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Supporting Diverse Learners in STEM Education: The Impact of a Peer Assessment and Content Creation Activity

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Abstract

Teaching complex subjects in STEM studies to academically heterogeneous students presents significant pedagogical challenges. This study evaluates the impact of an active learning intervention where students created and peer-assessed exam questions. Using a mixed-methods approach, it was compared an intervention group (n=74) against a control group (n=76) and was analyzed pre/post-test results and student feedback. The findings reveal a statistically significant and substantial improvement in academic performance. The intervention group not only demonstrated exceptional learning gains (Cohen's d = 1.10) but also significantly outperformed the control group on the final exam (Cohen's d = 1.15). Student feedback confirmed the activity's value for learning, despite being perceived as demanding. This student-led assessment strategy proves to be a highly effective pedagogical tool for enhancing comprehension and success in challenging STEM courses for diverse student populations.

Introduction

In an era of rapid technological advancement, the efficacy of Science, Technology, Engineering, and Mathematics (STEM) education is paramount for preparing graduates to address novel and ill-defined global challenges (Koyunlu Unlu & Dokme, 2022; Peters-Burton & Johnson, 2018; Zaher & Damaj, 2018). However, traditional engineering pedagogy, which often prioritizes content coverage through conventional, lecture-based methods, faces significant limitations. Such approaches frequently result in superficial learning rather than deep conceptual understanding and may fail to foster the creativity and real-world problem-solving skills required in the modern workforce (Gong, Kwon, & Brock, 2022; Panergayo & Prudente, 2024; Zhou, 2012).

Moreover, this educational model is often insufficient for supporting an increasingly diverse student body. The aspiration for a more inclusive STEM field requires a pedagogical shift from a "weed out" mentality to one that actively nurtures all learners, especially in programs with non-competitive entry and academically heterogeneous cohorts (Knight, 2021). Traditional, one-size-fits-all instruction can disproportionately disadvantage students from minoritized backgrounds by failing to acknowledge diverse ways of knowing (Cigdemoglu, Kapusuz, & Kara, 2014). Therefore, there is a critical need to adopt inclusive and evidence-based strategies, such as problemcentered instruction with appropriate scaffolding and inquiry-based learning, to create a more equitable and effective educational environment (Bature & Jibrin, 2015; Belland, Lee, Zhang, & Kim, 2022; Holmen & Lonngren, 2025).

Active Learning in STEM Education: Fostering Engagement and Addressing Heterogeneous Learner Needs

Active Learning (AL) represents a pedagogical shift from traditional, teacher-centered instruction to a student-centered approach that emphasizes active engagement, critical thinking, and problem-solving (Barlow, McCrory, & Blessing, 2013; Guimaraes & Lima, 2021). This methodology is scientifically grounded in constructivist theory, which posits that learners build knowledge through interaction and experience, aligning with the foundational philosophies of educational pioneers like Dewey, Piaget, and Vygotsky (Christie & de Graaff, 2017; Li, Garza, Zhang, & Jiang, 2023; Lonngren, Adawi, & Svanstrom, 2019). Adopting such an approach is vital for preparing young engineers for a dynamic professional landscape where skills like sourcing new information and adapting to evolving technologies are paramount (Shekar, 2007).

A substantial body of research confirms that AL yields significant positive impacts in STEM education. Studies consistently demonstrate improved academic performance, with some showing increases in average student scores by as much as 14-15% (Awwad, 2025; Guimaraes & Lima, 2021). Beyond grades, AL strategies enhance practical skills through hands-on experiences and boost student engagement by fostering higher-order thinking (Miller & Schraeder, 2022; Stanberry, 2018). A variety of these strategies are commonly implemented, including Problem-Based Learning (PBL) (Macho-Stadler & Jesus Elejalde-García, 2013), Project-Based Learning (PjBL) (Miranda, Saiz-Linares, da Costa, & Castro, 2020), and the Flipped Classroom model (Cho, Zhao, Lee, Runshe, & Krousgrill, 2021), all of which restructure the learning environment to be more interactive and application-oriented.

