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Leveraging a token economy system to motivate concept practice in a fluid dynamics classroom.

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ABSTRACT

Chemical engineering courses introduce students to novel concepts encompassing highly specialized applications of foundational chemistry, physics, and mathematics. In fluid dynamics, for example, the application of fundamental Navier-Stokes equations requires students to observe concepts under multiple contexts before they gain mastery. However, the fast-paced delivery of core curriculum classes can limit the number of quizzes or "low stakes" homework problems to practice a specific topic. Without sufficient practice, students will find recalling details and effectively applying concepts difficult to achieve during "high stakes" exams. Although the instructor can still advise students to consult supplemental resources and exercise habits of mind that increase practice opportunities, there is rarely a formal system in a didactic model course that helps support and motivate students to engage in this behavior.

This investigation explores how the adoption of a token economy can guide and motivate chemical engineering students in a fluid dynamics course to revisit concepts during the semester via revisions to previous assignment attempts. Under the token economy, students acquired tokens as they fulfilled expected class engagement standards and exchanged tokens to purchase resubmission opportunities on homework or quizzes, which rewarded back a portion of missed points to their assignment grade. It is also through these resubmission opportunities that students exercised goal-directed practices of identifying the original error(s) and explaining how the added revision resolved their error(s). Effects of the token economy on how the course was experienced were assessed through student survey responses with the focus around how introducing a token economy influenced students' 1) motivation to revisit assignments, 2) perceived time commitment to the class, and 3) approach for completing assignments knowing that their original attempt was not necessarily their only attempt. From token usage analysis, it was observed that the combination of reward benefits and the number of exchanges available in this study's token economy produced delayed interactions from students with most waiting until the end of the course to acquire and spend tokens. This lack of activity within the token economy also led to students experiencing little perceivable enhancement to instructional content from the strategy; however, the token economy was perceived to reduce student stress during the semester through the rewards it offered.

INTRODUCTION

The flexibility with which chemical engineers can occupy roles in fields across energy, health, and biotechnology is contingent upon an ability to apply a "toolkit" of fundamental mathematics and physical concepts to solve problems. Chemical engineering (ChE) students would ideally demonstrate mastery over this toolkit by correctly performing procedures associated with the concept while also being able to identify the appropriate contexts that allow for the concept's application[1]. Of course, developing this mastery over an instruction period requires targeted practice that not only helps students exercise the knowledge introduced during lecture but also layers in the multiple problem contexts that students would encounter in applied scenarios. However, this idealized practice schedule can be at odds against the demands of the course syllabus schedule.

The breadth of concepts that a ChE course must cover in its syllabus, especially one that is part of the core curriculum, limits both the amount of time and instructional strategies that lesson plans or homework can prescribe to a particular concept[2], [3]. This in turn can detract from students' targeted practice on a particular concept to either not sufficiently demonstrate all contexts or attempt to do too much at once within problems that can then strain the number of cognitive tasks students can successfully complete[4]. To bolster concept application practice outside of class lectures and homework, instructors can encourage students to exercise habits such as reattempting prior problems or consulting supplemental texts to generate more practice opportunities. However, adoption of these habits is highly reliant on the students' self-motivation if these actions are outside of class performance assessments. Even when students are self-motivated to adopt these learning habits, this advice alone still does not help guide students in constructing deliberate goals, such as understanding which physical variable descriptions define problem boundary conditions, when they perform their supplemental practice. Without this goal-directed approach in their practice, the time invested by students into learning a concept may become diluted due to effort being distributed across processes that require reinforcement and processes that the student may already be proficient in[5], [6].

One classroom strategy that has the potential to address both the challenges of motivating and guiding students to perform goal-directed practice of concepts outside of lectures and assignments is a token economy. In an educational setting, a token economy (TE) involves the instructor distributing resources or tokens to students after a specific behavior is demonstrated and managing the reward purchases that students make with their earned tokens[7], [8]. Once an action is associated by students with token generation and a set of rewards desirable to students is determined, TEs become effective behavior reinforcement tools as students are motivated by the rewards to regularly practice the behavior to earn the tokens required for purchases. Furthermore, this strategy is highly adaptable around its target behavior by allowing the instructor to adjust the schedules for token production (how often tokens are rewarded), token-exchange (the token price for a reward), and exchange production (when rewards can be purchased)[9], [10]. These design elements shaping student-token interactions also make the TE share qualities with classroom gamification where game attributes are adapted to education settings. Using gamification terminology established by Landers 2014[11], TEs can support students' engagement with instructional content through its point-reward system sustained by token acquisition and spending. When this game attribute and its induced student behaviors are aligned to complement learning outcomes (e.g. completing supplemental learning activities, participating during class), instructors and meta-studies over the past decade have demonstrated that these pedagogical approaches can also enhance how students cognitively, emotionally, and socially experience class content[12, 13].

