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An examination of undergraduate students' problem-posing and its interaction with problem-solving processes

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ABSTRACT

This paper presents the findings of a study involving 16 undergraduate students enrolled in a basic financial mathematics course. The study aimed to examine the nature of the students' problem-posing and problem-solving products and processes, as well as the interactions between the two. The findings revealed that the majority of the posed problems were valid but closely resembled the problems encountered in class. While most students modified multiple elements in the initial problems, these modifications were mainly cosmetic, such as changing numeric values. The modified problems could be solved by following the solutions used for the initial problems. Additionally, students' problem-posing and problem-solving processes interacted in numerous mutually beneficial ways. For instance, during problem-posing, students utilized their problem-solving skills to enhance the quality of their problems. Similarly, the students established deep and valid connections between various mathematical concepts learned and discovered potential limitations in their knowledge.

Keywords: problem-posing, problem-solving, interaction, undergraduate problem-posing

INTRODUCTION

Mathematical problem-posing involves creating new mathematical problems in specific situations and reformulating existing ones during problem-solving (Silver, 1994; Stoyanova & Ellerton, 1996). Although definitions of problem-solving vary in the mathematics education literature, the most widely accepted definition is that it involves solving a task for which the solver does not initially know the solution strategy, either partially or fully (Keleş & Yazgan, 2021). Therefore, in problem-solving, the objective is to find the solution to a problem, while in problem-posing, the objective is to create a problem for others to solve.

Researchers in mathematical problem-posing have shown that engaging students in this activity benefits their mathematics learning in several ways. These benefits include promoting positive attitudes toward mathematics (Akay & Boz, 2010), enhancing mathematical creativity (Van Harpen & Sriraman, 2013), improving mathematics achievement (Demir, 2005), increasing metacognition during task solving (Akben, 2020; Geteregechi, 2023), and enhancing general problem-solving skills (Cifarelli & Sevim, 2015). Motivated by these advantages, mathematics education researchers (e.g., Ellerton, 2013) and educational organizations (e.g., National Council of Teachers of Mathematics [NCTM], 2000) have advocated for including problem-posing activities in the mathematics curriculum at all levels. However, despite these calls, studies (e.g., Xie & Masingila, 2017) indicate that problem-posing is still rarely integrated into the mathematics curriculum. Instead, problem-solving activities remain the predominant focus, even though research shows that students are capable of generating meaningful and significant mathematical problems (Leung, 2013).

There are two main reasons for the slow permeation of problem-posing into the mathematics curriculum. First, there is limited understanding of the finer details of how students pose mathematics problems in specific situations, such as when they modify existing problems (Cai et al., 2015). This is the case especially among higher education students. While the literature has highlighted certain general problem-posing strategies such as constraint manipulation, goal manipulation, chaining, among others, there is limited research on how these strategies impact the students' posed problems. For example, a student may manipulate the constraints of a given problem in a way that renders the problem unsolvable or senseless. Students' awareness of this possibility can provide useful insights into the student's understanding of the involved mathematics concepts.

Second, while a lot of research indicates that there is a positive correlation between problem-posing and solving (e.g., Demir, 2005), there is limited research on the nature and reasons behind this relationship. This is mainly because most of the studies on the interactions between problem-posing and solving use quantitative approaches (Xie & Masingila, 2017) which makes it difficult to answer the question of "what actually happens" (p. 114) during the process. Therefore, this study uses mainly qualitative approaches to examine the nature of students' problem-posing products and processes and how those processes interact with their problem-solving. Specifically, I sought to answer the following questions:

1. What kinds of modifications do undergraduate students make on existing problems when posing new problems?
2. How do these modifications influence the nature of their problem-posing products?
3. In what ways do undergraduate students' problem-posing and problem-solving processes interact?

RELATED LITERATURE

Problem-posing task situations

Stoyanova and Ellerton (1996) developed a broad framework describing situations in which problem-posing occurs. These include:

(1) free problem-posing, where one is asked to generate new problems without any conditions or constraints on mathematical content,

(2) structured situation, where one is given a starting problem to modify in order to pose new problems, and

(3) semi-structured, where one is given a limited set of conditions such as a topic but does not provide a starting problem.

For educational purposes, most problem-posing occurs within a structured or semi-structured situation and hence much research on problem-posing is based on these situations (Voica & Singer, 2013).

To contextualize the discussion of the kinds of modifications that one can make on a problem, it is important to consider the elements of a mathematical problem. According to Singer and Voica (2013), a mathematical problem, in general, contains the background theme, parameters, data, operating schemes, and constraints.

The background theme sets the general context of a problem. In finance, for instance, a common background theme could be acquiring a mortgage. Parameters are attributes that provide more specific details about the background theme. Examples of parameters include the interest rate and loan amount. The numerical or literal values assigned to these parameters are referred to as data, such as an interest rate of 19.99%.

Operating schemes describe the actions suggested by a problem. These actions, which may be either implicit or explicit, include mathematical operations (e.g., addition and multiplication) and specific actions (e.g., "draw," "plot," and "compute").

Constraints are restrictions placed on the elements of a problem to maintain its structure or identity. These can be implicit or explicit. Different problems may share the same elements (background theme, parameters, and operating schemes) but differ in their constraints. For example, two problems might have the same loan period, initial balance, and interest rate, but one could apply the interest monthly while the other applies it daily.

One way to characterize the nature of student-posed problems in a structured setting is to examine the kinds of modifications made to the above elements. The various elements in a mathematical problem play specific roles and are not assigned arbitrarily. Singer et al. (2011) described the structure of mathematical problems in terms of their coherence and consistency. A coherent problem provides all necessary elements in a manner that fulfils their specific roles while having no redundancies or ambiguities in its data. A consistent problem has elements that are appropriately correlated, data that are noncontradictory, and at least one solution (or proof of non-existence of one) that assumes some mathematical model. It should be noted that it is possible for a problem to be consistent but not coherent and vice versa. In this study, we assessed the nature of student-posed problems in terms of their coherence/consistence as well as similarity to the initial problems (i.e., the problems that the students modified).