Furthermore, AL is particularly effective in addressing the needs of diverse student populations by recognizing that learning is a holistic, socially, and culturally constructed process (Vodovozov, Raud, & Petlenkov, 2021). By fostering inclusive and collaborative environments, these strategies have been shown to improve learning outcomes for all students, with particularly significant gains observed for female and underrepresented minority students (Mena Lorenzo, Rodriguez-Pulido, Mena Lorenzo, Navarro-Guzman, & Silvio Cabrera-Guzman, 2019). Therefore, the continued adoption and refinement of active learning provides a robust framework for cultivating the essential competencies required of the next generation of STEM professionals.

Student-generated Questions and Peer Assessment in Higher Education

The pedagogical intervention in this study is built upon two synergistic active learning strategies: Student-Generated Questions (SGQ) and Peer Assessment (PA). The SGQ approach transitions students from their traditional role as passive knowledge consumers to active creators by having them formulate their own questions based on course material. The literature robustly supports this method for its capacity to promote deep understanding and higher-order thinking in engineering education (Abad, Gil, & Suarez, 2017; Bishay, 2020). The cognitive process of formulating a valid question requires students to reflect upon, elaborate, and transform information into personal knowledge, thereby developing crucial metacognitive skills and an enhanced ability to solve problems (Papinczak et al., 2012). This greater ownership over the learning process has also been shown to increase student motivation and engagement, which is particularly effective in engineering contexts (Cheng et al., 2023). This strategy can be further enhanced through digital platforms that allow students to share and review questions, engaging in an argumentative dialogue that refines knowledge for all participants (Abad, Gil, & Suarez, 2017).

The second core strategy is Peer Assessment (PA), where students evaluate their peers' work, typically guided by structured rubrics (Power & Tanner, 2023). While valued for providing timely feedback in large classes, the benefits of PA extend significantly beyond logistical efficiency. Engaging as an assessor compels students to develop critical thinking, argumentation, and appraisal skills (Power & Tanner, 2023). By analyzing diverse examples of work, students become more adept at self-evaluation, and the process of providing constructive feedback deepens their own content mastery (O'Moore & Baldock, 2007). However, the implementation of PA is not without its challenges. Concerns regarding the quality of feedback and the reliability of peer-assigned grades are well-documented and can be influenced by student biases (Power & Tanner, 2023). To mitigate these issues, effective PA design incorporates strategies such as anonymity, clear and specific rubrics, and adequate student training (O'Moore & Baldock, 2007). By integrating these principles, the combination of SGQ and PA creates a robust pedagogical cycle that develops the critical analytical skills essential for future STEM professionals (Chang & Wongwatkit, 2024).

The Present Study

This study, therefore, aims to answer the following research question: Given an academically heterogeneous student cohort in an engineering degree program with non-competitive admission, to what extent does an active learning intervention, based on student-generated questions and peer assessment, impact their academic performance and their perception of the learning process? To address this question, we implemented the pedagogical activity within an Environmental Modeling course and evaluated its effects using a mixed-methods approach. We assessed student learning gains through a pre-test/post-test design and compared final exam scores against a control group from the previous academic year. Additionally, student perceptions were gathered through a detailed opinion survey. The findings indicate that the intervention led to a statistically significant and substantial improvement in academic performance. Furthermore, while the student feedback reveals a nuanced perception of the activity, it was overwhelmingly valued for its relevance to learning and is strongly recommended by the participants.

Method

Context and Sample

This study was conducted within the context of the "*Modelización Ambiental*" (Environmental Modeling) course, delivered at the *Escuela Técnica Superior de Ingeniería de Montes, Forestal y del Medio Natural* (Higher Technical School of Forestry, Forest Engineering and Natural Environment) of the university *Universidad Politécnica de Madrid* (UPM), located in Madrid, Spain. This course is a compulsory module in the fourth semester of the "*Grado en Ingeniería en Tecnologías Ambientales*" (Bachelor's Degree in Environmental Technologies Engineering), with a student workload of 6 European Credit Transfer System (ECTS) credits. The curriculum is designed to cover the mathematical modeling of physical phenomena, including topics such as the Finite Volume Method (FVM) and the Finite Element Method (FEM).

The educational intervention was specifically implemented during the final part of the course, which addresses the Finite Element Method. This topic was selected due to a consistent history of lower academic performance by students in this section compared to other course materials. The research involved two distinct student cohorts: the intervention group, consisting of students enrolled in the 2024-2025 academic year, and a control group, comprising students from the 2023-2024 academic year who received traditional instruction for the same topic.