While TEs have had more documented use in primary school classrooms[14], [15], reports of undergraduate classrooms using this strategy have steadily increased since the work of Boniecki & Moore 2003 who integrated a TE into an introductory psychology course and successfully saw greater class participation from students[16]. When attempted in undergraduate classrooms, TEs frequently have their rewards to students be centered around pathways that affect final grades via extra credit points or opening opportunities to influence assignment scores[17-19]. Apart from the high value that grade-adjusting actions have in an A-D interval grading system, the motivation to acquire these rewards may also align under self-determination theory where resources allowing for more control or autonomy over external circumstances are desired by students[20], [21]. For example, the extra credit rewards from tokens may help students combat instances where they received a lower grade on an assignment because an extracurricular commitment prevented them from dedicating time to the assignment.

When extending this TE framework to have goal-directed practice of concepts as the target behavior for reinforcement, an ideal TE system might be one that distributes tokens to students whenever they self-report an objective that they accomplished by working on supplemental problems or revisiting older assignments. However, literature around TE performances makes it uncertain whether students would readily engage in a target behavior if the behavior standards to earn a token are not specifically defined or described[22], [23]. Since a wide range of actions can constitute goal-directed practice, the identification of practice qualities that would allow students to receive tokens poses a challenge. One way that goal-directed practice behavior could still be involved and motivated by a TE without playing a role in token generation is through rewards like assignment resubmissions. TEs previously implemented in undergraduate chemistry and biology courses have offered assignment resubmissions as TE rewards that would replace their original attempt provided that students gave written explanations of their revisions[24], [25]. This associated exercise with resubmissions presents students with a practice opportunity that guides critical evaluation of their original attempt and gives a chance to perform a more informed application of older concepts. Herein, a case study was conducted to integrate a TE into an undergraduate fluid dynamics class and evaluate whether ChE students are motivated to revisit concepts in a goal-directed manner if the opportunity is embedded into a reward exchange process, specifically the assignment resubmission reward.

MOTIVATION

Two sets of motivations drive this study's investigation of the TE strategy. The first is a research question to interpret from students' token usage data and survey responses if student motivation to practice a goal-directed reattempt can be influenced when the behavior is being reinforced through a reward exchange process instead of token generation. The second set of motivations is to inform other ChE instructors about the impact of a TE strategy on core curriculum class as well as how a TE can be introduced and managed. To the authors' knowledge, this is the first documented use of a TE for undergraduate ChE education. Due to this, the student's perceived time commitment to the course and learning experience from assignments in a TE will also be investigated to determine for prospective practitioners what holistic outcomes can arise in students when this strategy is implemented.

METHODS

Course description and student population

Transport Processes I – Momentum Transfer is a 3-credit hour course that ChE-majoring students enroll in after their foundational courses of material and energy balances and thermodynamics. During this study, a student cohort consisting of one section was co-instructed by two of the authors (SK & SRC) in the Fall 2023 semester. Students were taught primarily through didactic instruction as well as problem-solving demonstrations. Instructors rotated teaching responsibilities on a weekly basis delivering on average 3 lesson plans before alternating. Student performance was evaluated through homework sets, 4 quizzes administered outside of class instruction, and written exams (2 midterms and 1 final exam). The weights of each evaluation component on the student's final grade are listed in **Table 1**. Topics covered during the semester included hydrostatics, integral balance equations, Navier-Stokes equations, and boundary layers.

Table 1: Grading breakdown of evaluation components for Transport Processes I – Momentum Transfer.

Component	***Weight Toward Final Grade***	***Final Grade Weight Per Assignment***
Homework	15%	1.9%
Quiz	12%	3.0%
Midterm	30%	15%
Final Exam	20%	N/A
Design Project	15%	N/A
Engagement (iClicker participation, writing reflections)	8%	N/A

A majority of students in this section (n = 45) were third-year undergraduates. They were approached for study recruitment under procedures approved by the University of Virginia's Institutional Review Board (IRB) with the pretext that their participation would assist their instructors in improving the TE for future ChE courses. Out of those who were enrolled in Fall 2023, 14 students agreed to participate in study, and they provided their TE interaction data as well as their survey responses generated throughout the semester.

Token economy description

The TE used digital tokens as a way to simplify token management and transaction recording. At the start of the course, each student was allocated 3 tokens as their initial balance. Tokens could be added to a student's balance by fulfilling specific milestones in the *token production schedule*. Events on the token production schedule (**Table 2**) were created to complement existing Engagement components as a way to ensure that every student could feasibly acquire all tokens. Each event on the token production schedule rewarded 1 token upon completion, which capped the maximum tokens that a student could possess in this system to 8.

