Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
ASEE
Paper ID #47378

Enhancing SQL Learning Through Gamified Deliberate Practice: The Impact of Engagement and Feedback in Undergraduate Education

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ABSTRACT

Retention and application of SQL skills pose significant challenges for undergraduate students, particularly in technical disciplines requiring high levels of engagement and practice. This paper introduces the Deliberate Practice Engine, an innovative e-learning platform designed to enhance SQL learning through deliberate practice, iterative feedback, and gamification elements, including point-based wagering. To evaluate its effectiveness, two experiments were conducted: (1) a controlled study with 16 undergraduate engineering students that examined the impact of wagering and iterative feedback on engagement and performance, and (2) a classroom study involving 24 students in a sophomore-level Industrial Engineering course that explored real-world application and metacognitive effects. Results from the controlled experiment showed wagering and feedback led to significant improvements in student engagement measured in terms of interest, enjoyment, and concentration. However, immediate performance gains were not observed. The classroom study revealed high levels of voluntary engagement, with students solving ten times as many problems as in traditional assignments and demonstrating wagering patterns indicative of metacognition. These findings offer insights into how gamified deliberate practice environments can address persistent challenges in technical education and inform the design of scalable, adaptive learning tools for broader implementation.

1. Introduction

The retention and application of SQL knowledge represent persistent challenges for undergraduate STEM students. At a large Midwestern university, students struggled to apply SQL skills acquired through lectures, in-class exercises, and homework when working on their semester projects, often within a month of initial exposure. Suspecting limited practice opportunities contributed to poor skill retention, we sought to improve student engagement, enjoyment, and performance with an effective e-learning system that emphasizes deliberate practice and immediate feedback.

Deliberate practice refers to the engagement in structured activities designed to improve performance through feedback and concentration [1]. It is an established method for fostering expertise. However, it can also be taxing and monotonous for students, potentially diminishing engagement and motivation. Combining deliberate practice with gamification elements, such as point systems, wagering, and iterative feedback, may mitigate these challenges by enhancing student enjoyment and motivation.

This paper introduces the Deliberate Practice Engine, an e-learning system designed to enhance SQL learning by:

1. Emphasizing deliberate practice with iterative feedback to improve knowledge retention.

2. Incorporating gamification elements, such as a point-based wagering system, to enhance engagement.

3. Providing real-time, individualized feedback to support self-regulated learning and metacognition.

We evaluated the impact of these features on student engagement, performance, and metacognition, first with a laboratory study, then in a classroom setting. Our findings provide insights into how gamification and deliberate practice can address key challenges in teaching SQL and similar technical skills.

2. Background

Numerous online SQL learning tools, such as SQLBolt, Khan Academy, and SQLZoo, offer structured practice exercises, however they do not provide progress feedback to the instructor, nor do they permit an instructor to tailor the topics or topic order. The SQLBolt [2] tutorial provides immediate, context-specific feedback and exercises for each of its 18 lessons. Khan Academy [3] offers video lectures and limited practice opportunities with instructive feedback. SQLZoo [4] provides a variety of structured practice exercises with error feedback. W3 Schools [5] is a text tutorial with an interactive component providing limited error feedback. SQL-Tutor [6] is an exception to the single-user approach. The learning environment automates student quizzing with intelligent, context-specific feedback. SQLT-Web, an online version of SQL-Tutor, [7] was studied as an educational tool, exploring the effect of gamification [8], various forms of feedback [9-11], and how problems/questions are chosen [12-14],[8]. Our goal is to develop a learning environment that provides students with broad opportunities to deliberately practice using SQL statements with immediate and informative feedback, which we expect will improve their knowledge retention.

Deliberate practice and immediate feedback help learners master material efficiently [15]. An online training environment can provide structured problems and context-specific, immediate feedback to facilitate structured deliberate practice. [16]

Although deliberate practice is efficient, students can feel taxed while addressing challenging, repetitive problems. Enhancing student engagement can encourage students to persevere. Student engagement emerges from a combination of interest, enjoyment, and concentration [17] and is essential to student satisfaction, motivation, and performance [18] [19] [20]. One technique for driving higher engagement is iterative feedback.

Iterative Feedback may be effective because it satisfies a need for competency as expressed by Self-Determination Theory. Self-Determination Theory proposes that individuals have three psychological needs: competence, relatedness, and autonomy, that must be met in order to motivate learning [21]. The sense of competency gained from finding correct solutions through iterative feedback can increase a student's motivation to further engage in learning. We therefore sought to include iterative feedback in our course to improve student engagement to overcome the challenges of deliberate practice. This sense of engagement might be further enhanced through gamification.

Gamification employs game elements in non-game contexts [22], which can increase educational engagement [23]. Games can divide complex concepts into simpler, manageable elements, building critical thinking skills while helping the learner retain previously learned information [24]. Gamification elements aid learning by lowering the cost of failure, providing copious feedback, focusing on well-ordered problems, and allowing students to see how they can accomplish their goals [25]. Learning games can significantly improve how beginners acquire new knowledge by offering individualized, continuous feedback. Positive feedback, either with a reward system or through encouraging comments, is shown to promote creative thinking [26]. Research from Morales-Trujillo and García-Mireles [27] demonstrates that gamification that includes a point system can positively impact student engagement. We therefore sought to include a point system in our learning environment, specifically a wagering system.