Previous studies (e.g., Cai et al., 2015; Daher & Anabousy, 2018; Xie & Masingila, 2017) have indicated that when students pose mathematics problems in structured settings, they often create problems very similar to the initial ones. Consequently, these problems score low on measures of creativity, cognitive flexibility, and complexity. The studies identified several reasons for this, including a lack of exposure to diverse problem-posing strategies, a focus on single elements (e.g., data or background theme) rather than a combination of elements, and limited mathematical knowledge and problem-solving skills. Although most of these studies provided students with opportunities to practice various problem-posing strategies such as the What-If-Not strategy, the students did not explicitly examine the elements of a mathematical problem and their roles in its structure. Since problem-posing is not typically taught in school, a focus on strategies alone does not give the students a complete picture of problem-posing. Thus, the current study provided opportunities for students to practice with various problem-posing strategies as well as examine the elements of mathematical problems and their role in the structure of a problem.

Relationship Between Problem-posing and Problem-Solving

Most researchers examining the relationship between problem-posing and problem-solving have reported that the two skills are positively associated. For example, Cahyani et al. (2020) conducted an experimental study involving 40 high school students to examine the effect of problem-posing learning on the students' problem-solving abilities. The findings indicated that students in the experiment group performed significantly better on problem-solving than their counterparts in the control group. Similarly, in another study involving 92 fifth grade students in a problem-posing experiment, Chang et al. (2012) reported that low performing students in the experimental group showed significantly higher problem-solving performance than their counterparts in the control group. Similar findings to these have been reported by other studies (Chen et al., 2015; Sadak et al., 2022; Zhang et al., 2022). A notable trend among these studies is that they involved K-12 students or preservice teachers and relied on quantitative (experimental) approaches for the most part. While such studies have provided useful insights into the relationship between problem-posing and solving, their reliance on largely quantitative measures makes it difficult to examine the “nature and features of the relationship” (Xie & Masingila, 2017 p. 102).

There have been a few qualitative studies whose findings provide insights into the nature and features of the relationship between problem-posing and solving. For example, Parhizgar et al. (2021) used problem-posing to investigate high school students’ understanding and misconceptions on the concept of a function. The findings of this study indicated that by engaging in problem-posing, students reflected on the function concept hence leading to deeper understanding and performance on problem-solving. Xie and Masingila (2017) examined the interactions between problem-solving and posing among preservice teachers enrolled in a problem-solving course. Findings of this study indicated that the preservice teachers relied on various aspects of their problem-solving skills to pose better problems and vice versa. For example, by attempting solutions to their posed problems, the preservice teachers were able to ensure that their posed problems were actually solvable and of varying difficulty. Similarly, students reflected on their prior knowledge and identified gaps in their own learning. This helped them acquire new knowledge and be able to solve even more complex problems. While these studies have contributed meaningfully to our understanding of the nature of the relationship between problem-posing and solving, much is still unknown about this relationship especially among college students not enrolled in pre-service mathematics teacher preparation programs.

METHODS

Participants

The participants in this study were 16 undergraduate students enrolled in a basic financial mathematics course during the fall semester of 2020 (August-December). The class was taught by the author synchronously online using Zoom as the main platform. There were three meetings every week each lasting about 50 minutes. Most of the students were in their first or second year of college and had no prior experience with problem-posing. The mathematics course is for non-math majors and does not have any specific prerequisites except simple algebraic skills that many students encounter in high school and middle school. The three main topics covered in the course were simple interest, compound interest, and annuities.

A Framework for Implementing Problem-posing

To integrate problem-posing into regular classroom instruction, I adopted Ellerton’s (2013) active learning framework. According to this framework, the initial step involves engaging students in solving model problems and then asking them to pose their own problems based on these models. The next step requires students to solve the problems they have posed, followed by a reflection on the entire process. This cycle of solving, posing, solving, and reflecting was implemented over at least six class periods with close instructor guidance and support.

During these sessions, students learned about the structure of mathematical problems and practiced various problem-posing strategies. In the first lesson, the focus was on the elements of a mathematical problem. The instructor presented a model problem and guided the students in identifying the background theme, parameters, data, operating schemes, and constraints. This was followed by a discussion on what it means to modify a given problem and how that can be done. It became clear at this point that students had started paying attention to specific elements of a problem and the consequences that these elements may have on a given problem. For example, some students asked whether changing the background theme alone would result in an authentic “new problem.”

The subsequent sessions engaged students in posing their own problems and solving them individually and sometimes in groups. The strengths and weaknesses of each posed problem and solution were discussed.

Tasks and Data

At the end of each major unit and the course, students were given a problem-posing assignment (PPA). Each PPA included one structured task, one free task, and one semi-structured task. The first PPA focused on simple interest (chapter 1), the second on compound interest, the third on annuities, and the final PPA covered all chapters. The data analyzed in this study came from students’ responses to the first task in the final PPA (see task 1 below). I chose to analyze the final PPA because, by this time, the students had gained experience in posing new problems and had learned enough content to pose a wide range of problems and make connections between various concepts. Task 1 in the final PPA stated, as follows:

> Task 1. Select one problem from each chapter covered in this course and pose a new problem by modifying the chosen problem. You are free to draw on ideas from multiple chapters when creating your new problem. For each new problem, provide a solution and explain your posing and solving processes.

Each posed problem was graded using three criteria: solvability, complexity, and originality (Silver & Cai, 2005). Solvability assessed if the problem was solvable or if a sound explanation was given for why the problem is unsolvable. Originality measured how similar the posed problems were to the initial problems. A problem scored high on originality if the modifications resulted in a problem significantly different from the initial problem. A problem was considered significantly different if it could not be solved by merely following the solution structure of the initial problem. For example, if a student changed only the background theme, the resulting problem would score low on originality because it could be solved by mimicking the solution to the initial problem. Complexity measured whether the problem required multiple steps for a solution. Generally, multi-step problems (at least two) scored higher on complexity than single-step problems.

Students' written responses to task 1 were the primary data sources for this study. Additional data sources included reflective essays on problem-posing and solving, as well as unstructured interviews conducted with nine students. The purpose of the interviews was to gain a deeper understanding of the students' thinking processes during problem-posing and solving. While some students provided sufficient explanations in their written work, others did not, or their explanations were insufficient. Only these nine students, who lacked adequate explanations in their written responses, were interviewed.

The written essay prompt asked students to reflect on their experiences with problem-posing and how it supported their learning of the course material. Since task 1 allowed students to choose any problem from each chapter as the initial problem, we analyzed problems that most students selected and for which a solution had been provided in class. Ensuring that students had access to these solutions was important, as it allowed us to analyze the modifications made while developing solutions to their posed problems.