Table 2: Token production schedule for token economy.

• Signed team contract before beginning group design project • Attended class and participated in iClicker polls for 18 lectures • Attended class and participated in iClicker polls for 27 lectures	• Submitted at least 2 Writing Reflection assignments • Engaged with and posted messages to the class Piazza discussion board at least 2 times

The exchanges that were available as rewards for token purchase are detailed in **Table 3** along with their token-exchange cost and *exchange production schedule* utilizing frequency-based restrictions for exchanges. For this TE's first implementation, the selection process for exchanges was limited to replicating pre-TE grading policies (dropping the lowest homework and quiz grade) and offering enough exchanges for students to potentially interact with half the homework and quiz assignments. Outside of this frequency-based exchange production schedule, there were no restrictions placed for when students could purchase an exchange. When students wished to acquire tokens or purchase exchanges, they were required to submit specific electronic forms detailing the token production event or exchange that they wished to complete. These form submissions were then verified by the instructors before transactions were recorded on online ledgers and student token numbers were updated. Students were able to view their own digital token count as an assignment grade out of 8 points in Canvas.

Table 3: Exchanges offered through the token economy, their token cost, and their production schedule.

Exchange Description	*Token-Exchange Cost*	*Exchange Production Schedule*
Resubmitting 1 homework for the opportunity to regain 1/2 of all missed points	1 token	Up to maximum token count
Resubmitting 1 quiz for the opportunity to regain 1/2 of all missed points	1 token	One-time
Selecting 1 homework and dropping its score from final Homework grade calculation	2 tokens	One-time
Selecting 1 quiz and dropping its score from final Quiz grade calculation	2 tokens	One-time

SK and SRC demonstrated all stages of TE interaction and detailed their guidelines to students at the start of the course. These guidelines were also compiled into an online resource that students could view throughout the semester. Along with the TE guidelines, an example resubmission attempt was also provided (**Figure 1**) in the compiled online resource. This was done to highlight the goal-directed approach we wanted students to practice when revisiting problems where they set the ability to correctly identify error occurrences and explain how a proposed revision fixes the error as key outcomes.

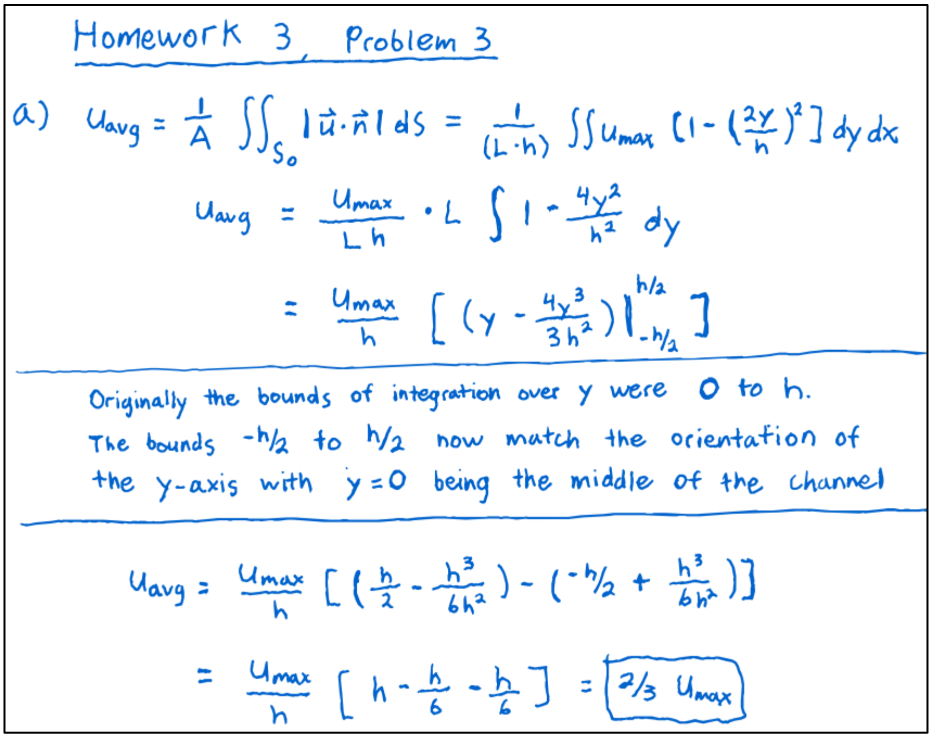

Figure 1: Example problem revision detailing the format that students would need to replicate in their assignment resubmissions if they purchased a resubmission exchange. The problem had to be fully reattempted alongside annotations from the student that described the error(s) made during the original attempt and how their revisions addressed the error(s).