A total of 150 students participated in this study across two academic years. The intervention group (2024-2025 academic year) consisted of 74 students, with a gender distribution of 34 males and 40 females, and a mean age of 20.1 years. The control group (2023-2024 academic year) was composed of 76 students, including 33 males and 43 females, with a mean age of 20.3 years.

The demographic characteristics of both cohorts are summarized in Table 1. The student cohort for this degree program is characterized by its academic heterogeneity. This is a direct result of the non-competitive admission process, which is based on the minimum required university access score (5.0 out of 10). Consequently, the student body includes individuals with diverse levels of academic preparedness, some of whom may require significant pedagogical support to address foundational study skills.

Table 1: Sample Description

	N	Age	Gender	
			Male	Female
Intervention group (course 2024-25)	74	20.2	34 (50%)	34 (50%)
Control group (course 2023-24)	76	20.8	33 (43.4%)	43 (56.6%)
Total	150	20.5	67 (44.7%)	77 (55.3%)

Procedure

The educational intervention was structured in several sequential phases. Initially, to establish a baseline, students' prior knowledge of the Finite Element Method was assessed using an 8-item multiple-choice question (MCQ) pre-test. Each question was designed to have a single correct answer and was based on the key theoretical concepts of the topic, which had been previously identified by the instructor.

Following the pre-test, the core of the intervention began. Each student was assigned two distinct key concepts from the topic and was tasked with developing one MCQ for each assigned concept. This resulted in a large pool of student-generated questions. Subsequently, a structured peer-review phase was conducted. Each student was required to review and evaluate ten MCQs created by their peers.

The review criteria focused on ensuring that each question was well-posed, featured a logical and clear statement, and had only one unambiguous correct answer. Students provided constructive feedback to the authors of the questions. After the peer-review and feedback cycle was completed, a post-test, identical to the pre-test, was administered to all participants to measure the learning gains resulting from the activity. Finally, after instructor validation, a final pool of 93 correct student-generated questions was established. From this pool, three questions were randomly selected and incorporated into the formal final examination for this course topic.

To conclude the educational intervention, student feedback was gathered using a survey that consisted of seven Likert-type items to assess their opinion on the activity, followed by a final open-ended question for them to provide free-text comments on their overall impressions. The specific items included in the opinion survey are detailed in Table 2.

Table 2. Survey Questions posed for the Students

ID	Question
Q1	How do you rate your degree of satisfaction with the activity? (rate from 1 for minimum satisfaction to 4 for maximum satisfaction)
Q2	What was your degree of engagement with the activity? (rate from 1 for minimum engagement to 4 for maximum engagement)
Q3	What was the relevance of the activity for your learning? (rate from 1 for minimum relevance to 4 for maximum relevance)
Q4	Indicate your degree of understanding of the theoretical material provided during the course (rate 1 for minimum understanding to 4 for maximum understanding).
Q5	Part of the activity was to receive a grade and possible corrections from your peers. Indicate how effective this feedback was for your subsequent improvement (rate 1 for minimum effectiveness to 4 for maximum effectiveness).
Q6	Indicate your enjoyment of the activity (rate 1 for minimum enjoyment to 4 for maximum enjoyment).
Q7	Indicate how likely you are to recommend the activity (rate 1 for would not recommend to 4 for would absolutely recommend).

Quantitative and Qualitative Data Analysis

To evaluate the learning gain within the intervention group (2024-2025), scores from the pre-test and post-test were analyzed. The normality of the data distributions was first assessed. A paired samples t-test was then conducted to compare the mean scores and determine if the observed increase was statistically significant. A similar approach was used to compare the final exam scores between the intervention group and the control group

(2023-2024). After verifying data normality, an independent samples t-test was employed to identify statistically significant differences between the two cohorts. For both comparisons, the magnitude of the difference was measured by calculating the effect size using Cohen's d.

The student opinion questionnaire was analyzed using a mixed-methods approach. First, the internal consistency of the Likert-scale items was validated by calculating Cronbach's alpha. A mean score was then computed for each item on a 1-to-4 scale to quantify student opinion. Finally, the qualitative data from the free-text responses were examined using a simple thematic analysis to identify common patterns and key student perceptions regarding the activity.