Point systems provide an opportunity for students to compete with themselves and each other, which improves engagement [28]. Wagering points on whether an answer is correct may also encourage a user to reflect accurately on their level of competence of a subject, which may refine their metacognition. Metacognition can be thought of as "our ability to know what we know and what we don't know" [29]. A student exhibiting metacognition of a task is engaged in that task [30]. By engaging students in a way that supports metacognition, an instructor is helping a student's development of self-regulated learning [31, 32]. The system encourages users who underestimate their ability to build confidence and wager more on their answers. The inverse is also true, the system disincentivizes users who overestimate their ability to answer questions correctly, encouraging a humbler approach to their strategy. Finally, wagering may boost engagement by turning learning into a fun and emotionally rewarding experience. [33]

In the teaching of programming, can iterative feedback and wagering be used to increase engagement and therefore performance? We expect that the informative and helpful aspects of iterative feedback (along with the inherently fun aspects of points and wagering) will increase the engagement of students, and by extension increase their performance. These expectations come from the proven success of both features in education context as well as their relevance to Self-Determination Theory. We further expect that students will engage with the wagering/point system in such a way, that we will be able to detect student metacognition.

H1: Students using the Deliberate Practice Engine with wagering will demonstrate elevated levels of engagement and performance when compared to students without the wagering feature. This result is suggested by the success of previous gamification research with point systems.

H2: Students using the Deliberate Practice Engine with iterative feedback will demonstrate elevated levels of engagement and performance when compared to students without the iterative feedback feature. This is more speculative but is supported by self-determination theory and the benefits of well-designed feedback.

H3: Students using the deliberate practice engine in a classroom setting will place larger wagers when they are more likely to answer a question correctly and smaller wagers when they are less likely to answer a question correctly, indicating a self-awareness of what they know or don't know. Further, students will answer more questions with the deliberate practice engine than with a traditional homework set and will report enthusiasm for the system.

This paper discusses our study of the benefit of an interactive, self-paced e-learning environment among university students in an introductory Industrial Engineering course. Our Deliberate Practice Engine will use iterative feedback and a built-in reward system. With the stand-alone Deliberate Practice Engine each student will be given the opportunity to learn and demonstrate their knowledge of MySQL. Students will receive feedback after each completed task and future questions will emphasize areas of weakness, providing an individualized structure. In addition, the self-paced system will allow students to move more quickly through material that they readily understand and get extra practice on new material.

This study consisted of two experiments. The first tests the first two hypothesis in a controlled experiment in which 16 recruited engineering students used different versions of the deliberate practice engine to begin learning MySQL with variations of the feedback and wagering features enabled. In the second experiment, a sophomore-level Industrial Engineering class used the deliberate practice engine with both feedback and wagering enabled. We evaluated student survey responses to evaluate student engagement and analyzed the anonymized engine wagering data looking for student metacognition.