Student surveys and token usage data

As part of their assessment for Class Engagement, students were asked to complete 2 surveys at the middle (Mid-Semester, MS) and at the end of the course (End-of-Semester, EoS) covering major topics of student time commitment to the course, effectiveness of course resources on student learning, effectiveness of co-instruction delivery on student learning, and interactions with the token economy. Sections of the EoS survey also mirrored the MS survey in question design allowing student opinions to be monitored in relation to course progression. Impacts of the token economy on the student class experience were qualitatively assessed using self-reported time commitments to the class, Likert questions related to the TE scaled 1 (strongly disagree) to 7 (strongly agree), and free response inputs from students on their TE interactions.

Token usage data detailing the exchange purchases made, completed token production events, and time of token transaction were gathered from each electronic form students generated as they engaged with the token economy. All surveys and electronic forms were created and distributed through Qualtrics.

RESULTS

Student engagement with the token economy

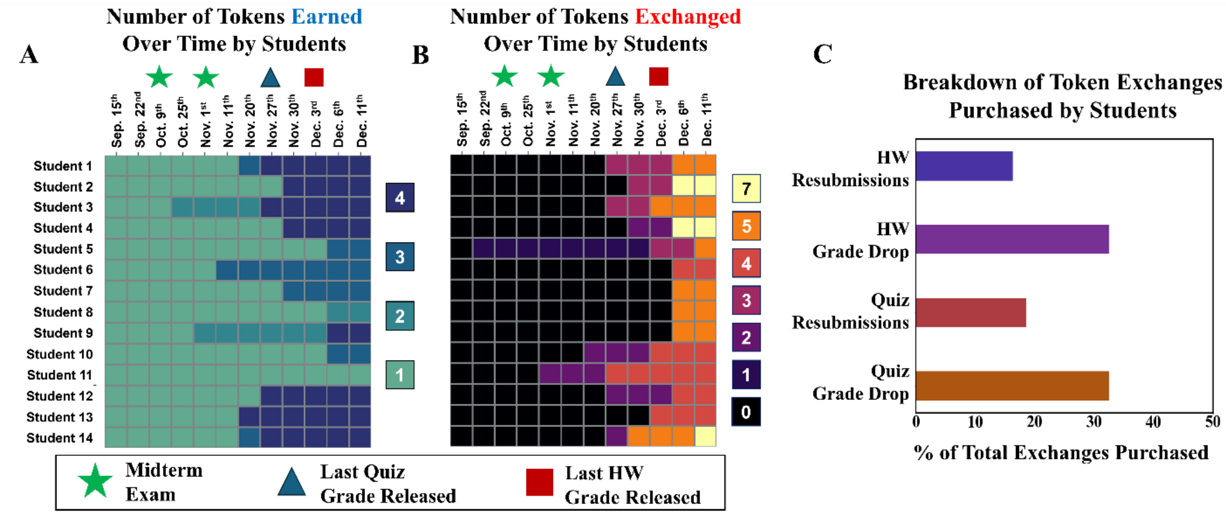

Figure 2: Individual and aggregated student activity in the TE. **A)** Heatmap tracking the number of tokens that students earned over the semester with each heatmap row representing 1 student's token-generating activity. The symbols above specific dates in the timeline represent when midterm exams were administered (green star), the last quiz grades were released (blue triangle), and the last homework grades were released (red square). **B)** Heatmap tracking the number of tokens that students exchanged to purchase TE rewards. Rows detailing each student's token-spending activity are matched and aligned with the heatmap rows in **2A. C)** Bar chart dissecting the component purchases making up all token exchanges performed by students during the semester (n = 43).

Table 4: Ledger of unique student counts for each completed token production event and token exchange purchase.

Token Production Event	***Students Who Declared Event Completion***
Signed team contract	14
Attended 18 lectures & participated in iClicker polls	13
Attended 27 lectures & participated in iClicker polls	10
Submitted 2 Writing Reflection assignments	9
Posted at least 2x to online discussion board	1
Token Exchange	***Students Who Purchased Exchange***
Homework resubmission to regain 1/2 of missed points	4
Quiz resubmission to regain 1/2 of missed points	8
Dropped 1 homework score from HW grade calculation	14
Dropped 1 quiz score from Quiz grade calculation	14

Token usage trends of individual students and their aggregated summaries are presented in **Figure 2** and **Table 4.** Using the number of tokens earned (**Figure 2A**) and exchanged (**Figure 2B**) over time as indicators of student activity in the TE, the lack of heatmap fluctuations prior to mid-October suggests that students did not engage in TE exchanges or report production events during the first half of the semester. The heatmaps only began fluctuating towards the end of the semester with high token production and exchanges occurring close to when students would have had full knowledge of all quiz grades and homework grades, Nov. 27th and Dec. 3rd, respectively. This token stockpiling behavior may have been influenced by the high proportion of one-time rewards in the exchange production schedule with no time restriction (**Table 3**). Multiple students also cited this factor when commenting on MS survey questions related to TE token usage that they wanted to "wait until they can use [tokens] the most effectively".