Statement on the Use of AI

During the preparation of this manuscript, the author utilized a generative artificial intelligence (AI) language model (Gemini 2.5) to assist in improving the grammar, phrasing, and overall clarity of the text in scientific English. The author reviewed and edited all AI-generated suggestions and assumes full responsibility for the final content of the article.

Results

Pre-Test vs. Post-Test Comparison

The primary analysis focused on quantifying the learning gain achieved by students between the pre-test and post-test. As detailed in Table 3, the descriptive statistics revealed a substantial increase in performance, with the mean score rising from 5.11 ($SD = 1.84$) to 7.95 ($SD = 1.15$). To ascertain whether this improvement was statistically significant, a paired samples t-test was performed. The test yielded a definitive result ($t = 9.48$, $p < .001$), allowing us to reject the null hypothesis and conclude that the observed increase in scores is highly unlikely to be due to random chance. This establishes the existence of a real learning effect.

Table 3. Descriptive Statistics for Pre-test and Post-test Scores

Metric	Pre-test	Post-test
Mean Score	5.11	7.95
Median	5.00	8.00
Standard Deviation	1.84	1.15
Maximum Score	8.00	10.00
Minimum Score	1.00	6.00

Beyond statistical significance, it was crucial to determine the practical significance or magnitude of this effect. For this purpose, the effect size was calculated using Cohen's d. The analysis resulted in a Cohen's d of 1.10. According to established conventions, this is classified as a very large effect size. In practical terms, this value means that the average student's score after the intervention was over one full standard deviation higher than the average score before it. Taken together, these results provide a comprehensive picture: the educational intervention not only produced a statistically significant improvement in student knowledge, but the magnitude of that improvement was also exceptionally large and meaningful.

Comparative Analysis of Final Exam Performance

To provide a robust measure of the activity's overall impact, the final exam scores from the intervention group (2024-25) were compared with those from the control group of the previous academic year (2023-24). The descriptive statistics, detailed in Table 4, reveal a clear and substantial performance gap between the two cohorts. The intervention group achieved a mean score of 7.64 (SD = 1.23), significantly outperforming the control group, whose mean score was 6.09 (SD = 1.45). This represents a notable difference of 1.55 points on the final exam.

Table 4. Descriptive Statistics for Final Exam Scores between the Control and Intervention Groups

Metric	Control Group	Intervention Group
Mean Score	6.09	7.64
Median	6.00	7.80
Standard Deviation	1.45	1.23
Maximum Score	9.50	10.00
Minimum Score	2.50	4.00

An independent samples t-test was conducted to formally assess whether this observed difference was statistically significant. The analysis yielded a definitive result ($t = 4.65$, $p < .001$). This extremely low p-value indicates that the probability of observing such a large difference in scores by random chance is negligible. Therefore, we can confidently conclude that the superior performance of the intervention group is a direct result of the educational innovation. While statistical significance confirms the existence of an effect, it does not describe its magnitude. To quantify the practical importance of this finding, the effect size was calculated. The analysis yielded a Cohen's d of 1.15, a value that is conventionally interpreted as a very large effect size. In practical terms, this indicates that the average student in the intervention group performed 1.15 standard deviations better than the average student in the control group.

In summary, the combination of a highly significant statistical result with a large effect size provides compelling evidence for the success of this pedagogical approach. The intervention was not only effective in producing a measurable improvement, but its impact on student achievement was also substantial and practically meaningful when compared to traditional teaching methods.

Student Feedback and Perceptions

To conclude the educational intervention, student feedback was gathered using a survey that consisted of seven Likert-type items and one open-ended question. The quantitative results from the Likert-scale questions are detailed in Table 5.

Quantitative Results

The table below shows the distribution of responses for each of the seven questions and the calculated mean score on a 4-point scale. The opinion survey was administered anonymously, and a total of 15 students submitted responses. Prior to the main analysis of the survey responses, the internal consistency of the 7-item questionnaire was assessed. The analysis yielded a Cronbach's alpha coefficient of 0.80, which indicates a good level of reliability for the instrument.