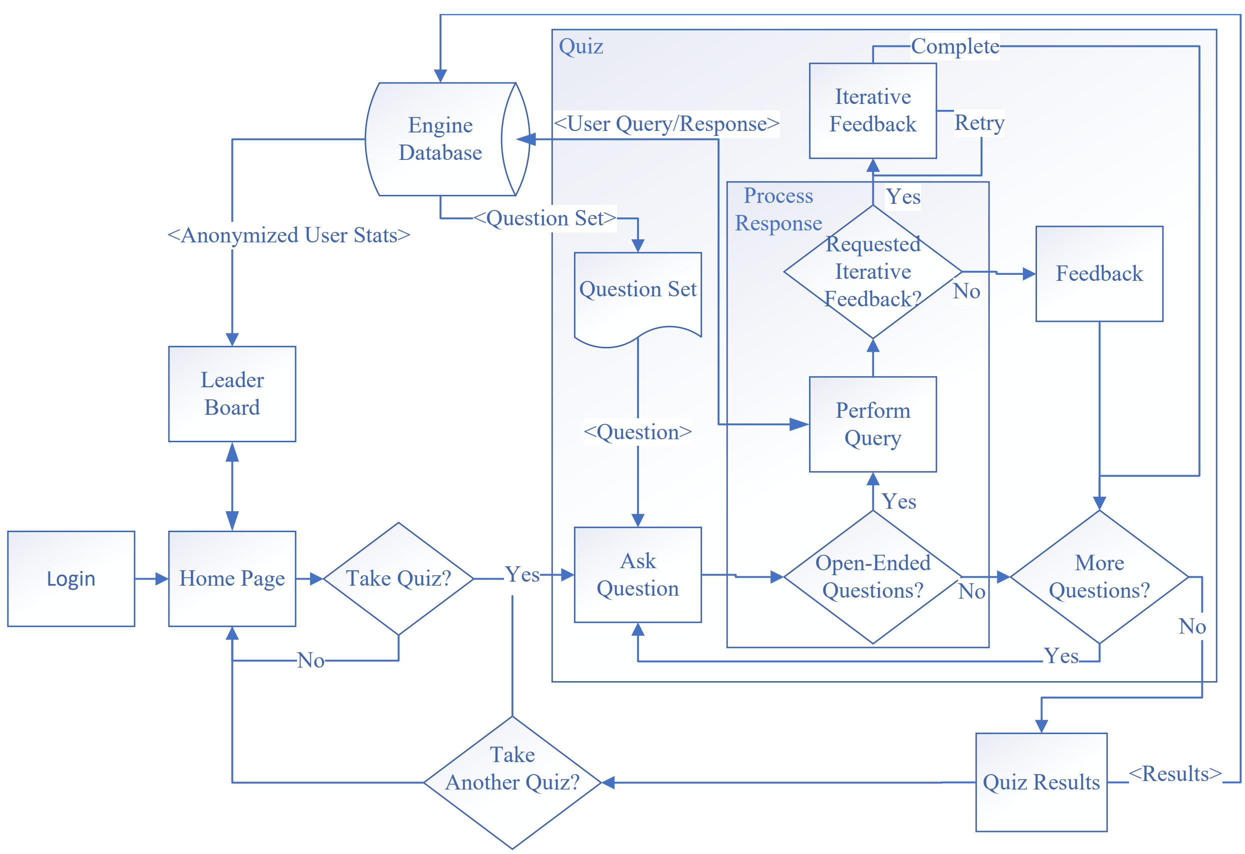

Figure 1. *Flowchart depicting the user experience in the Deliberate Practice Engine.*

3. The Deliberate Practice Engine

The Deliberate Practice Engine system originally developed by Campbell [34] and further developed by Yazvec [35], is a series of quizzes that guide a student through several topics central and unique to the MySQL language. Figure 1 describes the system flow.

After logging in, the user views a list of basic, intermediate, and advanced topics and their personal progress in each. There are between 6 and 8 topics at each level. Users are locked out of the higher-level topics until they complete the lower-level ones. From the home screen, users can visit the leaderboard or select one of the difficulty levels to begin a quiz. Each quiz is a mixture of eight multiple-choice, true/false, or open-ended questions covering three topics. Each question is categorized as easy, intermediate, or hard. The level of difficulty presented to the participant is based on the participant's earlier performance within that question's topic. The easy and intermediate questions are all multiple-choice or true/false. The answers to the easy questions are essentially self-evident; their purpose is to introduce users to a topic or syntax. Hard questions are mostly open-ended, designed to challenge users to apply what they've learned. Most open-ended answers require the participant to write complete MySQL queries. The system executes the proposed query on a database and returns the complete database response to the user. In the case of a query with a syntax error, this response includes the standard MySQL error feedback; in the case of a correctly structured query, the response includes the data returned by the database for the query.

The engine tracks user's progress on each learning objective and all 3 difficulty levels. Proficiency is assigned a numeric value from 0 (not started) to 4 (completed). Students with poorer proficiency (1 or 2) must get three of the last four learning objective questions correct before their proficiency score is incremented. Students with high proficiency (3) must get the last two questions correct to increase their proficiency score. The questions become more difficult at higher proficiency levels. A student's proficiency score in a learning objective is never decremented. Once student proficiency score reaches the "completed" level, students are half as likely to receive a question from that learning objective/difficulty combination.

The wager feature in this system awards 10 points (gebcoins) to participants for each correct answer. Participants can then wager between 0 – 100 (depicted in Figure 2) of their total points on all quiz questions and can additionally go "all in" to double their points on open-ended questions. Negative point totals are not allowed and when a student's point total is negative, the total points is automatically set to 0.

For the open-ended questions, all versions of the system provide the database response and a curated list of tips to improve the query (depicted in Figure 3). The iterative feedback feature enables users to immediately repeat the same open-ended question after receiving feedback on their previous attempt.

