A Study of Using Virtual Currency in a Discrete Mathematics Course

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***Abstract*—Effective gamification can only be based on understanding the relationship between learner motivation and the game elements which are used to gamify learning activities. Although frequently mentioned, Virtual Currency (VC) remains underused and scarcely studied in educational gamification. As a motivational affordance, VC can be thought of as supporting different types of motivation, but currently, there is a lack of empirical studies which investigate this. Recognizing this gap, the purpose of our study was to empirically investigate whether and how gamifying learning activities with virtual currency can engender motivation for out-of-class practicing and what type of motivation. In the limited research others have conducted, VC has been studied largely in combination with other game elements, which does not allow reaching reliable conclusions about the impact of the individual elements. For this reason, we studied the effects of VC in a gamified Discrete Math course isolated from other game elements. The study showed that using VC to gamify practicing increased students' practicing activity, which resulted in improved academic performance. The study also revealed that while gamified practicing did not increase students' intrinsic motivation, it supported internalization of motivation towards this learning activity.**

Keywords—Active learning, gamification, virtual currency, intrinsic motivation

I. INTRODUCTION

Gamification, defined as the use of game design elements in a non-game context [1], has become a widespread technological innovation in learning. In particular, gamification of learning refers to transforming learning activities to afford experiences similar to those afforded by games, with the goal of enhancing learners' engagement and motivation [1, 2, 3]. Gamification has been utilized in various learning settings where continuance and persistence are critical to the realization of the targeted outcomes. The common belief is that gameful experiences would support learner's motivation and thus sustain engagement with learning activities [2, 3, 4]. While many researchers believe that gamification has the potential to shape the motivation and engagement of learners (e.g. [3, 5, 6, 7]), there is insufficient empirical evidence supporting such beliefs as yet [5, 8, 9, 12].

Many of the educational gamification studies which have been conducted so far focus solely on learners' performance, e.g. grades [2, 8, 9], or on behavioral outcomes, such as time-on-task [8, 9, 10,11]. Notably, many of the gamification studies investigating different forms of engagement or learning performance have reported beneficial learning outcomes [8, 9], which led to optimistic conclusions with regard to the effects of gamification [8]. Motivation can be considered as an important intermediate variable in the relation between gamification and learning/behavioral outcomes. Nonetheless, the results from the studies do not allow conclusions to be drawn about how gamification has affected learners' motivation, and specifically, which gamification design features can lead to the motivational experience that gamification is believed to facilitate. Specifically, addressing the questions of if and how gamification can lead to increased motivation remains rarely studied to this day [3]. In particular, not enough is known about how the various game design elements affect the various dimensions of motivational experiences. This is partially a consequence of the fact that the majority of the studies focus on a small subset of game elements, such as points, badges, and leaderboards (the so called PBL triad) [2, 12]. As a result, the effect of game elements beyond the PBL triad on learning experiences were left underexplored. This gap was confirmed by a recent meta-analysis [13] concluding that there is much more potential in gamification beyond the prevalent PBL found in most applications. In an effort to contribute to bridging this gap, we conducted a study of gamifying students' out-of-class practicing in a Mathematics course with Virtual Currency (VC). As a gamification element, virtual currency typically stands for all kind of rewards which can be exchanged with virtual or real goods [14]. Although listed among the potential game elements [2], VC remains underused and scarcely studied in educational gamification research. Thus, conclusive evidence about the effectiveness of using virtual currency in learning contexts has yet to be produced.

The empirical work reported in this paper is grounded theoretically on Self-Determination Theory (SDT) which provides a framework for examining human motivation [15]. SDT postulates that the goal-directed behavior is triggered by two types of motivation: intrinsic motivation (making volitional choices while meeting one's needs of autonomy, competence, and relatedness) and extrinsic motivation (doing something for separable outcomes). Intrinsic motivation is observed when one engages in an activity out of genuine interest and is truly self-determined, in contrast with extrinsic motivation, where one acts for external incentives such as grades. Gamification research and practice, in general, underestimates the value of game elements facilitating extrinsic motivation [16, 17, 18] even though extrinsic motivation might be beneficial when the activity is not of inherent interest or value to learners. In reality, the initial goal of most learners is often extrinsic to the gamified activity, and thus, extrinsic motivation is what initially makes learners

choose to engage with it. However, the extrinsic motivation may become internalized, when an individual accepts the value or utility of a task and the extrinsic goal becomes self-endorsed and thus adopted with a sense of volition [15]. While SDT largely supports the superiority of intrinsic motivation, internalized extrinsic motivation can have some of the effects of intrinsic motivation [15, 19]. The engagement achieved through extrinsic motivation could serve as a mechanism to attract learners to discover the value of a targeted activity thus leading to internalized motivation. Maintaining internalized extrinsic motivation could be essential to sustaining learners' engagement.

In their meta-study, Huang et al [13] provide evidence that not all game elements have the same effect on student learning outcomes. This entails that it is important to have nuanced knowledge about which game design elements work under which circumstances. In particular, in order to foster the design of applications that effectively motivate and appeal to individual learners, we need to improve our understanding of the relationship between game elements, such as virtual currency, and the motivation that can emerge in learning activities gamified with them. However, motivation is a heterogeneous concept consisting of different motivation types, such as intrinsic motivation, extrinsic motivation, and internalized extrinsic motivation. As a motivational affordance, VC can be thought of as supporting these motivation types to varying degrees. Yet, as of now there is a lack of empirical studies investigating the effects of virtual currency on different types of motivation over time. Recognizing this gap, the purpose of the study we present here was to empirically investigate whether and how gamifying learning activities with virtual currency can engender motivation for out-of-class practicing. To this end, we addressed the following research questions:

RQ1: Does virtual currency encourage more active engagement in out-of-class practicing?