Data Analysis

We analyzed the data in two phases. First, two colleagues and I independently read through the posed problems, their solutions, reflective essays, and interview transcripts to familiarize ourselves with the data. We then identified various problem elements in each posed problem and assessed whether these elements resulted in a coherent and/or consistent problem. Problems that were both coherent and consistent were labeled as type A, while those lacking coherence and/or consistency were labeled as type B. Finally, we categorized the problems as either *near* or *far* transfer problems (Singer et al., 2011) based on their similarity to the initial problems. Near transfer problems closely resemble the initial problems and can be solved by closely following the initial solution model, whereas far transfer problems involve modifications that require a different solution strategy. The three of us then met to compare our classifications and found over 85% agreement. The main disagreements arose from identifying the problem elements, as certain aspects often fell into multiple categories. In such cases, we selected the element that most of us initially chose.

In the second phase of our analysis, we aimed to identify instances where interactions between the processes of problem-posing and solving occurred. To achieve this, we primarily used priori themes and codes derived from Xie and Masingila's (2017) study, while remaining open to the emergence of new themes. The a priori themes were, as follows:

Problem-posing supporting problem-solving

This theme captures instances where students engage in activities during problem-posing that enhance their problem-solving skills. Such activities include checking the solvability of posed problems, which promotes a deeper understanding of the structure of certain problem types. Other activities involve metacognition, such as being aware of their thinking processes and verifying the accuracy of their solutions.

Problem-solving supporting problem-posing

According to Xie and Masingila (2017), when students face a problem-posing task, they often engage in problem-solving activities before, during, or after the posing process. These activities help students understand problem structures and check for solvability, among other functions. We examined if such problem-solving occurred and its role in the overall problem-posing process.

Managing prior knowledge

This theme occurs when students integrate different mathematical concepts meaningfully while posing new problems. A key aspect of this theme is that it involves concepts that students understand well.

While these themes were prevalent in our study, we also identified a new theme that we named *Opportunities for New Knowledge*. This theme involves posing problems that require new knowledge for their solution. Such problems often involve modifications that necessitate understanding not typically covered in the course or knowledge that students do not fully grasp.

RESULTS

Distribution of Problem Type by Chapter

The 16 participants modified three initial problems (one from each chapter), resulting in the creation of 33 new problems. Most of the posed problems were both coherent and consistent (i.e., type A problems). Type B problems were those that lacked in coherence and/or consistency. The problem posed by Korma (see **Figure 1**) is an example of a type B problem. Note that all names used in this paper are pseudonyms.

Korma's problem was created by modifying a chapter 1 initial problem which stated, as follows:

> Suppose that on 3/1/2021, you invest $5,000 in an online savings account that earns 5.99% simple interest. On 10/21/21, you find a better bank that gives 6.49% and decide to close the first account and transfer all your money to the new account. How much money in total would you have by 7/4/2022?

This initial problem was set in the context of cash investment for the purpose of earning interest. The problem includes multiple parameters and data values such as interest rates (e.g., 5.99%), principal amounts (e.g., $5,000), and investment periods

Simple Interest:

***Simple Interest** - Gonna blind side them with the Banker's Rule. If the person solving forgets it exists, they're gonna have a hard time. This also uses tricky wording because it'd seem like perhaps you don't have to solve for the six months and 17 days the $345 accrued interest, however it's entirely necessary to or the problem will be unsolvable. You need the first answer to solve the second.*

Suppose you decide to save $345 at Delta Airlines Bank. Your money acures 2% annually in interest. However, you take it out after six months and 17 days, spend $6.17, then put it back in for a full year. How much interest will your money accrue by the end?

PART A
P: $345
r: 2%(1)
t: 6 months, 17 days
I: .90083333 OR .90

PART B
P: $339.73
r: 2%(1)
t: 1 year

Figure 1. Korma's chapter 1 problem (Source: Author's own elaboration)

This problem requires computation of exact # of days that your money stays in both banks. The future value from the first bank will be the present value for the second. Note that we use the Bankers Rule for # of days in a year.

Using exact time table, # of days between 3/1/21 and 10/21/21 is 234.

$$S_1 = P(1+rt)$$
$$= 5000\left(1+\frac{5.99}{100}\times\frac{234}{360}\right) = \$5194.68$$

5194.68 is the present value for the next step

$$S_2 = 5194.68\left(1+\frac{6.49}{100}\times\frac{256}{360}\right) = \boxed{\$5434.42}$$

Figure 2. Chapter 1 initial problem solution (Source: Author's own elaboration)

(e.g., 234 days). The constraints include the requirement that all the money must be transferred to a different account. It is important to note that the solution to this problem (see **Figure 2**) was discussed in class.

As a general rule, the class learned that when problems provide specific dates as in the initial chapter 1 problem above, the bankers' rule is used. According to this rule, the exact number of days between two dates is used while assuming a 360-day year. This is reflected in the computations in **Figure 2**.

Korma made multiple modifications to this problem when posing his version (see **Figure 1**). Although the background theme remains the same (earning interest), he introduced slight changes, such as naming the bank Delta Airlines Bank. He also adjusted the parameters, data, and constraints. The posed problem has a clear underlying mathematical model (i.e., simple interest), and all data are sensible and non-contradictory. Furthermore, the problem is solvable, making it consistent.

Although Korma's problem is consistent, we identified a few issues that render it incoherent. First, it is unclear how much is to be withdrawn after "6 months and 17 days". This ambiguity means one person may solve the problem assuming withdrawal of the full amount (including interest), while another may assume withdrawal of only the original principal. Second, it is not clear when the counting for the exact number of days should begin and end. Consequently, "6 months and 17 days" could yield different exact day counts depending on when the counting begins and whether it is a leap year. For these reasons, we classified the problem as incoherent.

We repeated the above analysis process for the rest of the problems posed by the students. **Table 1** presents a summary of the results of this analysis.