The aggregated exchange purchases performed through the TE (**Figure 2C & Table 4**) also align with this student approach of primarily using their tokens to maximize final grade benefits. Assignment grade drops for homework and quizzes were universally purchased by students and together make up nearly two-thirds of all completed token exchanges. As for resubmissions, more students purchased this exchange for a quiz than for homework. In their decision-making process when choosing between a homework and quiz resubmission, students may have calculated that the points recovered through a quiz resubmission purchase is more beneficial due to each quiz having a 3% contribution towards their final class grade compared to 1.9% contribution from each homework (**Table 1**). Interestingly, 3 out of the 4 students who purchased a homework resubmission ended up purchasing multiple homework resubmissions until their token balances were completely withdrawn. For this study however, the authors were not able to determine whether this homework resubmission trend was due to the student(s) being highly motivated to do all available practice opportunity or having poor homework assessments for the class.

The final trend in student TE engagement is the decreasing number of students completing token production events that were expected to be accomplished between the middle and end of the semester (**Table 4**). As token production events were only cataloged by the instructors when the student submitted an electronic form, it is difficult to conclude whether this trend suggests students did not reach the milestone or if the student lost track of what token production events to submit. Still, it could be said that online discussion posts may have had the lowest completion rate due to instructors being less involved in generating these opportunities compared to other Engagement activities. Despite losing potential tokens in undeclared token production events, 71% of students (n = 10) nevertheless agreed in their EoS surveys that they had acquired enough or more tokens to use for the exchanges they wanted to purchase (data not shown).

Influence of token economy on student motivation

A section in the EoS survey also posed statements to students that directly addressed whether the TE had or had not enhanced their motivation to attend lectures, earn tokens, and independently do assignment reattempts. Students were asked to rate each statement on a Likert scale based on how applicable the statements were to them. Mean Likert scores for each survey statement are listed in **Table 5** along with the proportion of students that agreed or strongly agreed with a statement.

Table 5: Student Likert responses on the token economy and motivation.

Statement Description	***Mean***	***St. Dev***	***Percent & Number of Agree (6) / Strongly Agree (7)***
I would have attended the same number of lectures as I did this semester if tokens were not awarded for class attendance.	6.00	2.1	78.6 % (n = 11)
The exchange rewards (assignment resubmissions, grade drops) motivated me to earn as many tokens as possible.	5.21	1.6	35.7% (n = 5)
I would have reattempted homework assignments or quizzes without having the token economy system reward me back a portion of missed points.	4.36	1.7	28.6% (n = 4)

The responses to the lecture attendance statement demonstrate that many students had the innate motivation to attend as many classes as possible during their learning experience even if the TE had not been implemented. This outcome also provides further context to the Likert scores surrounding the effectiveness of exchange rewards as motivators to acquire more tokens. While token-generating activities in this TE aligned with actions that students were already motivated to do, the lower Likert rating average and half the number of affirming opinions both point to the exchange rewards not providing enough purchase appeal for students to want more tokens. Input from one student in their additional comments referred back to this reward question and identified the homework resubmission as offering too few points back for the price of a token. This token-exchange pairing along with the TE exchange production schedule underline potential areas for enhancing the appeal of exchange rewards to better motivate token acquisition. The questionnaire responses involved with the TE enhancing motivation to perform assignment reattempts share a student response distribution that is similar to the exchange reward results. Compared to responses gathered for class attendance, it is apparent that fewer students were inclined to do assignment reattempts as a form of conceptual practice without the added reward of regaining lost points.

Perception of average time commitment to the class under a token economy

Any new implementation of a teaching strategy has the potential to also alter how students delegate their time to the class. In the TE, students may be faced with situations where token exchanges coincide with other class assignments, or they may have to manage their Engagement activities more closely to make sure they can complete a token production event. To evaluate how students perceive any added time commitments from TE participation, the MS and EoS surveys asked students to self-report their time commitment and evaluate how closely their actual time spent for the class matched their expected time commitment. The two surveys were then paired for each student to gauge any time commitment shifts students were experiencing as the course progressed. **Figure 3** presents the MS versus EoS question responses dealing with student time commitment. All but one of the participating students answered both surveys during the Fall 2023 semester.