RQ2: Does virtual currency improve students' academic performance?

RQ3: Do gamified activities using virtual currency improve intrinsic motivation?

RQ4: Do gamified activities using virtual currency support internalization of extrinsic motivation?

In the next section we review the related work. The design of the study and the data collection process are described in Section 3, and the results of the experiment are reported in Section 4. In Section 5, we discuss the limitations of the study and Section 6 concludes the paper.

II. RELATED WORK

Various combinations of game elements have been used to gamify learning with the dominating popularity of points, badges and leaderboards. Notably, the scarcity of studies on the effectiveness of virtual currency in learning environments is disproportionate to the growing body of literature on gamification research in education [2]. The work that we are aware of and which is pertinent to the research questions is reviewed briefly in this section to contextualize our study.

Virtual currency was introduced in online games and adopted subsequently in gamified learning systems. O'Donovan's gamified course [20] is among the first examples demonstrating the use of VC, together with a storyline, badges and a leaderboard in a university-level gamified course. Although the study concludes that the in-game currency was very well received, its effect was not statistically confirmed. Another early attempt of using VC was Vassileva et al.'s study of the effects of adding VC along with some social motivators to a peer help system to incentivize learners to help their peers [21]. In such cases, where gamification is driven by several game elements, the isolation of the effect of individual elements is difficult.

In Classcraft [22], a role-playing environment developed for classroom management at the high school level, students can earn VC points and "powers" for proper classroom conduct and use the accumulated VC to "purchase" new accessories for their avatars or to obtain pets that they can train. In a similar fashion, a form of VC called "virtual credits" was introduced in UniCraft [23]. These credits were earned by engaging in a variety of class activities and could be spent in turn for equipping the participants' avatars. Although these environments utilize VC, we were unable to identify studies reporting its effect on learners.

Gamifying a Computer Science course with virtual currency (BitPoints) used together with levels and stars was proposed by Lopes [24]. BitPoints are earned for overcoming obstacles associated with challenges (practical assignment exercises) where the earned VC amount is proportional to the difficulty level of the challenges. The available BitPoints can be used for purchasing tools (to be used for solving other tasks) or information. Explicit evaluation of the VC impact on student learning has not been performed. An alternative kind of VC, in a form of coins, used in gamifying a Software Testing course [25] has been studied recently, but with inconclusive results. Outside of computing subjects, Munday [26] describes an application of Duolingo [27] in a college-level second language courses, where the Duolingo VC (lingots) were used together with points, streaks and crowns. Lingots were awarded for learning skills, going up levels, and long streaks (playing many days in a row) and can be used to unlock bonus skills, a timed-practice option, a progress quiz or power-ups. Another version of virtual currency, eCoins, was used in a Statistics course [28] in combination with levels, progress feedback, time pressure and pathways. The amount of eCoins awarded for a successful attempt is a function of the experience points and the difficulty level of the attempted task. The earned eCoins can be used to remove parts of a question or an entire question from an activity test set. Virtual currency, as a feature for enhancing engagement, has also been studied in a MOOC environment [29], where redeemable points were reported as the second most engaging gamification mechanic.

Outside educational institutions, the effect of VC has been studied in museum environments, e.g. to promote re-visiting a disaster museum [30] and in an online social platform aimed at fostering sustainable communities [31]. The first study yielded inconclusive results, while the second study following design-based research did not perform an adequate evaluation.

While empirical research requires examining research questions with statistical methods, the above studies, on the whole, provide anecdotal evidence based on observed results with subjective assessments and without adequate empirical evaluations. We are aware of two papers that report empirical studies on the effect of virtual currency on learning-related outcomes. The first is the work of Snow et al [32]. Their study utilizes students' process data to gain understanding of how in-game currency impacts in-system performance and learning outcomes in the context of a game-based learning

environment incorporated in a previously built Intelligent Tutoring System. The VC (iBucks) that students earn throughout their interactions with the environment can be used to unlock game-based features within the system. Students' propensity to use the VC as a way to engage with the game-based features was defined as their *spendency* (total points spent / total points earned). The study reveals that students who were more interested in spending their earned currency did not perform well and also had lower scores on the learned skills. These results also demonstrate the impact of the spending rules as they can act as distractors influencing goal prioritization. The second study was on the effect of VC (together with badges, leaderboard and progress feedback) on learners' engagement, performance and attitude in a Data Structures course [33]. In the gamified course, students earned and spent VC based on rules specified by the instructor. The earning rules were based on the amount, the level of difficulty, and the correctness of the solution of completed problem-solving exercises. Students could spend their VC on purchases of deadline extensions, resubmission of homework, etc. The idea behind this form of gamification economy was to stimulate students to practice more in order to achieve the course-defined learning outcomes by incentivizing them with purchasable course-related 'benefits'. The reported results of the study confirmed that the targeted motivational effect with the form of gamification employed was achieved but without isolating the motivational impact of VC.