Overall, there were more consistent and coherent (type A) problems than incoherent and/or inconsistent (type B) problems. The distribution of type A problems appears to be about the same across the chapters with chapter 2 having the most. On the

Table 1. Problem category type by chapter

Problem category	Chapter 1	Chapter 2	Chapter 3	Total
Type A	9	10	8	27
Type B	1	2	3	9
Total	10	12	11	33

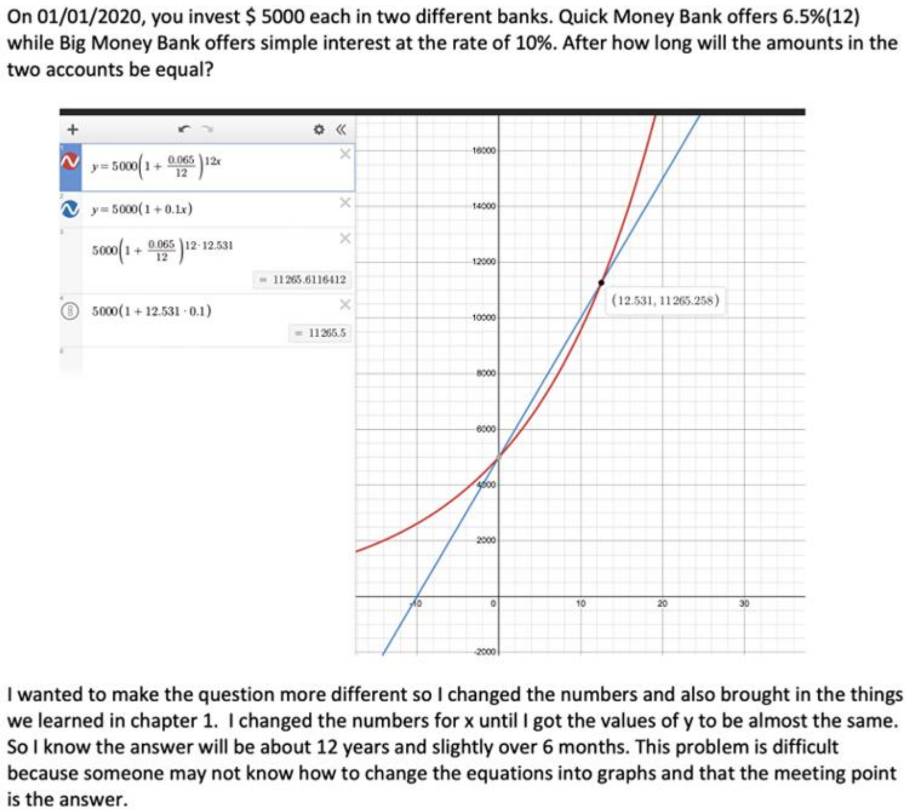

Figure 3. Narjo's chapter 2 problem (Source: Author's own elaboration)

other hand, chapter 3 had the most type B problems while chapter 1 had the least (just one). This trend may be explained by the fact that chapter 3 concepts (annuities) were generally more complex because they built on ideas from the previous chapters. For example, the future value of an annuity formula,

$$F = R \times \frac{(1+i)^n - 1}{i}, \tag{1}$$

where F is future value, R is recurring payment, and i is periodic interest rate, requires a clear understanding of the compound interest formula,

$$F = P(1+i)^n. \tag{2}$$

Similarly, the compound interest ideas and formulas build on ideas learned under simple interest.

The Nature of Problem-Posing Products

In this section, we conduct a deeper examination of the effects of students' problem-posing processes on the problems they created. We determine whether each posed problem is a *far transfer* problem or a *near transfer* problem based on its similarity to the initial problem and its solution. We begin by examining Narjo's chapter 2 problem and solution (see **Figure 3**).

To better understand the kinds of modifications that Narjo made, we begin by examining the elements in the initial chapter 2 problem (**Figure 4**) followed by those in the posed problem.

The background theme for this initial problem is money investment, with the parameters and data being the starting amounts ($10,000), interest rates (4.49% compounded monthly and 4.99% compounded semi-annually), and the target amount ($15,000). The constraint is that one can only withdraw from an account once the investment has grown to $15,000. The goal of the problem is to determine which investment scheme reaches $15,000 sooner.

Narjo's posed problem modifies several of these elements. First, he changed the background theme by renaming the investment schemes to banks (Quick Money and Big Money). These changes are mainly cosmetic and do not significantly alter the background theme. More profound modifications were made to the parameters, data, and the problem goal. For example, he changed one of the rates from 4.49% to 6.5% and converted the other to a simple interest rate of 10%.

Suppose you invest $10,000 in an investment scheme that pays 4.49 %(12) and another $10,000 in a second scheme that pays 4.99%(2). If your aim is to withdraw money from each of these accounts once they reach $15,000, after how long will you make your first $15,000 withdrawal and from which scheme?

First sheme: $S = P\left(1+\frac{r}{m}\right)^{mn}$

$$15{,}000 = 10{,}000\left(1+\frac{0.0449}{12}\right)^{12n}$$

$$1.5 = \left(1+\frac{0.0449}{12}\right)^{12n}$$

$$\ln 1.5 = \ln\left[1+\frac{0.0449}{12}\right]^{12n}$$

$$12n = \frac{\ln 1.5}{\ln\left[1+\frac{0.0449}{12}\right]} = 108.57$$

$$n = \frac{106.57}{12} \approx 9.0475 \text{ years}$$

Second Scheme:

$$15{,}000 = 10{,}000\left[1+\frac{0.0499}{2}\right]^{2n}$$

$$\ln 1.5 = \ln\left[1+\frac{0.0499}{2}\right]^{2n}$$

$$n = \frac{\ln 1.5}{2\ln\left[1+\frac{0.0499}{2}\right]} \approx 8.23 \text{ yrs}$$

∴ Second Scheme gets you to $15000 sooner.

Figure 4. Chapter 2 initial problem and solution (Source: Author's own elaboration)

Chris's grandmother deposits $4500 into an account earning 7%(4) interest and her mom deposits $1000 into an account earning 5%(52) interest. How long does it take to have $10,000 in each account and which one will get their first.

- **This is a harder problem, because you need to solve for two problems using the base formula S=P/(1+i)^n (P(1+r/m)^n, as well as making sure you use the proper compounding periods and the number of times it is compounded. With the grandmother's investment that is 4 for m and the mother's is 52m . You ultimately have to solve for n and then t and compare the two.**
- **In the first deposit P=$4500, i=0.07/4 and in the second P=$1000, i=0.07/52. You have to solve for n using a log function.**

Figure 5. Xinze's chapter 2 problem (Source: Author's own elaboration)

Additionally, he altered the constraint from a specific target amount of $15,000 to a generalized figure (the same amount in each account). Finally, although the problem goal still involves finding the time taken, the focus is now on determining the time based on the constraint of having the same amount in both schemes.

By examining the setup of the elements in Narjo's problem, we classified it as both coherent and consistent (type A). For instance, the choice of interest rates ensures that the two functions intersect at some point, as shown on the graph. Furthermore, the problem is based on the mathematical concepts of simple and compound interest and has a solution, thereby meeting all the criteria for a consistent and coherent problem.