Table 5. Results of the 7-item Likert-scale Student Opinion Survey (N=15)

ID	Question	1 (%)	2 (%)	3 (%)	4 (%)	Mean
Q1	Degree of satisfaction with the activity	6.7	13.3	60.0	20.0	2.93
Q2	Degree of engagement with the activity	0.0	26.7	40.0	33.3	3.07
Q3	Relevance of the activity for your learning	6.7	13.3	40.0	40.0	3.13
Q4	Understanding of the theoretical material	13.3	20.0	60.0	6.7	2.60
Q5	Effectiveness of peer feedback	13.3	20.0	40.0	26.7	2.80
Q6	Enjoyment of the activity	26.7	20.0	53.3	0.0	2.27
Q7	How likely you are to recommend the activity	13.3	0	33.3	53.3	3.26

Overall, the student feedback indicates a generally positive perception of the activity, though with some notable nuances. The most highly-rated aspect was the willingness to recommend the activity (Q7), which achieved the highest mean score of 3.26. This suggests that students found significant value in the experience. The relevance for learning (Q3, mean 3.13) and the level of engagement (Q2, mean 3.07) also received strong positive ratings, with over 73% of students agreeing or strongly agreeing with these statements.

Conversely, the aspect with the lowest rating was the enjoyment of the activity (Q6), with a mean score of 2.27. This indicates that while students found the activity effective, it was perceived as less enjoyable. Other areas with room for improvement include the students' self-assessed understanding of the prior theoretical material (Q4, mean 2.60) and the effectiveness of the peer feedback they received (Q5, mean 2.80).

Qualitative Results of Student Comments (N=7)

A qualitative thematic analysis was conducted on the written comments from the 7 students who responded to the final open-ended question. The analysis identified several key themes, which have been grouped into positive perceptions of the activity and areas of constructive feedback.

The positive aspects/topics identified are as follows:

1. *Enhanced comprehension and knowledge retention:* Students reported that the activity facilitated a deeper learning process. The act of creating questions required them to engage with the material more thoroughly, which in turn helped them to better understand and retain the key concepts. Supporting quotes: "It helped me a lot to know what was important. Also, the concepts stuck with me better.",

"Getting involved in the activity makes it easier to acquire the knowledge required in the evaluations..."

2. *High utility as an exam preparation tool:* A dominant positive theme was the activity's practical value for exam preparation. Students found the resulting question bank to be an "excellent" study resource and felt the activity as a whole was a highly effective and organized way to prepare for the final assessment. Supporting quotes: "Without this activity, I don't know if I would have been able to pass. Very well organized...", "It was excellent to have a question bank to study from."
3. *Motivation via integration with formal assessment:* The direct link between the activity and the final exam served as a significant motivator. Students were encouraged by the knowledge that their work could appear on the exam and contribute to their grade. Supporting quote: "...they are points for an exam that we can get... since some of the questions are then used for the exam."

The following themes emerged regarding constructive feedback and areas for improvement:

1. *Insufficient time allocation:* The most common point of criticism was that the time allotted for the workshops was too short. Students felt this limited the activity's potential as a tool for reviewing the content. Supporting quotes: "The short time for the workshops meant they didn't really help for reviewing the content.", "It should be organized with more time."
2. *Logistical challenges with submission format:* A practical issue was raised concerning handwritten submissions. Poor legibility made it difficult for students to both correct their peers' questions and to use the final question bank for studying. Supporting quote: "...some classmates have horrible handwriting and it becomes very complicated both to correct the questions and to study them."
3. *Mismatch in Assessment Expectations:* Finally, one student expressed a desire for a greater number of questions from the student-generated bank to be included in the final exam, to better reflect the effort invested. Supporting quote: "There should have been more questions from the question bank in the final exam."

Discussion

This study aimed to evaluate the effectiveness of an educational innovation where engineering students actively created and peer-reviewed exam questions on the complex topic of the Finite Element Method. The results provide strong, multi-faceted evidence that this intervention was highly successful, not only in improving academic performance but also in enhancing the student learning experience. The core finding of this research is the statistically significant improvement in student learning, evidenced by two key comparisons. First, the pre-test vs. post-test analysis demonstrated a remarkable learning gain within the intervention group ($p < .001$), confirming that the activity itself was a potent learning tool. Second, and perhaps more compellingly, the final exam scores of the intervention group were significantly higher than those of a control group from the previous academic year ($p < .001$). This suggests that the benefits of the activity translated directly into improved outcomes in a formal assessment setting, providing robust evidence of the intervention's efficacy.