The scarcity of studies on the effect of VC on learners behavioral or learning outcomes is perhaps due to two factors: its infrequent use and the more complex nature of this game element. The motivational effect of VC depends on both earning rules and spending rules. Earning rules typically specify the cost of obtaining a certain amount of VC in terms of effort, time, skills, or some other resources, while spending rules specify the rewards obtainable with the earned currency. If the perceived cost is too high, it may avert some learners from attempting to earn some currency. On the other hand, if the perceived value of the offered purchasable items is high it will make the earning of VC more desirable. Hence, the motivating effect of VC depends on the interplay of these two categories of rules. As a result, the questions of whether VC is effective at motivating learners and if so what type of motivation is driving learners engagement remains partly unresolved.

In the educational gamification research, VC has been studied largely as a combination of interacting elements, and, thus, a reliable conclusion about the effect of the separate elements is difficult to draw. Differing from previous works, the objective of our study was to shed more light on the effects of virtual currency by studying it isolated from other game elements and focusing on its motivational effects. In addition, the approach of isolating the motivational effect of earning and spending rules further differentiate our study from prior research on VC.

III. METHODOLOGY

In this section we outline the course and the tool with which the experiment was conducted. Then we describe the use of virtual currency along with the metrics we used to measure student activity, academic performance and motivation.

A. The Course

The course, Discrete Mathematics I, provides the theoretical base and support for computer science and includes operations on sets; Cartesian products and tuples; combinatorial objects; Venn diagrams; event spaces and basic probability; number systems; the statement calculus; rules of inference and validity of arguments; inductive proofs; the concept of an algorithm; equivalence relations; partial ordering relations; graphs and digraphs as relations; basic definitions and notations of functions; and recurrences for the analysis of algorithms. The formative assessment is in a form of 10 homework assignments, which are sets of problems given in McGraw-Hill Connect and are accessible via the Canvas Learning Management System. These assignments count for 20% of the course grade. There are three in-class tests and one take-home test. The average of the best three test scores contributes 50% of the course grade. The comprehensive final exam weighs 20% and class attendance/participation weighs 10%.

B. Participant Characteristics

Demographic information was collected electronically as part of the pre-test survey. Most participants were men (i.e., 70.8%), with 58.3% of participants majoring in computer science and 33.3% of participants majoring in mathematics. Most participants (i.e., 37.5%) were of junior-level academic standing, whereas 29.2% were freshman, 20.8% were sophomores, and 12.5% of participants were seniors. Over half of our sample were African American/Black (i.e., 54.2%), whereas 20.8% were European American/White and 4.2% were Mexican American/Hispanic/Latin American. About 80% of participants fell into the 18 – 25 age range.

C. The Tool

The Discrete Mathematics course was gamified by using the OneUp course gamification platform [34]. The platform is highly configurable and allows the instructor to turn on and off the supported gamification elements to map their preferences. The supported elements include experience points (XP), skill points, progress bar, avatars, leaderboard, skill board, badges, virtual currency, content unlocking, activity streaks, goal setting, challenge duels, callouts, learning dashboard, and chat. We have chosen to use virtual currency, as it is underused and scarcely studied in educational gamification research.

OneUp provides extensive built-in support for using Virtual Currency (VC). It enables the instructor to define rules for earning VC (earning rules) and rules for spending VC (spending rules). The *earning rules* are based on student performance in specified learning activities created for the course. These activities can be either automatically graded by the system, such as practice quizzes (called warm-up challenges) and graded course tests or quizzes (called serious challenges), or course-related activities, such as assignments, labs, projects, attendance, etc., which are not automatically graded and the instructor has to enter students' scores/grades for them. The instructor creates the VC earning rules in the OneUp interface by specifying the condition which has to be satisfied as well as the amount of virtual currency (course bucks) that will be given to a student who satisfies the condition. The condition can be quite complex, including a Boolean expression containing logical operations and quantifiers. An example of a rule is: *Give 2 course bucks to a*

student who takes at least 5 practice quizzes with a score >= 85%.

OneUp also supports time-based rules, which are checked at specified time intervals. When defining time-based periodic rules, the instructor has to specify the time period in which the system will check if the rule is satisfied, e.g. every week, every two weeks, once per month. Here is an example: *Give 4 course bucks to a student who takes at least 5 practice quizzes with a score >= 75% in one week.*

OneUp has a built-in game engine which is responsible for checking if the instructor-defined rules are satisfied. It does this when prompted by events such as 'student submits a practice quiz' or 'instructor enters a grade for a student for an activity'. When a rule is satisfied for a given student, the rule engine automatically gives the corresponding award, e.g. course bucks, to the student.

The *spending rules* describe how the students can spend the earned virtual currency. These are also defined by the instructor and reflect their "cashing" strategy. Typically, VC is spent for course-related benefits, such as extending a homework deadline, re-submitting of an assignment, excusing skipping of a class, awarding extra-credit points to a lab or homework, etc. It is left to the instructor to decide the nature and quantitative parameters of the rules. Clearly, the purchased benefits cannot be automatically fulfilled by the system. It is the instructor who "turns them into reality". The purchasable goods are displayed to the students, so that they know what they can 'buy' in the OneUp's *Course Shop*. To spend their virtual currency, the students go to the course shop, which functions as a traditional online shop. They choose the item (benefit) they want to buy and the desired quantity and submit their order. The system issues a receipt for the purchase (as a PDF file). Meanwhile, the system sends a notification to the instructor that a purchase has been performed and needs their attention. The system maintains the *status* of the purchases, starting from 'requested' (upon purchasing) to 'in progress' (when the instructor acknowledges seeing it and their intention to complete the requested action) to 'complete' (when the instructor acknowledges that they have completed the requested action). When changing the status of a purchase, the instructor can also send the student a message related to it.