Additionally, the modifications Narjo made resulted in a solution significantly different from that of the initial problem. While the initial problem was solved purely algebraically using logarithms, Narjo's solution combines algebraic methods with graphical (geometric) approaches. He transformed the underlying simple and compound interest equations into functions (linear and exponential, respectively) and sought their point of intersection on the graph. It should be noted that using the solution from the initial problem as a model to solve Narjo's problem would be ineffective because the problems differ significantly. Indeed, Narjo acknowledges in his explanation of the problem-posing process that he wanted to "make the question more different" [sic]. For these reasons, we categorized this problem as a *far transfer* problem.

Similar to Narjo's problem, Xinze's problem (**Figure 5**) makes cosmetic changes to the background theme while keeping the parameters unchanged. Her new theme involves a grandmother and a mother investing in two different accounts (presumably on behalf of Chris), but the underlying context remains investment for the purpose of earning interest. However, the data values associated with the parameters are modified. For example, the new interest rates are 7% compounded quarterly and 5%

Table 2. Modified elements vs. transfer type and chapter

Chapter	Transfer type	Target elements					Total
		Background	Data/parameters only	Constraints only	Operating schemes	Multiple elements	
Chapter 1	Near	1	2	0	0	3	6
	Far	0	0	0	0	2	2
Chapter 2	Near	1	3	0	0	3	7
	Far	0	0	0	0	2	2
Chapter 3	Near	1	3	1	1	3	9
	Far	0	0	0	0	1	1
Total		3	8	1	1	14	27

Table 3. Multi-element modification problems vs. ıransfer type and chapter

Chapter	Transfer type	Multiple target elements					
		Data & background	Data & constraints	Data & schemes	Data, schemes, background	Data, schemes, constraints	All elements
Chapter 1	Near	2	0	0	0	0	1
	Far	0	0	0	1	0	1
Chapter 2	Near	1	1	0	0	0	1
	Far	0	0	0	0	1	1
Chapter 3	Near	1	0	1	0	1	0
	Far	0	0	0	0	0	1
Total		4	1	1	1	2	5

compounded weekly. Notably, the initial investment amounts are different, unlike in the initial problem where these amounts are equal. Finally, although she rephrased the problem goal, it remains the same as in the initial problem.

Although Xinze's modifications are mostly cosmetic, we determined that the resulting problem is unambiguous and is solvable. Therefore, it is classified as type A. In terms of transfer, we examined the solution explanation and found that it closely follows the initial problem solution. Thus, we categorized this problem as a near transfer problem.

We conducted similar analyses on all posed (and solved) problems, comparing them to the initial problems and solutions. Additionally, we tracked the specific elements that the students modified. **Table 2** presents a summary of these analyses.

Table 2 indicates that 14 problems (51.9%) involved modifications on multiple elements (e.g., data and background theme), while the rest involved a single element modification (e.g., background theme only). Among the problems involving a single element modification, 8 problems (61.5%) involved a modification of data values, while 3 problems (23.1%) involved the background theme of the corresponding initial problem. Problems involving modifications on constraints or operating schemes only were rare, with only one problem in each of these categories, both from chapter 3, which was more challenging for the students than the other two chapters.

In regard to transfer, we found that there were more *near transfer* problems than *far transfer* problems overall. Notably, there was no *far transfer* problem among those with single-element modifications. This finding is not surprising, as modifying a single element usually results in a problem quite similar to the initial one. Among the problems with multiple element modifications, the vast majority were still *near transfer*. For instance, in chapter 3, only one problem (10%) was a *far transfer* problem. Chapter 1 and chapter 2 had two *far transfer* problems each out of 8 and 9 problems, respectively. As noted earlier, most students found chapter 3 (annuities) to be more challenging, which might explain why they did not pose more *far transfer* problems form the chapter.

Since more than half of the posed problems involved a modification on multiple elements, we examined these modifications further as well as their impact on the kind of transfer. **Table 3** presents the results of this analyses.

First, we note that most modifications involved either all elements or both the data and the background theme. These two categories alone had a total of 9 problems (64.3%) while all the other categories combined had a total of 5 problems (35.7%). Notably, all problems involving multiple-element modifications had data as one of the modified elements. At the same time, there were more near transfer problems (4) involving data and the background theme than any other multiple modification category. Furthermore, *far transfer* problems tended to involve modification of 3 elements or all elements of the initial problems. For example, there were 3 *far transfer* problems involving all elements and 1 involving both data, operating schemes, and constraints. Similarly, there was only 1 *far transfer* problem involving data, operating scheme, and background theme. There was no *far transfer* problem involving modification of 2 elements.

Relationship Between Problem-Solving and Problem-Posing

Our findings suggest that the participants' processes of problem-posing and solving interacted in multiple ways. These interactions occurred not only at the outset of the problem-posing task but also throughout and afterward. We have categorized these interactions into three main groups: (1) using problem-solving to improve problem-posing, (2) using problem-posing to improve problem-solving, and (3) opportunities for acquiring new knowledge.

Problem-solving enhancing problem-posing

Our participants' problem-solving practices contributed to their problem-posing in various ways. For instance, before deciding on the final version of a problem during problem-posing, they posed and solved intermediary problems. Their solutions to these intermediary problems played various roles that ultimately ended up improving the quality of the final posed problem. For example, when a given modification of the initial problem resulted in an unsolvable problem, the students were able to detect this and seek a reasonable fix before proceeding. This ended up improving the consistency and coherence of their posed problems. In his explanation of his chapter 2 problem (**Figure 2**), for example, Narjo recognized that there are certain data values (in this case interest rates) that would not result in a solution and ruled them out of consideration. During an interview with Narjo, he confirmed that he had initially used values that would not result in a solution. See excerpt:

> **Researcher:** Why did you use 6.5% and 10% as the rates?
>
> **Narjo:** No specific reason. I just wanted to use numbers that would work.
>
> **Researcher:** What do you mean by numbers that would work? Are there numbers that wouldn't work?
>
> **Narjo:** I tried to use 5% for simple interest and 6.5% for compound interest and those were not working. The lines were meeting on the negative side, but the answer cannot be negative.
>
> **Researcher:** Why can't the answer be negative?
>
> **Narjo:** Because the money is growing, and the problem is asking about a time in the future not in the past.
>
> **Researcher:** Ok. Did you try to solve the problem without using a graph?
>
> **Narjo:** I tried to set up the formulas equal to one another, but I could not solve the equations. When you put the answer from the graph, it works but I don't know how to solve it without graphing. I'm not very good with algebra.
>
> **Researcher:** Okay.

