
3. Clarity and level of difficulty of questions
    - How did you find the problems? Were they too easy or too difficult?
    - Were the problems worded clearly? Were the instructions clear? How can we improve on the instructions or the wording?
4. WeBWorK platform
    - What do you like best about the WeBWorK platform?
    - What problems did you face regarding the format of answers?
5. Difficulties and recommendations
    - What are some difficulties you faced, if any, while working on the WeBWorK problems?
    - Do you have any suggestions on how we can improve on the WeBWorK prelab problems

Conclusion

Are there any other comments or feedback about the WeBWorK prelab problems?

If not, we will really like to thank all of you for your time and participation in this discussion. Thank you very much for all the information you have shared about the good and not so good of the WeBWorK prelab problems. (*Mention some examples of ideas shared during the discussion*.)