The system supports a transaction log, where all earning and spending transactions are recorded. Thus the students and the instructor can inspect the flow of the VC.

D. Course Gamification

In the Discrete Mathematics course, OneUp was used to increase student practicing, motivated by the common belief that more intensive practicing enhances students' knowledge and improves their academic performance (grades). Accordingly, 33 warm-up challenges (practice quizzes) containing problems, similar to the test and final exam problems were created in OneUp. The warm-up challenges covered the following topics: Propositional logic (8), Sets, Sequences and Algorithms (9), Recurrence Relations (8), and Counting & Discrete Probability (8). The problems in the challenges, 73 altogether, were from 3 types: multiple choice problems (33), true/false problems (17), and dynamic problems (23). Note that dynamic problems actually generate many problems of the same kind. The dynamic problems in OneUp are problems for which the system does not contain 'canned' solutions entered by the instructor. These problems are actually short computer programs, which use a random seed to generate a unique instance of a particular programming or calculating problem and then grade the correctness of the answer submitted for that problem [34]. An example of a dynamic problem in the Discrete Mathematics course is "Calculate the value of the given expression in the truth table below where T is for true and F is for false". In this dynamic problem, the expression is generated dynamically, thus each time the student selects the problem a different expression will be displayed,

For gamifying the course, only one game element was used, virtual currency, since our goal was to study the impact of this particular element alone. To this end, 6 rules were created for earning virtual currency, and 5, for spending the earned currency. By completing challenges students could earn up to 76 course bucks. They could use their course bucks to buy a limited number of points to be added to selected test scores, make-ups of some test problems, and some deadline extensions for homework sets. The VC earning and spending rules created by the instructor are given in Tables 1 and 2.

TABLE I. RULES FOR EARNING VC

Condition	VC
First taking of a warmup challenge with a score > 70%	10
Taking a new warmup challenge with a score >= 70%	1
Max score of a warm-up challenge taken multiple times >= 90%	1
Completion of the first 5 distinct warm-up challenges with a score >= 75%	2
Completion of the first 10 distinct warm-up challenges with a score >= 75%	2
Bonus bucks earned in an activity in class	Varies

TABLE II. COURSE SHOP

Item	VC	Limit
7 points to be added to a test score (max test score 150)	10	3
Make-up of two test problems (no later than one week after posting the test grade)	5	2
5-day extension of a homework set deadline	3	5
Drop of the lowest homework score	10	1
An excuse for a class absence	5	6

E. Research Methods

Our study was a quasi-experiment [41]: we used the fall 2019 class (19 students) as a control group and the spring 2020 class (21 students) as an experimental group. The same instructor taught both classes using the same instructional materials, teaching methodology, and student assessment. Both groups used the OneUp platform for out-of-class learning and practicing, but for the control group all gamification features were disabled, while for the experimental group the Virtual Currency feature was enabled. All participating students in both groups signed an Informed Consent Form to participate in the study.

To answer the research questions we used three complimentary methods. For the first research question (RQ1), we used the OneUp system log to extract data for tracking student visits to the gamification-related pages, how many practice quizzes they have completed, etc. To evaluate the impact of gamifying the course on students' academic performance (research question RQ2), we compared the final course grades of the control group and the experimental group. To answer the third research question (RQ3), we conducted a motivational survey with the experimental group. The survey was a modified version of the Basic Psychological Needs

Satisfaction Scale – Work Domain [36]. This 21-item scale was chosen because there is considerable research linking elements of Self-Determination Theory to basic psychological needs, i.e., Autonomy, Competence, and Relatedness ([36, 37, 38]). For the current study, we hypothesized that these basic psychological needs applied to work completed in the classroom domain, so the Likert-type scale items ranging from 1 (not at all true) to 7 (very true) were slightly modified to represent work being done in the classroom as opposed to the career setting, e.g., "I feel like I can make a lot of inputs regarding how my classwork gets done" vs. "I feel like I can make a lot of inputs regarding how my job gets done".

IV. RESULTS

A. *Student Engagement in Out-of-class Practicing*

To answer the first research question, whether the use of virtual currency encourages more active engagement in out-of-class practicing, we extracted data from the OneUp system log. In this section, we report statistics on use of virtual currency by the students in the experimental group and also compare the use of OneUp as a platform for out-of-class practicing by the students in both the control and the experimental groups.

1) Virtual Currency Use

During the course, 554 VC earning transactions were recorded with a total of 807 virtual bucks earned. Each VC earning transaction was a result of satisfying a particular VC earning rule as defined by the instructor (see Table I). Fig. 1 shows the distribution of transactions by students. The students with only 1 transaction (17%) actually did not practice in OneUp, they earned 5 course bucks for participating in a class activity. Thus, we can see that from the real users of OneUp, the majority have more than 20 VC earning transactions, with 26% of the students having more than 40 transactions. The virtual bucks actually earned are shown on Fig. 2. The maximum amount that can be earned for the semester is 76 virtual bucks. As we can see, about 35% of the students have earned more than 51 virtual bucks, which shows considerable engagement.