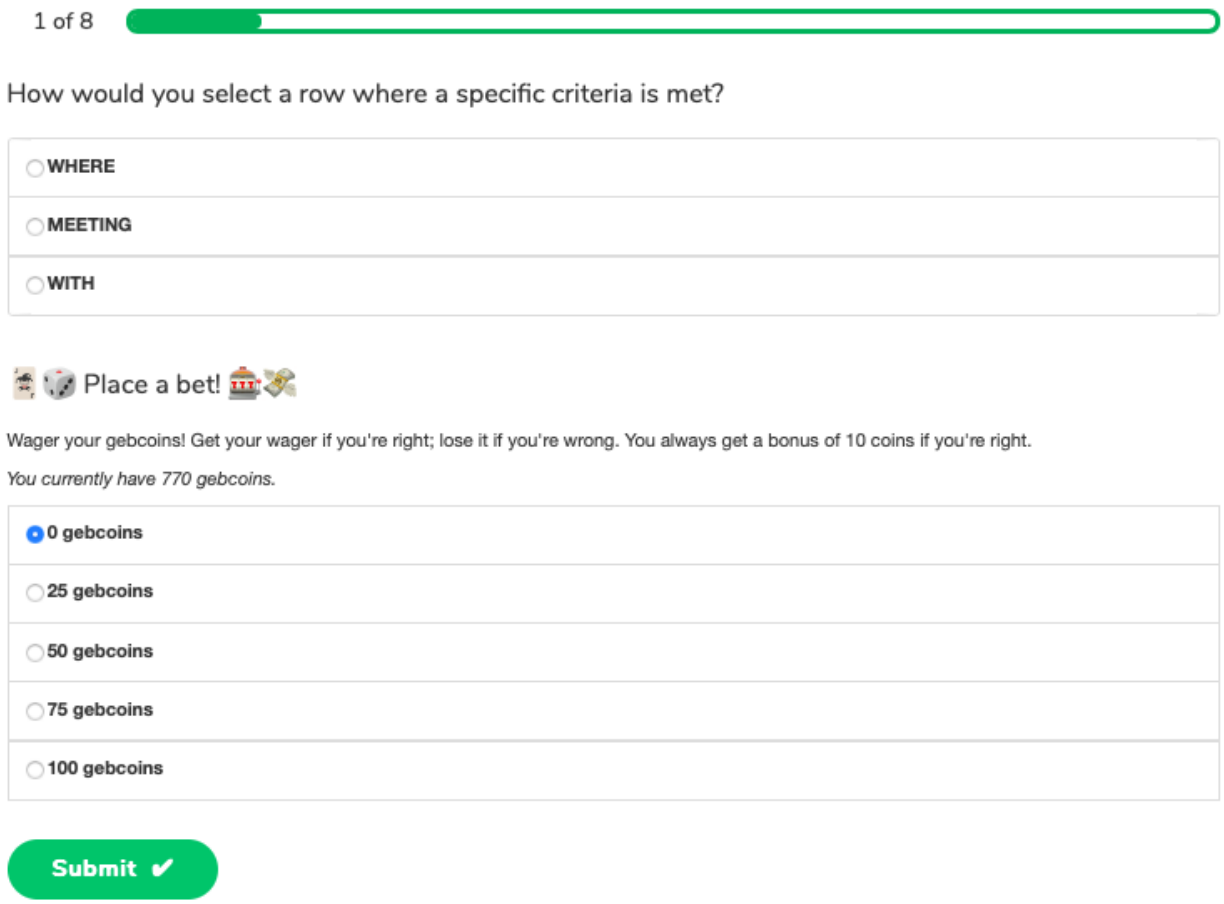

Figure 2. A sample quiz question at the top, followed by the wagering element at the bottom.

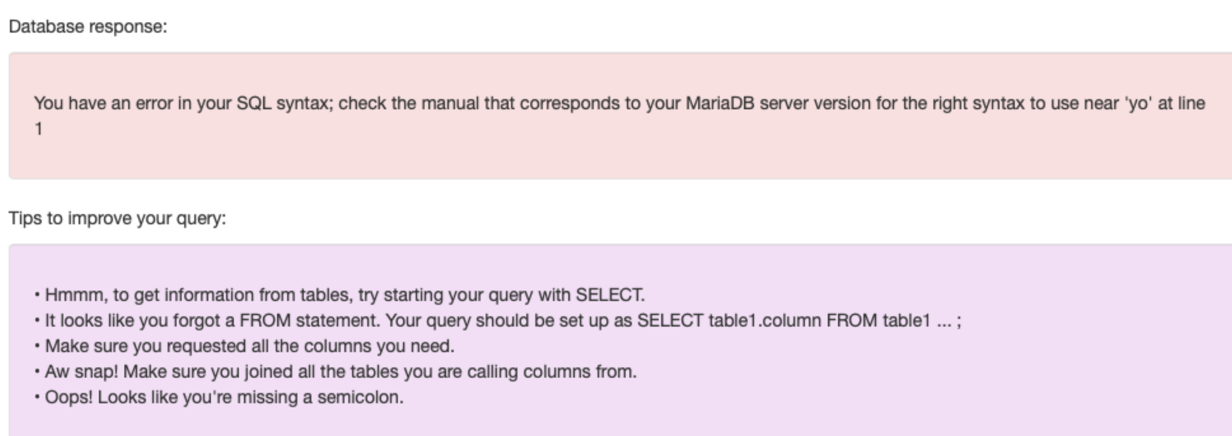

Figure 3. Sample feedback to an open-ended question requiring a query. The top response is provided by the SQL database, the bottom portion is the curated feedback.

The source code for our implementation is available upon request.

4. Experiment 1: Controlled Experiment on Wagering and Feedback

The first experiment focused on H1 and H2. It explores the effectiveness of iterative feedback and wagering on engagement and performance by comparing four versions of the practice engine that included: just wagering, just iterative feedback, both wagering and iterative feedback, and neither wagering nor iterative feedback.

4.1. Methods for the Controlled Experiment

Sixteen engineering students were recruited for this IRB-approved experiment, with the following selection criteria: fluent English, a computer with an internet connection, and no prior experience with MySQL. The participants, who were not compensated for their participation, included five women and eleven men.

Participants were randomly assigned to one of two groups. Each group interacted with two versions of the practice engine, as shown in
Figure 4. Members of the "Full Monty Group" used the version with no features and the version with both wager and feedback. Members of the "Fine Discrimination Group" played the version with feedback only and the version with wagering only. Within each group, the version order was balanced and randomly assigned. Both versions were played with the same questions and reset when participants began their second version. Participants interacted with each version of the practice engine for 15 minutes.