Narjo's posing process, as elucidated in the excerpt above, demonstrates his reliance on problem-solving skills to refine his posed problem. Through solving his initially posed problem with interest rates of 5% and 6.5%, he recognized the infeasibility of such a scenario and opted for alternative values. Consequently, his problem-solving practices facilitated the posing of a consistent and coherent problem. Similarly, the work of several other students highlighted the pivotal role of problem-solving skills in their problem-posing. For instance, in her reflective essay on problem-posing, Eva indicated that, …

> If you don't know how to solve problems, then you cannot succeed in problem-posing. I feel like I made better problems because I solved them and made sure that they worked. I did not make great problems for annuities because I did not understand that topic well.

In addition to improving the consistency and coherence of posed problems, we observed that problem-solving activities facilitated the creation of higher-quality problems in terms of complexity and transferability. Although *far transfer* problems were scarce, we noticed that participants who posed such problems also relied on their problem-solving skills. They achieved this by solving intermediary and/or final problems they posed and then comparing their solutions to those of the initial problems. When significant similarities were identified, further modifications were made. For instance, in elucidating his posing and solving processes for the chapter 2 problem mentioned earlier, Narjo expressed his intention to "make the question more different" by altering the numbers and incorporating concepts learned in chapter 1. Additionally, he compared his solution to that of the initial problem and observed that "someone may not know how to change the equations into graphs and that the meeting point is the answer." This indicates Narjo's recognition that his solution differed significantly from the class solution, which relied on an algebraic approach. These modifications, informed by efficient problem-solving, not only rendered the final posed problem consistent and coherent but also facilitated *far transfer* (higher quality).

Problem-posing enhancing problem-solving

We found that engaging students in problem-posing promoted their problem-solving skills in various ways. For example, by reflecting on the problem-posing processes, students showed deeper understanding of the structure of certain types of problems, typical solution strategies and possible difficulties. As an illustration, consider Rano's chapter 3 problem (**Figure 6**).

This problem was based on a two-part initial problem that required students to determine the future value of an annuity and the time it would take to reach a specific amount (see **Appendix A**, chapter 3). Since several students were unfamiliar with the logarithm function used in chapter 2, the amortization table helped to alleviate the algebraic complexity associated with logarithms. Despite the fact that the class solution did not involve using the logarithm function, Rano recognized this alternative strategy, indicating a deeper understanding of this type of problem. Additionally, she accurately identified one of the most confusing aspects of such problems–difficulty in choosing between future value and present value formulas. Unlike in chapter 1 and chapter 2, where the future value and present value formulas are straightforward, distinguishing between them for problems involving annuities is often challenging.

This deeper understanding of the structure of problems and their solutions was demonstrated in the work of several other students. See Seyca's chapter 3 problem in **Figure 7**.

Like Rano, Seyca's work shows a recognition of a possibility of using multiple strategies for solving the problem and sought to build this into her problem-posing. She recognized that a solver could use an amortization table or the log function in solving the

Annuities:

You start to put $450 per month into a savings account that earns 3%(12) interest. How long will it take for you to have $70,000 in your account? How much of this money is interest?

This problem is difficult for a few different reasons. First, the student solving it might be confused because it is a problem where you need to use the present value formula, S=R((1+i)^n-1/i), but a student might be confused and think to use future value. You are solving for n and this will involve using logarithms, something we did not come across very often in class. We did not use logarithms during in-class examples for this chapter, but we did in chapter two, so students will either have to refer back to notes or remember back to how to use logarithms. Not only do you need to find how long it will take to get to $70000 in the account, but also, you need to know how much of the money is interest if the account earns 3%(12) interest. I=Prn is used at the end, so it counts on finding the correct answer for n. Problems that involve multiple steps, include concepts that are not talked about very much in class, and are sequential in getting previous parts of the problem correct to get a correct final answer make the problem challenging.

Figure 6. Rano's chapter 3 problem (Source: Author's own elaboration)

You just got your first promotion at your first job and want to start saving to get a bigger apartment. You decide you have $25 extra dollars you can put into the account each month. Will you have enough saved in 2 years to make a $2750.25 deposit for security and first months rent if the bank offers 7.2% (12) apr? If not how long would you need to save?

This is challenging because it has more than one way you would solve it. Students could make an amortization table in excel, where they would have to understand how to use the formulas in excel and expand them. I think this is challenging because I personally needed a lot of help from my group to figure out how the put the formulas in right when we were doing the case studies in class. If there is not enough saved the student will also have to use the log formula to find n, which I think is hard because it requires an understanding of log properties on top of an understanding of the annuity formula listed in the first problem posing section and we have not had as much practice with it in class.

Figure 7. Seyca's chapter 3 problem (Source: Author's own elaboration)

problem and went ahead to reflect on possible challenges that a solver would face. Indeed, in her solution she correctly used an amortization table. Problem-posing provided Seyca with an opportunity to engage in reflection of the solution processes and possible difficulties. These are important characteristics of good problem-solvers.

Other than providing opportunities for understanding the problem structure and typical solution strategies, problem-posing provided students with opportunities to assess the solvability of certain problems before starting their solution process. In her reflective essay about problem-posing, Carol indicated this when she wrote:

> I feel like knowing how to pose problems makes me think about if a problem that I am solving has an answer or not. If it has no answer, I can be able to say why it has no answer instead of spending a lot of time trying to figure out what the answer might be.

The assessment of solvability of problems happened through an examination of the problem elements (especially data) and the way these are set up in a problem. Indeed, in a follow up interview that focused in part on the above quote, Carol said that "I know a problem can have numbers that are not matching. We saw these in class when some students posed problems like that". Similar sentiments to Carol's were raised by other students in various forms. For example, we saw this in Narjo's chapter 2 problem (**Figure 3**) that he reflected on interest rates that would result in an unsolvable problem and avoided using them. This assessment of the solvability of a problem is one of the key elements of good problem-solving and was enhanced by the fact that these participants engaged in problem-posing.