Fig. 3 shows the distribution of the VC earning transactions by category (VC rules). As can be seen, students earned most of their VC for submitting a solution 90% correct or better for a warm-up challenge, possibly taken multiple times (55%), followed by taking a new warm-up challenge with a score >= 70% (34%). Notably, the most virtual currency was received for achieving a max score of 90% or greater on a warm-up challenge taken multiple times. This demonstrates the persistence of the students to keep re-taking some warm-up challenges until they get them correct. The remaining transactions include taking the very first warm-up challenge with a score > 60%, completion of the first 5 distinct warm-up challenges with a score >= 75%, completion of the first 10 distinct warm-up challenges with a score >= 75%, and bonus bucks for participating in an activity in class.

When we consider the spending of the earned virtual currency, students have made 46 purchases in the Course Shop (see Table II), spending 487 virtual bucks in total. Fig. 4 shows the VC spending transactions and Fig. 5, the virtual bucks spent by students. It is interesting that about one third of the students who earned virtual currency have not made any purchase in the shop. This may be due to various reasons including:

- The student didn't manage to earn enough course bucks to purchase a desired item.
- The student collected bucks with the intention of making purchases at the end of the course, but then realized that they didn't need any of the offered course benefits.
- The student withdrew from the course after March, when the course was converted to an online course because of the Covid-19 pandemic.

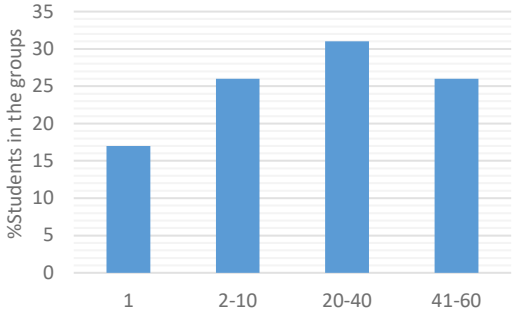

Fig. 1. Completed VC Earning Transactions by Students.

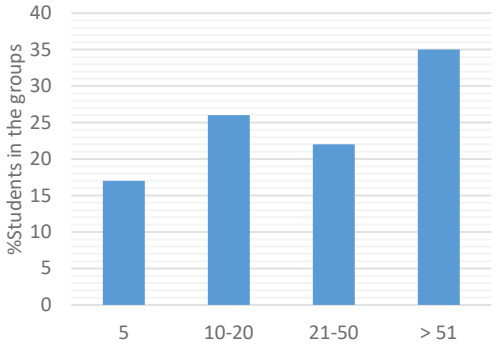

Fig. 2. Earned Virtual bucks by Students.

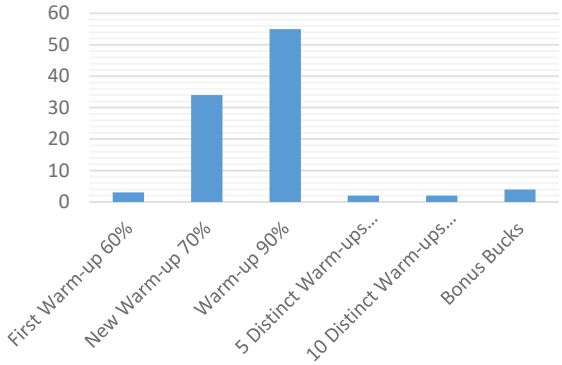

Fig. 3. Completed VC Earning Transactions by Category.

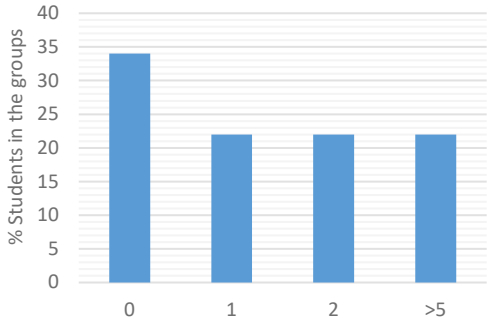

Fig.4. VC Spending Transactions by Students.

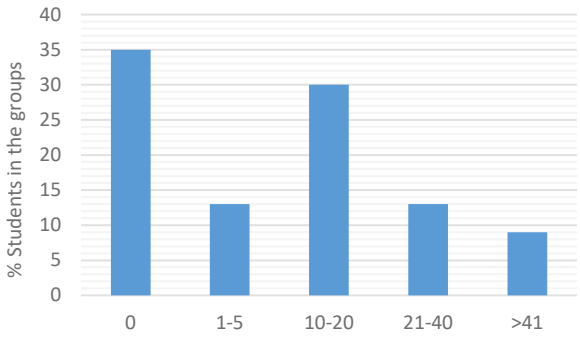

Fig. 5. Spent Virtual bucks by Students.

Approximately the same number of students (22%) made 1, 2, and more than 5 transactions (Fig. 4). Fig. 6 depicts the distribution of the students' spending transactions by category. This distribution shows that students' favorite was buying extra credit points for a test (they were allowed to buy a maximum of 7 points for a test with a total of 150 possible points). The next was buying an extension for a homework deadline, followed by allowing a retake of two test problems. Concerning the reasons for spending VC (as reported by students at the time of completing a purchase), 27% selected that they did it because they were busy and could benefit from some extra time, 22% - because they had a good quantity of VC and wanted to spend some, 18% - because they worried about their performance in this course, and 33% preferred not to say the reason. Fig. 7 shows the remaining balance of the students.