As shown in Figure 5Figure 5, participants were interrupted every 3 minutes to respond to the three-element Experience Sampling Method survey ([23]) that asked participants to rate their subjective feeling of concentration, interest, and enjoyment on a 5-point scale ranging from "Not at All" to "Very Much." These short surveys indicate the participants' experience from one moment to the next [36].

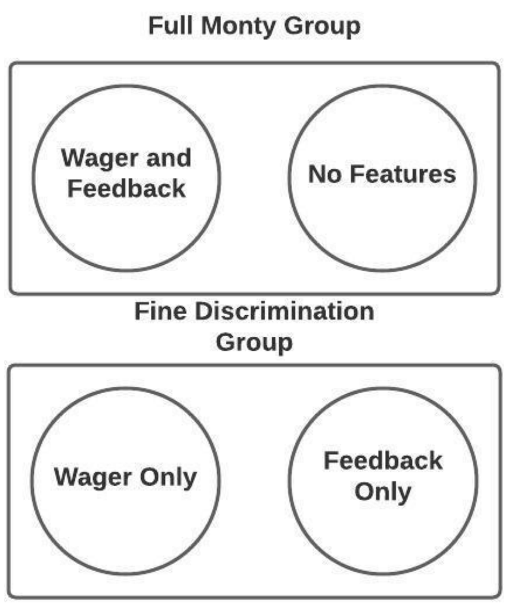

Figure 4. Diagram of study groups.

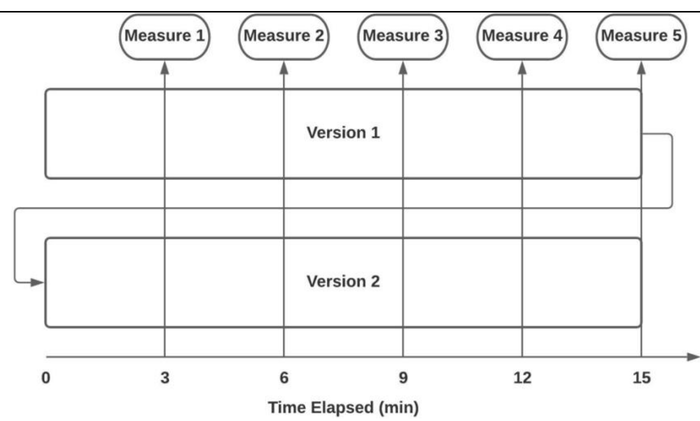

Figure 5. Administration of experience sampling method.

4.2 Dependent Variables and Statistical Analysis for the Controlled Experiment

The dependent variables were performance and engagement. Performance was measured by the percentage of correct answers with each version. Engagement was measured by the ratings of concentration, interest, and enjoyment at 5 intervals for each of the two versions tested by each cohort. The ratings of each dimension of the survey and the sum of all three dimensions were compared within subject, between each version of the game.

The results were analyzed with a general linear model using Minitab. The model used the fixed effects of feedback, wagering, and cohort as independent variables. For the performance model, the order of presentation was also included. For engagement elements, time was also included as a fixed effect.

4.3. Results for the Controlled Experiment on Wagering and Feedback

Performance scores ranged from 46% to 96%, with an average score of 73% and a standard deviation of 13% across 32 attempts. A general linear model of performance considering wagering, feedback, cohort, and order of presentation, indicated that only cohort and order were significant at the 5% level. A post-hoc Tukey comparison showed that the fine discrimination group performed significantly better with an average of 80% compared to the full monty group, which had an average performance of 68%. Another post-hoc Tukey comparison showed that the performance on the first variation was on average smaller (67%) than the second variation (80%).

Engagement scores were analyzed first for the three separate components: interest, enjoyment and concentration, then for the three elements combined. The 160 interest scores averaged 4.08 on the five-point scale. A general linear model of the interest score as a function of feedback, wager, and cohort, with time as a covariate, indicated that only wager, feedback and cohort were significant. Post-hoc Tukey comparisons suggested that the average interest score was higher when wagering was present (4.33 compared to 3.83), feedback was present (4.24 compared to 3.93), and in the fine discrimination compared to the full monty cohort (4.41 compared to 3.75).

A similar pattern held true for the enjoyment measure. The average participant estimate of enjoyment was 3.97 on a five-point scale. A similar general linear model to interest indicated that only wager, feedback and cohort were significant, all at less than, $p < 0.01$ level. Again, participants experiencing the wager, feedback condition and in the fine discrimination group expressed higher levels of enjoyment (4.28 vs 3.66, 4.20 vs. 3.74, and 4.33 vs 3.62, respectively).

The pattern of significant effects was somewhat different for concentration. The average participant estimate of concentration was 4.41 on a five-point scale. A similar general linear model indicated only wagering was a significant effect. A post-hoc Tukey comparison indicated that participants using wagering rated their concentration at 4.57, compared to those without wagering (4.25).