Opportunities for new knowledge

Through the process of problem-posing and solving, we discovered that some students generated scenarios that required new knowledge. In many instances, these students critically evaluated their own solutions, suggesting the existence of more efficient strategies. For instance, we refer to a problem posed by Nina in chapter 3 (see **Figure 8**). It's important to clarify that the course content was limited to simple ordinary annuities. These are defined as a series of equal payments made at regular intervals over a certain period, with interest accumulating on the remaining balance. However, Nina's problem from chapter 3 deviates from this definition because the payments increase by $30 each year. To tackle this unique situation, Nina divided the problem into two segments: one segment considers the initial payment of $200, and the other considers the annual increments of $30.

In her solution, Nina acknowledged that the $30 increments begin after the first year (12 months). Consequently, she subtracted 12 from 300 in the second part of her equation, which led to an incorrect assumption that there were 288 increments of $30.

Upon reflection, Nina realized her solution might be flawed, potentially due to the division of the equation and suggested that a single formula capable of solving such problems could exist, although she was not aware of it.

If James increases savings by $30 every year, will he reach the goal of 300,000$.

$$S = 200\times\frac{\left(1+\frac{.1}{12}\right)^{300}-1}{\frac{0.1}{12}} , \quad 30\times\frac{\left(1+\frac{.1}{12}\right)^{300-12}-1}{\frac{0.1}{12}}$$

$$200\times\frac{12.0569449-1}{0.008333} \quad 30\times\frac{10.9140964-1}{0.008333}$$

$$265{,}377.29 + 35{,}690.89$$

301,068.18. James will reach goal

I made the R to change after the first year by $30. This problem is more challenging because we did not have an example that changes R. To solve I split the formula in two parts for the first R = 200 and for $30. I think there is a way to use one formula but I don't know it.

Figure 8. Nina's chapter 3 problem (Source: Author's own elaboration)

Nina's acknowledgment that this type of problem was not covered in class, coupled with her alternative approach, indicates her understanding of simple ordinary annuities. However, it also highlights her need to comprehend other types of annuities.

CONCLUSION AND DISCUSSION

This paper presents the results of a study in which 16 undergraduate students enrolled in a basic financial mathematics course were involved in problem-posing and solving. The main goals of the study were to examine the nature of the students' problem-posing and solving processes and their implications. As pointed out in the literature review, most studies on problem-posing involve school children and students in mathematics education programs hence leaving a dearth of research among higher education students outside such programs. Furthermore, the study examined the relationship between problem-posing and solving qualitatively hence answering the question of "what actually happened" which, according to Xie and Masingila (2017) has not been adequately addressed. Thus, this study makes an important contribution to the mathematics education literature on problem-posing.

In general, the findings of this study showed that undergraduate students are capable of making various modifications to existing problems to pose new problems of varying nature. The most common modifications were ones that targeted numerical data values alongside other elements in the initial problems. For example, if the initial problem was based on getting credit from a bank and provided the interest rate and loan period, but asked for the repayment amount, a majority of students opted to modify numerical values (data), and at least one other element (e.g., background theme). These findings are reminiscent of findings in previous studies (e.g., Voica & Singer, 2013; Xie & Masingila, 2017). Unlike these previous studies, our findings also indicate that several students made modifications to all elements in the initial problems while still having consistent and coherent problems. This could be an indication that the students paid attention to the effect of their modifications on their posed problems. We may attribute this to the fact that the participants in this study were trained in the various elements of a mathematical problem, a feature that is missing in many studies on problem-posing.

Although most problems posed by our participants were coherent and consistent, an examination of the posing processes revealed that these problems mostly resembled initial problems already encountered in class. Similar findings to this have been reported in other studies (e.g., Lavy & Shriki, 2010; Voica & Singer, 2013). This might be explained by the fact that our participants did not have experience with mathematical problem-posing prior to taking this course and thus were reluctant to take risks. They focused more on posing problems that they could confidently solve as opposed to those that they could not. We also found a general trend where far transfer problems tended to be problems with at least three elements modified in the initial problems.

Another significant finding of this study was that problem-posing and problem-solving interact in numerous mutually beneficial ways. For instance, participants in general attempted solutions to a series of intermediary problems during the problem-posing process and used these solutions to increase the quality of their final problem-posing products. Whenever an intermediary solution was unsuccessful, for example, the participants sought and fixed the issues behind this, resulting in more coherent and consistent final problems. Some participants also used solutions to these intermediary problems to pose higher quality (far transfer) problems. While this posing of a series of intermediary problems has been reported to be a useful exploration tool in problem-solving (Christou et al., 2005; Cifarelli & Cai, 2005), we found in this study that the intermediary problems can also support problem-posing. This finding also confirms the assertion by Xie and Masingila (2017) that problem-solving can happen before, during, and after problem-posing.

We also found in this study that by engaging in problem-posing, students got the opportunity to reflect on not only the structure of certain classes of problems, but also potential solution approaches. This reflection on multiple solution strategies is positively associated with effective problem-solving as reported by several studies (e.g., Carlson & Bloom, 2005; Cifarelli & Cai, 2005; Parhizgar et al., 2021). Apart from reflection on the solution strategies, we also noted some participants made the posing of problems with multiple solution strategies a goal in itself. The recognition that mathematical problems can have multiple solution strategies is an important characteristic of successful problem-solving. It means that if someone cannot solve a problem one way, they are likely to seek and attempt alternative approaches.

We also found that problem-posing provided opportunities for students to integrate various concepts learned in the course and beyond. For example, apart from posing problems that were drawn from multiple chapters, some students sought to use geometric strategies for solving problems that were only solved algebraically in class. Furthermore, we found that problem-posing presented opportunities for students to identify what they did not know. By posing problems that they could not confidently solve, students were able to reflect on the kinds of knowledge that they may need to solve such problems. Creating such scenarios is likely to present a strong rationale for delving into new topics or areas of mathematics.

Finally, in characterizing the nature of posed problems, this study focused more on the mathematical aspects of the problem than non-mathematical ones. For example, we noticed that some students posed linguistically interesting problems that are very captivating for the reader. Others appeared to give meaning to the mathematical content in the course by turning the background theme into personal stories. Including such factors in assessing the nature of posed problems may be a worthwhile addition to the literature on mathematical problem-posing.