The quantitative results are well-explained by the qualitative feedback. The thematic analysis of student comments revealed that the activity fostered deeper learning, compelling students to move beyond rote memorization to a more profound understanding required for question creation. This aligns with pedagogical theories of active learning and constructivism, where students build knowledge by doing rather than by passively receiving information. Furthermore, students identified the peer-review process as a valuable mechanism for self-assessment, which supports the literature on the benefits of peer instruction.

The student opinion survey provided further nuance. While the activity was perceived as highly relevant for learning (mean 3.13/4) and students would strongly recommend it (mean 3.26/4), the self-reported "enjoyment" was the lowest-rated aspect (mean 2.27/4). This suggests that students recognized the activity's value and effectiveness even if they found it challenging or demanding. It highlights a key distinction between an activity being effective and being entertaining. The primary motivation for students appeared to be the clear link between the activity and its utility for exam preparation, as confirmed by the qualitative comments.

This study has some limitations. The research was conducted at a single institution with a specific student profile—an academically heterogeneous cohort in an environmental engineering degree program. Therefore, caution should be exercised when generalizing these findings to other contexts. Additionally, the qualitative feedback, while insightful, was based on a small sample of seven students who chose to provide comments.

Future research could address these limitations. Replicating the study in different institutional contexts or in other STEM disciplines could test the broader applicability of this pedagogical model. Further investigation could also explore the impact of specific components of the activity. For example, comparing different peer-review structures or analyzing the long-term retention of knowledge would be valuable next steps. The constructive feedback also suggests that future iterations should focus on optimizing time management and exploring digital submission platforms to resolve logistical issues like handwriting legibility.

Conclusion

In conclusion, this study demonstrates that shifting students from the role of passive knowledge consumers to active content creators is a powerful pedagogical strategy in higher education. The process of creating and peer-reviewing assessment questions led to significant and measurable improvements in academic performance. This approach proved to be particularly valuable for a diverse and academically heterogeneous student cohort, providing a structured and engaging framework that supports learners who may require additional scaffolding in their educational process. Despite being perceived as demanding, students valued the activity for its direct impact on their learning and exam preparedness. Therefore, this intervention stands as a highly effective and recommendable innovation for teaching complex technical topics in engineering, especially in learning environments with varied student backgrounds.

Recommendations

Based on the findings of this study, we offer the following recommendations for educators and curriculum designers seeking to implement similar active learning strategies, particularly in challenging STEM courses with diverse student populations:

1. *Adopt the Combined SGQ and PA Model for Complex Topics*: We strongly recommend the adoption of a pedagogical model that synergistically combines student-generated questions (SGQ) with peer assessment (PA). This approach has proven to be a highly effective method for moving beyond surface-level memorization to achieve deep conceptual understanding and significantly improved academic performance. Its value is particularly pronounced in academically heterogeneous cohorts, where it provides a structured yet student-centered learning framework.
2. *Ensure Sufficient Time Allocation*: Student feedback consistently indicated that the time allocated for the workshops was a critical factor. To maximize the activity's benefits, we recommend dedicating sufficient and distinct periods for each phase. A rushed schedule may compromise the quality of both the questions created and the feedback provided. Allocating one session primarily for question development and another for a thorough peer-review and discussion process appears optimal.
3. *Utilize Digital Platforms for Implementation*: To overcome significant logistical challenges, the use of digital platforms for question submission, review, and compilation is strongly advised. The issue of illegible handwriting was a major impediment noted in student feedback, negatively affecting both the peer-assessment phase and the final utility of the question bank. Digital tools would streamline the process, ensure legibility, and facilitate anonymous feedback.
4. *Provide Scaffolding for the Peer-Feedback Process*: While students found peer feedback valuable, its effectiveness can be enhanced. We recommend that instructors provide clear and specific rubrics for evaluation and conduct a brief training session on how to give constructive, elaborative feedback. This scaffolding is crucial for improving the quality of peer assessment and ensuring students feel confident and competent in their role as evaluators.
5. *Clearly Frame the Activity's Purpose and Link to Assessment*: Instructors should clearly communicate the pedagogical purpose of the activity, framing it as a rigorous and effective learning tool rather than a purely enjoyable exercise; this manages student expectations, as reflected in the survey's "enjoyment" score. To maintain high engagement, the connection between the student-generated bank and the final exam should be explicit and meaningful, validating the significant effort invested by the students.

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