The sum of the three measures indicated that wagering, feedback and cohort were significant at the $p < 0.01$ level and followed the pattern of interest and enjoyment.

4.4. Discussion for the Controlled Experiment

The results suggest that both wagering and iterative feedback had a positive effect on student engagement, as expected. However, the main effects of wagering and feedback had no effect on the performance. This lack of a strong performance effect was somewhat disappointing, as we had expected that the more engaging environment would lead to greater success. The significant effect of cohort may suggest that having either wagering or iterative feedback, but not both, was beneficial to the students. However, the effect of cohort was confounded with the second-order interaction of wagering and iterative feedback. Either way, the results suggest at best a complex relationship between performance, wagering and iterative feedback that the experiment was not designed to detect.

Several studies have reported that the gamification elements such as wagering and feedback, improves performance, at least in the short term [33, 37, 38]. However, other work with gamification has emphasized the role of gamification elements in increasing student engagement. Although the study did not show performance improvements, it may be that the expected performance benefits are an outcome of improved engagement and may be better observed in a longer study.

Both wagering and iterative feedback produced positive effects for interest, enjoyment, concentration and the sum of all three elements of engagement, except that iterative feedback did not seem to improve concentration. This is broadly consistent with many studies of gamification elements [33, 37, 39]. It is perhaps surprising that such a robust effect could be observed in a short, controlled experiment.

The positive effects of iterative feedback shown in this study adds to positive effects observed by Kickmeier-Rust, et al. [38]. Our results show that the effect of feedback is not just about the feedback itself, but also about allowing the student to apply that feedback. Curated feedback was present in all versions of the game, but it appeared to be mostly ignored in versions without the opportunity to improve your answer. When given the opportunity to improve your answer in the presence of feedback, participants can immediately apply that feedback and identify their mistake.

The controlled study of wagering and iterative feedback suggested that both have a positive effect on student engagement, but failed to reveal a performance benefit. However, it is reasonable to assume that better engagement would lead to improved performance in a longer-duration experiment, so we applied both techniques in a regular class setting.

5. Experiment 2: In-class Experiment

To address the third hypothesis, the second experiment explored how students reported their engagement levels and demonstrated their metacognitive abilities while using the practice engine.

5.1. Methods for the In-class Experiment

Twenty-four students enrolled in the course participated in this study, 20 male and 4 female. Students participated as part of the standard process of the course's two-week SQL module. Classroom data were anonymized and the results of the analysis did not impact student grades.

At this point, student usage of the deliberate practice engine had been standard practice for several semesters. Students were not asked to perform any tasks beyond their normal participation in the class but were made aware of the research nature of the engine and our interest in their results and feedback.

The engine had both iterative feedback and wagering features enabled. The quiz questions drew from a pool of 211 questions, 36 of which were essay/open-ended questions and 175 were multiple choice, true/false questions. Of the 211 possible questions 204 of the questions were asked at least once, 29 of which were essay/open-ended questions and 174 were multiple choice, true/false questions. The questions are categorized into three levels of difficulty (easy, intermediate, and hard) at three different learning objective levels (basics, intermediate, and advanced). All but one (question 65) of the hard questions is open-ended. Three of the Intermediate questions (22,45, 59) were open-ended.

At the beginning of each week's class, students received a short lecture introducing some of the week's SQL topics and were given class time to work with the Deliberate Practice Engine. The engine was available from the beginning of the SQL module (week 4) through the end of the semester (week 16), although the study concluded at the end of week 6. By the end of the first week, students were expected to achieve at least 90% mastery of the basic level and 50% of the intermediate level. By the end of the second week, students were further expected to achieve 90% master of the intermediate level and 90% of the advanced level.

The results are derived exclusively from an analysis of the practice engine database and the anonymous student survey.

5.2. Results for the In-class Experiment on Engagement

When the students completed each week's assignment, they were requested to complete a survey asking them about their experience. Figure 6Figure 6 charts their 7-point Likert Scale responses to the following 3 questions relevant to engagement:

1) I enjoyed the game more than a typical lecture.
2) I felt motivated to continue playing because of the points system.
3) I felt motivated to continue playing because of the wager system.

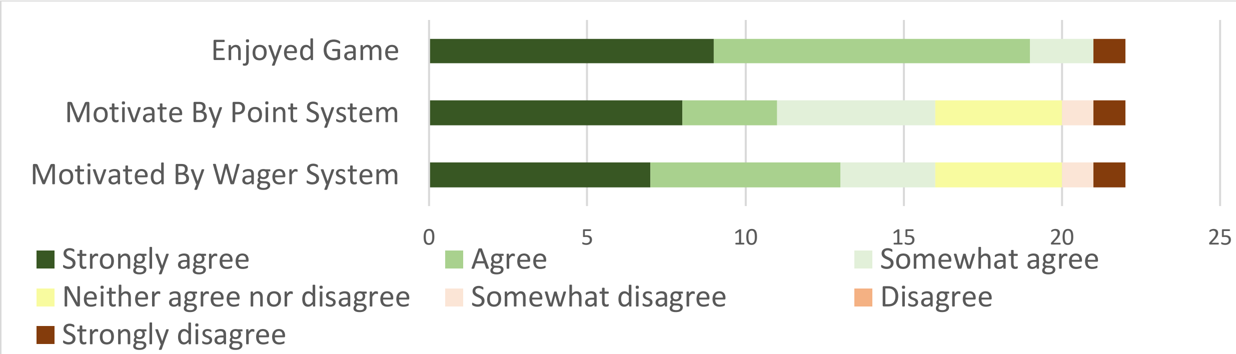

Figure 6. Student survey responses to engagement related questions.