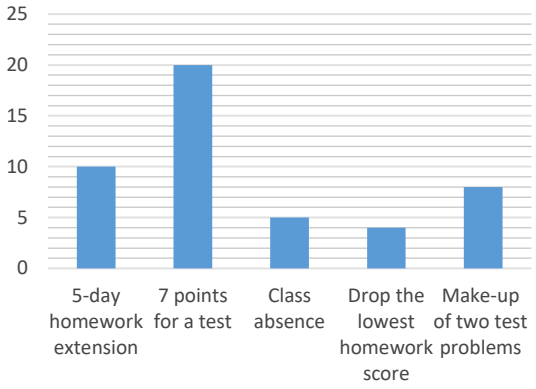

Fig. 6. Spent Transactions by Category.

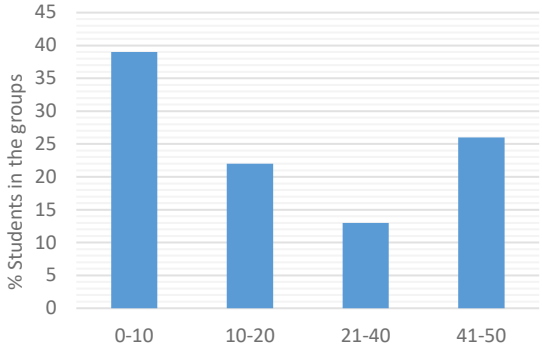

Fig. 7. Remaining balance (not spent virtual bucks) by Students.

2) Taking Practice Tests

The control group (Fall 2019) took 242 unique warm-up challenges with a total of 507 attempts, while the experimental group (Spring 2020) took 343 unique warm-up challenges with a total of 746 attempts. This shows that adding the gamification features increased the unique warm-up challenges taken by around 50%. Fig. 8 shows the percent of students who have taken between 1-10, 11-20, and 21-40 unique challenges in both groups. It can be seen that that the majority of the students in the control group (56%) have taken between 11 and 20 unique challenges, while the majority of the experimental group (47%) have taken between 21 and 40 challenges, with half of them – more than 30 challenges. Considering the total number of challenges taken, we observe the same tendency. As Fig. 9 shows, while the majority of students in the control group fall in the intervals of 11-30 (44%) and 31-50 (50%) challenges taken, the experimental group students are in the intervals 31-50 (26%) and 51-170 (27%). There were no students from the control group with more than 50 warm-up attempts. The average number of warm-up challenge attempts for the control group was 28.16, while for the experimental group it was 39.26.

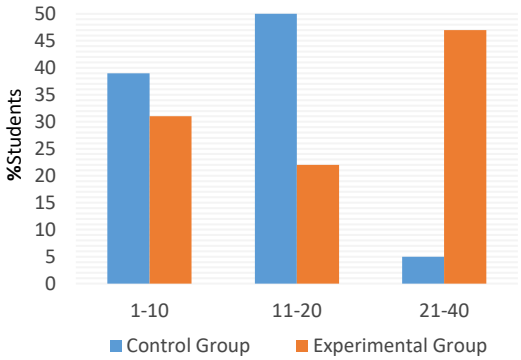

Fig. 8. Distinct warm-up challenges taken.

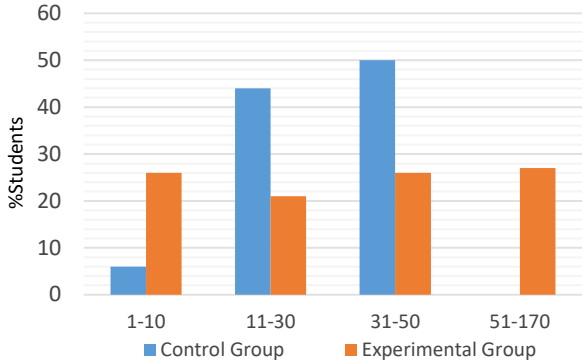

Fig. 9. Warm-up challenges attempts.

Although we see an improvement in the students' engagement with practicing, we expected a more pronounced difference between the warm-ups challenges taken by the control and the experimental groups, since we have observed such a phenomenon in other gamified courses. Our explanation for this is the change of the course to an on-line mode in the middle of the semester due to the Covid-19 pandemic, which impacted the normal instructional process.

B. Student Performance

To compare the level of knowledge in discrete mathematics of the incoming students in the control and experimental groups, we gave the same entry test in both groups in the beginning of the semester. 74% of the students in the control group and 81% of the students in the experimental group took the test. Although the picture is not complete, since not all students took the pre-test, the results are comparable: the mean score for the control group is 70.71,

while the mean score for the experimental group is 73.82. The test grade distribution for both groups are given in Fig. 10.

In assessing the impact of introducing virtual currency on student performance, we chose to compare not only the final course grades of the students but also their grades on Test 2. The reason was that while all tests for the control group (Fall 2019) were administered in class, the same was not true for the experimental group. Due to the COVID 19 epidemic, the class in the spring semester was switched to an online format in March 2020 and only the first two tests were administered in class. Thus, in order to obtain results under similar conditions, we decided to compare the grades on the second test in addition to the final course grades of both groups.

The grade distribution for Test 2 of the control group (Fall 2019) and the experimental group (Spring 2020) are shown in Fig. 11. The mean score of the test grades is 78.68 for the control group and 81.67 for the experimental group. The final course grade distribution for both groups is presented in Fig. 12. The mean score of the final grades is 82.37 for the control group and 85.53 for the experimental group. The mean scores, as well as the grade distributions for Test 2 and the Final Grades are fairly similar for both groups, which indicates that the transition to the online format of the course for the experimental group didn't have a significant impact on the students' performance, which would have been a threat to the validity of the study.