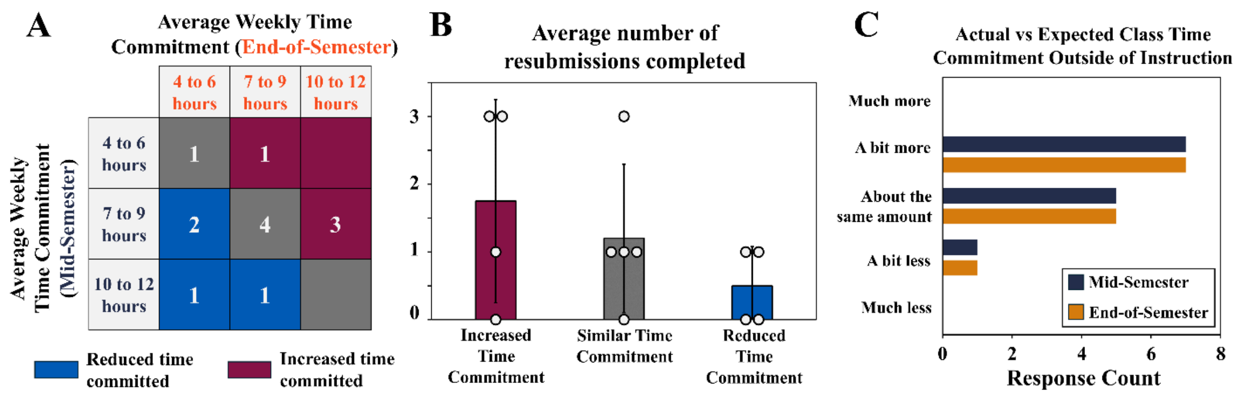

Figure 3: A) 2D histogram of student-reported average time commitments per week to the class outside of instruction (n = 13). Responses are compared between MS (navy blue) and EoS (orange) surveys. Histogram bin shading indicates if students experienced reduced (blue), similar (grey), or increased (red) time commitment as the semester progressed. **B)** The average number of resubmissions (homework and quiz) that students in each time commitment group completed. Data points of individual students in each group are also overlayed as filled circles to visualize their distribution (Increased, n = 4; Similar, n = 5; Reduced, n = 4). Error bars represent 1 standard deviation. **C)** Horizontal bar graph of how students characterized the difference between the average time per week they spent on the class and the average time per week that they expected to spend.

Figure 3A shows students distributed fairly evenly between experiencing reduced, similar, and increased time commitment to the class as the semester progressed. Based off the earlier token usage trends, the time range where one would expect the largest added time influence from the TE near the end of the course. Neither the MS or EoS survey had a question that addressed if the TE or qualities of the TE directly influenced how much time students delegated to the class; however, one measure that could be examined is the number of resubmissions completed by each student. This metric was chosen since resubmission purchases frequently occurred near the end of the semester, and they were the most time intensive activity that students would have done as a result of the TE. From **Figure 3B**, the group of students that experienced increased time commitment also completed on average more homework and quiz resubmissions through the TE; however, this difference is not significant. Overall, any time commitments that TE engagement added to what students delegated for the class does not appear to have drastically shifted total time commitment away from students' expectations. **Figure 3C** shows that despite the wide range of hours each student delegated most students felt that it was either the same amount or just over what they expected to set aside. This perception was also maintained as the semester continued.

The presence of the token economy on overall class learning experience

The EoS survey concluded with free response questions where students addressed whether having a TE in the course influenced how they attempted and prepared for assignments, their learning experience, and their opinions on extending TEs to other ChE classes. Excerpts of representative responses for each question are presented in **Table 6** and grouped by students acknowledging either perceivable or no effects.

Table 6: Short responses from students on the token economy and their learning experiences.

How, if at all, did the token economy influence how you approached or perceived homework problem sets during your first assignment attempt?	
Perceivable effect (n = 6)	No effect (n = 8)
• *"I felt like I had a buffer if I really couldn't figure out a homework. Kept me from taking the easy way out on assignments and motivated me to really learn how to do them."* • *"It was definitely a safety net when doing assignments… encouraged me to attempt the assignments first without worrying as much."*	• "*It had very little influence. I approached almost all assignments as if I was going to fail them if I did not do them.*" • *"I still treated each homework assignment as seriously as I would if I had no tokens available."*
How, if at all, did the token economy influence how you approached or perceived studying for quizzes?	
Perceivable effect (n = 2)	No effect (n = 12)
• *"It also made taking quizzes less stressful… It's reassuring to know that if you fumble one quiz you can still recover it."*	• *"I didn't find telling myself it was okay to not try on a quiz because I would just be able to drop it."* • *"I always still tried my best on quizzes with the hope that I would not have to use a token"*
How, if at all, did the token economy influence your learning experience in this course outside of homework and quizzes?	
Perceivable effect (n = 3)	No effect (n = 9)
• "*It made it a lot less stressful to complete the assignments and allowed me to devote more energy towards learning the concepts.*"	• "*I don't think the token economy influenced my learning experience outside of homework and quizzes because tokens weren't what motivated me to come to class.*"