In addition to Likert Scale questions, students were also asked the following open-ended questions:

1) What aspects of the game should be improved?
2) What new ideas for the game do you have?
3) What final thoughts or suggestions do you have?

Some of the more constructive responses that demonstrate engagement/dis-engagement are:

Table 1: Student-Suggested Improvements to the Deliberate Practice Engine

Response
I think during the feedback when you get a question wrong it would be nice to explain why something is wrong vs. right.
Make an option to wager any amount of your coins.
More skills covering more topics
The "all in" wager should still exist, but because of the exponential rise in point totals, gaining 100 points or going all in is a massive wager. You should be able to wager like 5,000 points.

Table 2: New Ideas Suggested by Students

New Ideas
Add in explanations for the multiple choice questions when you get something wrong. You could also have a mini-game that allows you to "challenge" other players then you go head to head and wager a specific amount of gebcoins
Try to add more of a variety of questions, after a while it was more memorizing the questions then learning the material.
You could use the wagering tool as a confidence indicator that affects the rank of a player's understanding. For example, betting high and getting it wrong shows that the person was confident they were right but wrong, rather than a low bet and getting it wrong shows that they understood how little they knew.
Just want more content
Challenges where you face off against other players.

Table 3:Final Thoughts from Student Feedback

Final Thoughts
I think this game is very engaging and definitely helped me learn the material in an engaging way.
I really enjoyed the game, I thought it was a great change of pace and a great way to learn this material.
I really enjoyed the game, keep it up :)
It has really help me with learning the material faster than just reading an article or listening to a lecture.
This concept of the game should be applied for other topics on the class.

5.2. Results for the In-class Experiment on Metacognition

In total, students answered 5909 questions, getting 4422 correct and 1487 incorrect. Figure 7*Figure 7* depicts the breakdown of questions answered by the difficulty level and the accuracy of the response. By the end of the SQL module each student answered questions more accurately than inaccurately. On average students answered 246 questions each. This is in contrast a typical SQL homework assignment of 20 problems.

Figure 8Figure 8 depicts the wagering patterns of the students and the accuracy of their answers. Wagers of 999 occur when a student chooses to go "All In" during a free-response question. Null wagers occur when students choose to test their open-ended answers with the iterative feedback feature. As we can see, students are overwhelmingly willing to risk 100 points. The next most frequent wager is 0 points. Wagers 25, 50, and 75 are infrequently used. Because wagers 25, 50, and 75 are used infrequently and students appears to use them as hedges when they are not confident, Figure 9Figure 9 consolidates wagers 0, 25, 50, and 75 into a single entry labeled "<100".

4.3.2 Discussion for the In-class Experiment

Students were not required to wager anything. They could have completed the entire mastery requirement without wagering a single point, yet we see students choosing to "play the game" in such a way as to maximize their point total. We even had one student bust the point calculator by accumulating more points than 4,294,967,295 points. Students clearly want to engage with the wagering system. The survey analysis shows 95% of students expressing enjoyment while interacting with the practice engine and 73% stating that they were motivated by both the point system and the wagering system.

The open-ended section of the survey was overwhelming positive, and we had one student directly state: "I think this game is very engaging and definitely helped me learn the material in an engaging way." Another student requested the practice engine be implemented in other classes ("This concept of the game should be applied for other topics on the class").

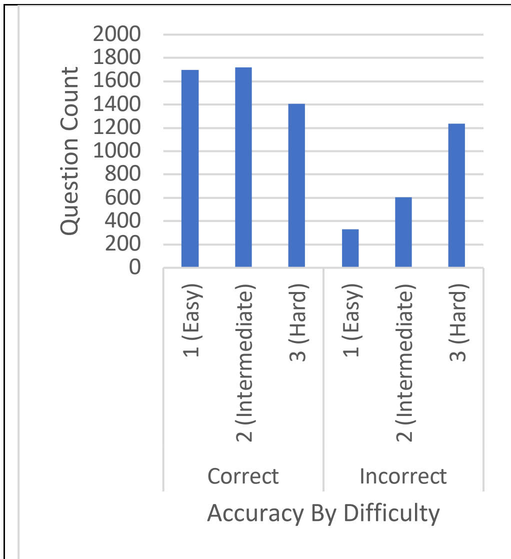

Figure 7. Question breakdown, by accuracy and difficulty.