The experimental group has consistently higher mean scores on the second test and on the course grades. The differences between the mean scores are 2.99 and 3.16, correspondingly. As the graphs show, there is a significant increase of the number of As for the experimental group in both Test 2 and Final course grades. It is also noticeable that for the experimental group, there is a significant decrease in the Ds and Fs in the final grades in comparison to Test 2 grades. This could also be attributed to the more intensive use of OneUp in the second half of the semester.

The results in Sections IV.A.2 and IV.B positively confirm RQ1 and RQ2.

C. *Motivational Survey*

A series of exploratory analyses were conducted to respond to RQ3 and RQ4. Because Self-Determination Theory [39] posits that satisfaction in all three domains of psychological need (i.e., autonomy, competence, and relatedness) is related to enhanced intrinsic motivation, the first set of analyses centered on exploring pre- to post-test differences in autonomy, competence, and relatedness as measured by the Basic Psychological Needs scale [40,41,42]. The second set of analyses were designed to elucidate a relationship between academic performance as measured by participants' grades and participants' task-specific activity perceptions as measured by the Intrinsic Motivation Inventory (IMI) [43]. Factors of the IMI were drawn for the current study because they are directly related to intrinsic motivation (i.e., Interest/Enjoyment and Perceived Choice) or to internalization of motivation (i.e., Value/Usefulness). All analyses discussed in this section were conducted using IBM SPSS Statistics for Windows, Version 25 [44].

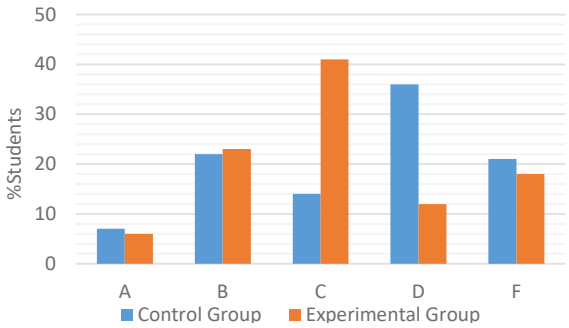

Fig. 10. Pre-test Grade Distribution.

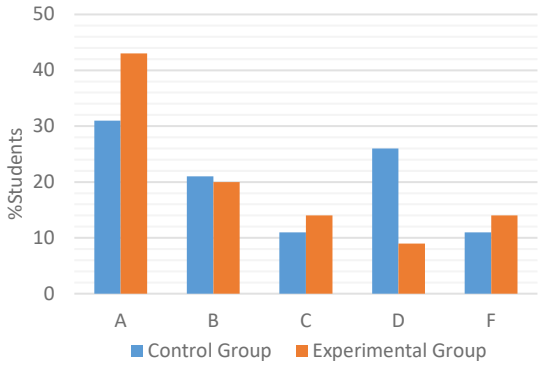

Fig. 11. Test 2 Grade Distribution.

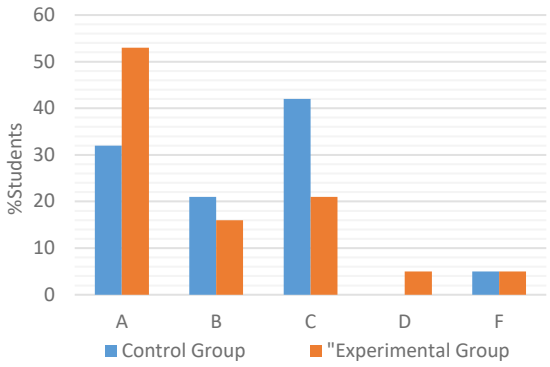

Fig. 12. Final Course Grade Distribution.

A paired-samples t-test was conducted to answer research question RQ3 and to explore potential pre- to post-test differences in participants' autonomy, competence, and relatedness. The original pre-test dataset included 24 participants and the original post-test dataset included 22 participants. Due to participant attrition from the fall of 2019 to the spring of 2020, 17 participants' data matched for the analysis.

Participants demonstrated no significant pre- to post-test effects for Autonomy, Competence, nor Relatedness (see Table 3).

TABLE III. PAIRED-SAMPLES T-TEST EXPLORING AUTONOMY, COMPETENCE, AND RELATEDNESS.

Dependent Variables	**Pre-Test**		**Post-Test**		**t**
	M	SD	M	SD	
Autonomy	4.7	.53	4.96	.73	1.18
Competence	5.04	.76	4.83	.72	1.25
Relatedness	4.22	.72	4.26	.88	.69

*$p<.05$, $N=17$

However, the factor-level means scores for autonomy, competence, and relatedness indicated that participants came to the study with strong ratings in these domains and those strong ratings remained stable from pre- to post-test. These durable rather than malleable intrinsic motivation markers demonstrate that introducing VC as a gamification element did not significantly alter participants' basic psychological needs.

To answer RQ4 "Do gamified activities using virtual currency support internalization of extrinsic motivation?" the current study explored relationships between participants' final course grades and intrinsic motivation as measured by three factors of the Intrinsic Motivation Inventory - Value/Usefulness, Interest/Enjoyment, and Perceived Choice [45]. A stepwise regression analysis was conducted to determine which of these IMI factors predicted participants' final course grades. Thus, the independent variables (i.e., predictor variables) for this regression model were Value/Usefulness, Interest/Enjoyment, and Perceived Choice and the dependent variable (i.e., outcome variable) was the participant's final course grade. Because participants' final course grades were collected in letterform, integer coding was applied to transpose the letter grades into numerical scores (i.e., A, B, and C was recoded into 1, 2, and 3). As seen in Table 4, Value/Usefulness emerged as a significant predictor of participants' final course grades, whereas Interest/ Enjoyment and Perceived Choice were excluded from the final model. For our participants, the final model of the stepwise regression was significant and accounted for 32% of the variance in grades.