As a majority of token exchanges were done near or after all midterms, quizzes, and homework were administered and graded (**Figure 2B**), it is not unexpected that a majority of students perceived no effect from the TE while attempting homework and studying for quizzes and exams. A factor that was not considered during TE design for this class was how this strategy would affect student stress. However, stress reduction was frequently mentioned across all the questions in **Table 6** when the student acknowledged that the TE had a perceived influence. This outcome was also observed by Gomez *et al.* 2020 after introducing a TE to promote in-class participation in an undergraduate human physiology course[17]. The authors attributed this effect to the TE offering students approaches for countering mistakes that would have otherwise irreversibly detracted from their academic performance, a concern that is frequently cited by students as contributing to anxiety and stress in their learning experiences[26]. Select students also elaborated that this stress reduction was helpful for them to individually learn how to apply concepts rather than submitting work that would simply earn them a high grade on assignments. One notable absence from all the student responses was the lack of commentary on the resubmission process itself and its goal-directed practice for reattempting assignments, which suggests that the TE did not reinforce this learning approach into students' regular study habits.

Although the majority of students did not report personally experiencing any influences on their learning experience from the TE, 79% (n = 11) would still recommend that the TE be extended to other ChE courses largely citing stress reduction as their reason (**Figure 4**). For the other 21%, their decision to not recommend the TE strategy highlights the major areas that this study's TE struggled with, specifically the exchange rewards and reinforcing the habits of mind that support student learning.

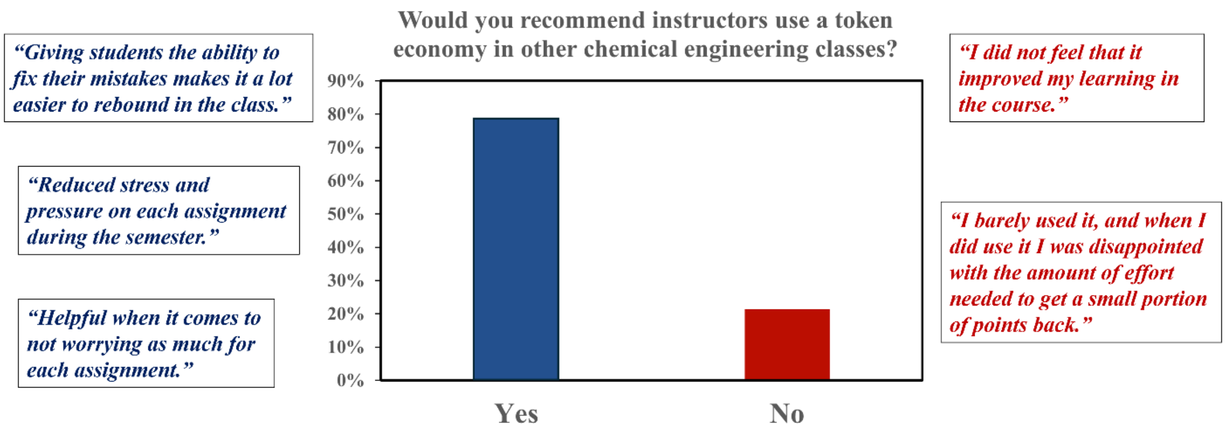

Figure 4: Final recommendation from students and their decision rationale on if the TE should be extended to other ChE classes.

DISCUSSION

Based off student token usage trends over time and the exchanges that were purchased, one can observe the unanticipated influence that token-exchange and exchange production design had on TE activity. This study's exchange production schedule of frequency-based restrictions, but no time limitations, encouraged students to accumulate tokens and wait to determine which assignment grades would benefit the most from token purchases. Although the homework resubmission had the least limitations around its purchase, the token-exchange reward was likely not impactful enough to a student's final homework grade to motivate its purchase and performing the associated task. This reward-to-motivate-purchase vulnerability also highlights an issue with only using the token exchange process to reinforce a behavior as students who do not see the appeal in an exchange will not initiate the token exchange process. In the case of quiz resubmissions where the token-exchange reward was more appealing to purchase, questionnaire results indicated that a TE motivated students to engage in the designed activity or behavior that they would otherwise not have attempted. A context to note however is that the question was posed to a group that included students who did not submit any resubmissions in the TE. Removing the questionnaire responses from those students marginally increases the Likert average (4.89), but the few agreeing opinions that remain (n = 3) do not offer a stronger trend of students being self-motivated to perform the resubmission practice without the TE.