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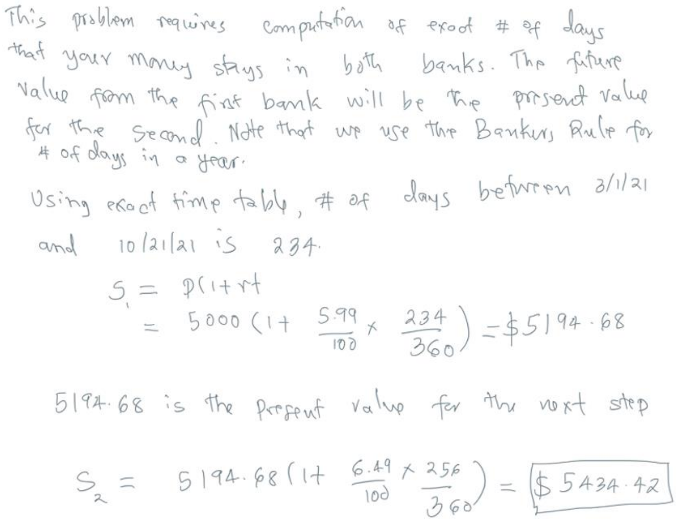
APPENDIX A

Task 1. Select one problem from each chapter covered in this course and pose a new problem by modifying the problem. For each new problem that you pose, provide a solution and explain your posing and solving process.

Chapter 1. Initial Problem

Suppose that on 3/1/2021, you invest $5,000 in a savings account that earns 5.99% simple interest. On 10/21/21, you find a better bank that gives 6.49% and decide to close the first account and transfer all your money to the new account. How much money in total would you have by 7/4/2022?

Solution



This problem requires computation of exact # of days that your money stays in both banks. The future value from the first bank will be the present value for the second. Note that we use the Bankers Rule for # of days in a year.

Using exact time table, # of days between 3/1/21 and 10/21/21 is 234.

$$S_1 = P(1+rt$$
$$= 5000\left(1+\frac{5.99}{100}\times\frac{234}{360}\right) = \$5194.68$$

5194.68 is the present value for the next step

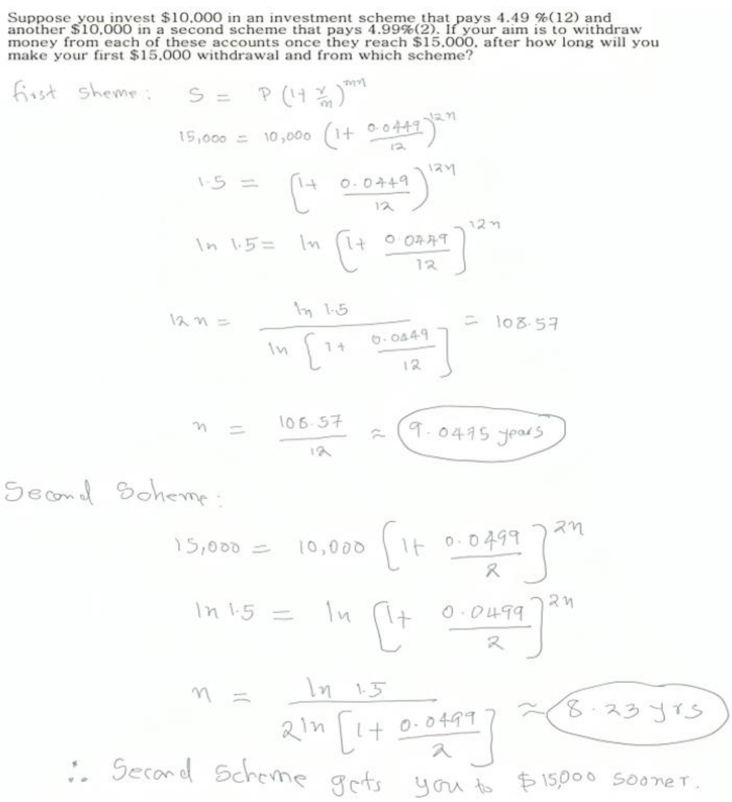
$$S_2 = 5194.68\left(1+\frac{6.49}{100}\times\frac{256}{360}\right) = \boxed{\$5434.42}$$

(Source: Author's own elaboration)

Chapter 2

Suppose you put $10,000 into an investment scheme that pays interest at the rate of 3.5% (4). How long will it take to double your money?

Solution



Suppose you invest $10,000 in an investment scheme that pays 4.49 %(12) and another $10,000 in a second scheme that pays 4.99%(2). If your aim is to withdraw money from each of these accounts once they reach $15,000, after how long will you make your first $15,000 withdrawal and from which scheme?

first sheme: $S = P\left(1+\frac{r}{m}\right)^{mn}$

$$15{,}000 = 10{,}000\left(1+\frac{0.0449}{12}\right)^{12n}$$

$$1.5 = \left(1+\frac{0.0449}{12}\right)^{12n}$$

$$\ln 1.5 = \ln\left(1+\frac{0.0449}{12}\right)^{12n}$$

$$12n = \frac{\ln 1.5}{\ln\left[1+\frac{0.0449}{12}\right]} = 108.57$$

$$n = \frac{108.57}{12} \approx 9.0475 \text{ years}$$

Second Scheme:

$$15{,}000 = 10{,}000\left[1+\frac{0.0499}{2}\right]^{2n}$$

$$\ln 1.5 = \ln\left[1+\frac{0.0499}{2}\right]^{2n}$$

$$n = \frac{\ln 1.5}{2\ln\left[1+\frac{0.0499}{2}\right]} \approx 8.23 \text{ yrs}$$

∴ Second Scheme gets you to $15,000 sooner.

(Source: Author's own elaboration)

Chapter 3

James has just started working and plans to retire in 25 years. To live comfortably post-retirement, James thinks that he will need $300,000. Supposing that he saves $200 monthly in a retirement scheme that pays interest at a rate of 10% compounded monthly, is he able to meet his retirement goal? If not, how much more should James save at the same rate to meet his retirement plan?

Solution

Notice that this is an ordinary annuity problem. The recurring payment is $200 and the rate is 10% (12). Total number of investments (n) will be 12 × 25 = 300. We need to find the future value (S) and check if it exceeds the required $300,000.

$$S = R\left[\frac{(1+i)^n - 1}{i}\right]$$

$$= 200\left[\frac{\left(1+\frac{.10}{12}\right)^{300} - 1}{\frac{.10}{12}}\right]$$

$$= \$265,366.68$$ James cannot meet $300,000 goal *

To find how much James needs, we solve the equation below for R.

$$300,000 = R\left[\frac{\left[1+\frac{0.10}{12}\right]^{300} - 1}{\frac{0.10}{12}}\right]$$

$$300,000 = R \times 1326.83$$

$$R = \frac{300,000}{1326.83} = \$226.1$$

∴ James needs to save $26.10 more.

(Source: Author's own elaboration)