TABLE IV. FINAL MODEL FOR STEPWISE REGRESSION OF VALUE/USEFULNESS, INTEREST/ENJOYMENT, AND PERCEIVED CHOICE (PREDICTOR VARIABLES) ON FINAL COURSE GRADES (OUTCOME VARIABLE).

Predictor Variables	**Zero-order correlation with grades**	**Beta**	***T***	***p***
Value/Usefulness	-.56	-.33	5.08	.00*
Interest/Enjoyment[e]	-.40	.08	.25	.81
Perceived Choice[e]	-.49	-.32	-1.41	.18

Model $F(15) = 6.9$, $p < .05$
$r^2 = .32$; Adjusted $r^2 = .27$
Note: [e] Variable excluded from the final stepwise regression model; $*p < .05$

The finding that the Value/Usefulness factor explained 32% of the final course grades variance indicates that participants found the task at hand to be of value. That value assessment of the task seems to be related to processes inherent to extrinsic motivation's internalization. For instance, previous research suggests that interest and self-relevance are associated with increased internalization of extrinsic motivation [45]. This explains the fact that the Interest/ Enjoyment and Perceived Choice factors of the IMI linked with intrinsic motivation in the literature [46] were excluded from the final regression model. All these taken together provide a positive answer to RQ4. It is also in line with the finding of Zeng et al [47] that reward-based and recognition-based gamified elements were associated with extrinsic motivation improvements and were also implicated in motivation internalization.

V. LIMITATIONS

As with many experiments, our study has some limitations, indicating need for a more critical look at the data and the results of the analyses discussed above. As a result of the pandemic, the teaching mode in the second part of the Spring 2020 semester (for the experimental group) was switched from face-to-face to online. While this transition to online teaching may have impacted some learners, the targeted learning activity (out-of-class practicing) was not different in any aspect for both groups. We also excluded from consideration the students from the experimental group who withdrew from the course in the second half. To address further this limitation, in assessing the impact of introducing virtual currency on student performance, we chose to compare not only the final course grades of the students but also their grades on Test 2, which was taken in the same conditions (face-to-face) for both groups, the control group (Fall 2019) and the experimental group (Spring 2021). We compared the mean scores, as well as the grade distributions for Test 2 and the final course grades and the results were fairly similar, which indicates that the transition to the online format of the course for the experimental group didn't have a significant impact on the students' performance.

The sample size in this experiment is another potential limitation of the study. However, since the present study is a part of a longitudinal investigation examining learners' behaviors toward using virtual currency and exploring the relation of such behaviors with learner motivation, this limitation is tolerable. Ultimately, the reported results will be incorporated and interpreted relative to the findings from forthcoming studies.

VI. CONCLUSION

Previous gamification research mostly centers on the PBL triad or other combinations of gamification elements and how they boost students' task-specific learning outcomes. Differently, this investigation focused on parsing out the unique impact of a single gamification element, virtual currency, on students' learning. Moreover, past empirical studies mainly focused on evaluating the acceptance of specific gamified learning prototypes or measuring the effect of gamification on particular learning outcomes, while its effects on intrinsic motivation and internalization of motivation towards learning activities were rarely evaluated. Thus, the extent to which gamification can be used to reinforce different types of motivation in learning contexts remains uncertain. With the aim of bridging this gap, our gamification experiment used virtual currency, expecting it to play a role of a psychological factor [48] linking the gameful experience to some perceived benefits of practicing. Since in this implementation earning virtual currency evokes perception of benefits with positive impact on course outcomes, it is more extrinsic in nature. Still, extrinsic motivation can be beneficial in some situations where it can be seen as a process towards developing intrinsic motivation [49].

This study showed that gamifying practicing with VC increased students' practicing activity, which resulted in improved academic performance. On the other hand, the study revealed that gamified practicing did not increase students' intrinsic motivation, which can be interpreted as meaning that VC was not making the practicing activity more enjoyable or more interesting compared to the corresponding pretest perceptions. More interestingly, our analyses revealed that the Value/Usefulness factor explained 32% of the final course grade variance. This finding is in line with the internalization process incorporated in the Self Determination Theory. The Value/Usefulness subscale is widely used in internalization

studies, the premise being that people internalize and become self-regulating for activities that they perceive or experience as useful or valuable for themselves [43]. Additional supportive evidence for potential internalization derives from our performance measurements showing that incorporating VC resulted in improved measurable outcomes. As the inclusion of VC did not affect intrinsic motivation significantly, we conclude that these improvements are caused by perceived benefits associated with earning VC. This suggests in turn that gamifying the practicing activity enabled learners to recognize its value which further backs the finding demonstrating the relations between Value/Usefulness of the activity and internalizing motivational drivers.

While the use of VC as a gamification element is not new, its motivational effect on learners is not sufficiently understood. Considering the complex person-environmental factors associated with motivational studies, the series of studies detailed here were well-situated to better understand the conditions by which intrinsic motivation is either improved or diminished in a gamified context.

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