Still, it is evident that if reattempting previous assignments was a desirable study habit for students to pick up through the TE, then the practice would have needed to occur multiple times over an extended period for stronger behavior reinforcement. One approach to increase the frequency of resubmission practice might be adding time limitations into the exchange production schedule that encourage students to react in a timelier manner to their graded assignments instead of holding onto tokens. An alternative direction could be having the resubmission practice be a part of the token generation process. To dissociate the requirement for a resubmission to be work already produced by the student, the instructor could use teaching techniques like worked examples that still allow students to practice identifying errors and explaining how their added revision fixed the error[27]. Token production through this worked example approach may also help alleviate the time demands of a course syllabus allowing instructors to distribute out problems that broaden concept contexts without giving students more homework and quizzes. Another perspective to utilize when promoting student engagement with this strategy might be viewing TE interactions through the lens of gamification. The point-tracking and rewards system used in the TE have frequently been the foundations of reported gamification designs, which were further supported by game attributes like achievement badges earned when students demonstrate some exemplary behavior to promote engagement with the gamified activity[28], [29]. Incorporating achievement badges or similar game attributes into the TE could then motivate students into participating as a way to affirm their competency with course material in addition to gaining more agency through the token-exchange rewards.

As for the holistic impacts that the TE had on the class experience, the activities added by the TE did not lead to major time commitment misalignments between what the student had to delegate for the class versus what they expected to delegate. This outcome though may have been influenced by students primarily interacting with the TE at the end of the semester. These limited interactions with the TE also caused the strategy to have little influence on how students actively approached completing homework assignments and studying for quizzes. However, the grade-altering actions provided by the TE gave some level of stress reduction to students as they were completing assignments with the knowledge that major mistakes on assignments could be alleviated through a resubmission or grade drop. This promising finding shows that TEs as an undergraduate classroom instruction strategy has influence beyond behavior reinforcement with the potential to emotionally support a student’s learning experience. If the exchange production schedule and token generation process are changed in the manners mentioned above, the TE could increase the amount of time students commit to the class and possibly even exceed student expectations, still this will have to be weighed with any added influence that the TE has on the student learning experience.

Implementing a token economy in your classroom

For instructors who envision using this strategy in their own ChE classes, it is highly encouraged that time be invested at the beginning of the course to explain and explicitly demonstrate how tokens are acquired, exchanged, and monitored in your TE. While a TE can be exercised with a physical token, a digital token and electronic transactions can help both the instructor and students keep track of their tokens, completed production events, and exchanges. To help determine what rewards will be appealing to students, a preliminary survey can be distributed to students asking students to select their top preferences from a list of possible rewards. When managing the token economy during the semester, the instructor or a member of the instruction team will need to regularly check (at least once a week) what students are requesting to best ensure that token counts are accurately displayed to the student. To minimize high intensity workload, an exchange production schedule with time restrictions will help distribute student purchases across a semester rather than all at one time.

Study limitations

The results of this study were collected under some limiting contexts. First, data sources for this investigation were confined to token usage metadata and surveys distributed by the instructor due to the study settings originally approved by the IRB. As a result, informed consent was not collected from participants to compile demographic data or assignment evaluations preventing their use in further contextualizing TE impacts on class performance. Similarly, participant recruitment was limited to students enrolled in Fall 2023 Transport Processes I and thus a suitable control population for the TE strategy was unavailable. Metrics for student time commitment and motivation from the MS and EoS surveys were self-reported by the student. Furthermore, student motivation was not directly measured using established tools like the Academic Self-Regulation Questionnaire, which would facilitate future investigations in assessing what areas of intrinsic and extrinsic motivation the TE interacts with.

FUTURE WORK

Further work with the TE could add summative assessment grades and student course evaluations distributed by University of Virgina to evaluate how student learning performance is influenced by TE engagement. Additional work could also investigate student token usage under the different exchange production schedule and a token generation process discussed in this study to evaluate how such TE alterations influence the student experience with this strategy. Student motivation under the TE could be more robustly measured with more dedicated questionnaire tools. Once TE schedules and survey tools are better refined, a future investigation could involve classrooms with and without TE strategies to assess if the TE improves students' academic performance.

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