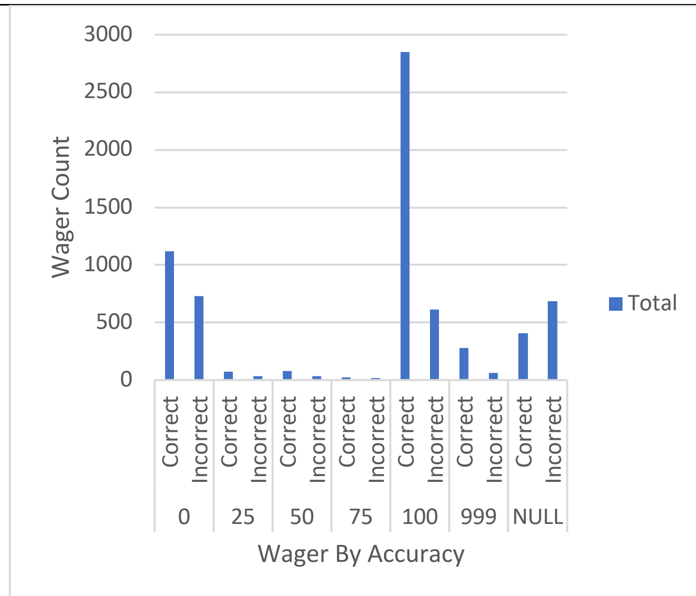

Figure 8. Wager breakdown, by wager value and accuracy.

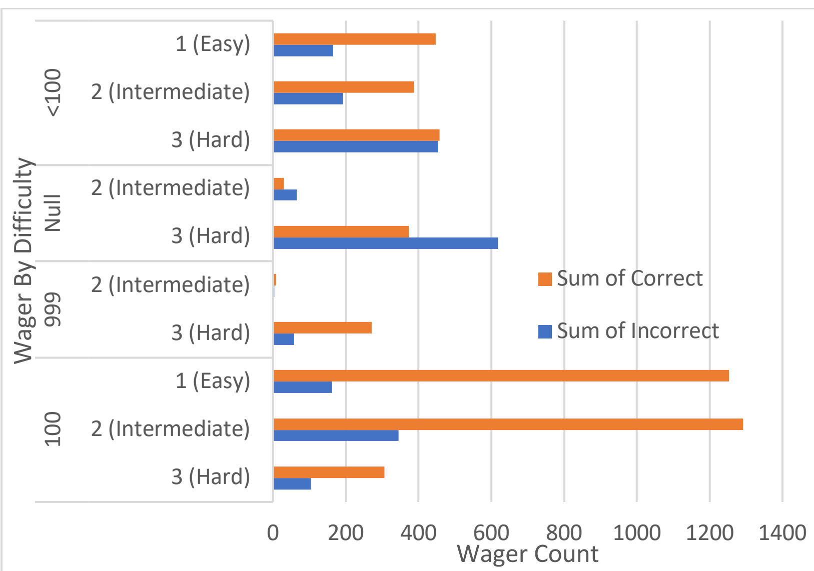

Figure 9. Wager breakdown (consolidated), by wager value, difficulty, and accuracy.

Student motivation for wagering is purely about topping the leader board. Students solved more than ten times the number of problems than a typical homework set and predominantly reported elevated levels engagements (supporting hypothesis 3). While the feedback was mostly positive, perhaps giving students additional positive feedback at certain milestones or on an individual question basis would amplify the engagement. A student suggested we "could possibly do confetti when you get a question right for a bigger reward." Another possibility is to link leaderboard status will "real world" perks, e.g. candy for the top 3 performers.

Hypothesis 3 predicted that student betting patterns would reflect the accuracy of their answers, thus exposing student metacognition. To analyze this, we looked at student wagering patterns. The student Correct to Incorrect Answer ratio was 1292:813 (1.59 relatively low) for wagers <100 and the ratio was 405:683 (0.59) for NULL wagers. The low ratio here suggests that students are betting less on questions they are less likely to get correct, which suggests that they are aware of what they do not know, or exhibiting meta-cognition. This is especially true as the difficulty increases. When students wager higher stakes, the Correct to Incorrect Answer ratio increases to 3130:674 (4.64). Students wager higher stakes when they are more likely to choose the correct answer, another indication of meta-cognition. One student was sufficiently aware of the metacognitive predictability of the quizzes, that the student responded to the survey stating: "You could use the wagering tool as a confidence indicator that affects the rank of a player's understanding. For example, betting high and getting it wrong shows that the person was confident they were right but wrong, rather than a low bet and getting it wrong shows that they understood how little they knew."

5. Conclusion

Deliberate Practice Engine 2.0 moved to a dedicated standalone practice engine and shows that both wagering and iterative feedback have a significant positive effect on engagement when applied in a MySQL teaching context. Both features are effective on their own and together. This study also showed that iterative feedback has a significant positive effect on performance. In a classroom environment, we showed that students voluntarily engaged with the wagering feature and exhibited evidence of metacognition.

The Deliberate Practice Engine can be expanded to other courses by emphasizing initial, highly structured introductions that emphasize information recognition and recall, then working towards more open-ended exercises. University courses can be designed for more efficient learning. They can be designed to invoke less distress in students and promote an environment for consistent educational growth. This increase in efficiency is likely to be attractive to students who are pressed for time or struggle to learn new material. These features are particularly valuable for learning abstract, complex, and challenging academic material. This can ultimately reduce costs, reduce the drop-out rate, and generally increasing access to higher education.

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