Algebraic Activities: Adding To The Description Through Non-Routine Problem-Solving In Financial Mathematics

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This study explored pre-service mathematics teachers' (PSMTs) learning experiences in solving non-routine mathematical problems in financial mathematics at a South African university. Algebraic activities guided this study. 11 purposively selected pre-service mathematics teachers took part in this study. These were divided into three groups. Data were generated throughPSMTs' written responses,observations, and interviews. Deductive and inductive analysis were used to interrogate the data. The results show that PSMTs were fluent and effective in the use of representational and transformational activities of algebra but fell short in the use of contextual activities of algebra. All the groups committed more contextual errors than mathematical errors. The study recommends that the teaching of financial mathematics should emphasize the time value of money principle and banking practices to alleviate difficulties experienced by PSMTs and learning mathematicians in solving non–routine mathematical problems in financial mathematics.

Key words: *Algebraic Activities, Contextual Activities, Financial Mathematics, Learning Mathematician, Non-Routine Problem, Teaching Mathematician*

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Introduction

The common problem across all schools in South Africa is learning mathematicians[1]' relatively low performance in mathematics, as reflected by international assessments, such as TIMMS (Reddy et al., 2013; van der Berg et al., 2011). Learners' underachievement in a critical subject like mathematics has prompted all stakeholders to ponder a solution to the national crises. At the heart of this relatively low performance is learning mathematicians' in ability to solve non–routine mathematical problems in financial mathematics (Khalo and Bayaga, 2014; DOE, 2011-2019). Learning mathematicians are not alone in this debacle. Studies conducted on pre-service mathematics teachers (PSMTs)show that PSMTs lack knowledge of the financial mathematics they are expected to teach (Makonye, 2013,2020). On the other hand, Kilpatrick et al., (2001) argued that success in mathematical problem-solving is guided by three algebraic activities which are representational activities, transformational activities and generalizing and justifying activities.

Algebraic Activities

Kilpatrick et al.(2001) coined the term algebraic activities to describe the mathematical competences which school leavers should be able to demonstrate when solving mathematical problems. These are representational activities, transformational activities, and generalizing and justifying activities.Representational activities involve translating verbal information into symbolic expressions and equations that often, but not always, involve functions. Representational activities are underpinned by a conceptual understanding of mathematical concepts, operations, and relations expressed in verbal form and strategic competence. Strategic competence is the ability to formulate and represent verbal information using equations and expressions that involve symbols.Transformational (rule-

[1] The term 'learning mathematician' refers to anyone who is enrolled to learn mathematics either at a school, college or university outside the faculty of education. This researcher uses this term to incorporate pupils, learners, students, and scholars, as these terms are used contextually in different countries. For example, in South Africa, a learner is anyone who is enrolled in a school, while a student refers to anyone enrolled at a college or university level.

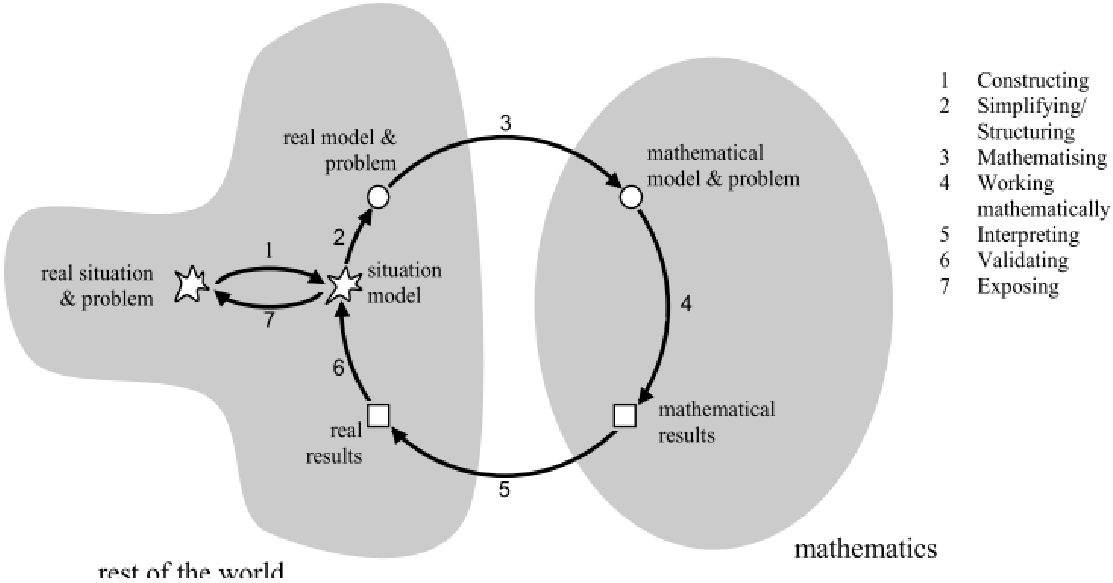
based)activities are concerned with changing the form of an equation or expression through the use of various actions such as substitution, collecting like terms, factoring, expanding, substituting, solving equations, simplifying expressions, and so forth using the rules for manipulating algebraic symbols.Generalizing and justifying activities entails the use of mathematical practices such as observing,identifying patterns, investigating, proving, justifying, predicting, and problem-solving, etc. which are not algebraic but use algebraic tools and language.

Solving mathematical problems in financial mathematics requires the problem solver to engage in one or more of these activities. For example, when $R500$ is invested for n years at $6\% \; p.a$simple interest, iterative calculations would give the value of the investment after each year but the representational, transformational, and generalizing and justifying activities of algebra make it possible to predict the amount after n years to be $F_v = 500 + 30n$. Hence proficiency in algebraic activities can help citizens to understand and manage their consumption of financial products. algebraic activities in their current formdescribe the competenciesthatPSMTs should demonstratewhen solvingmathematical problems. However, they seem to discountthe importance of the context in which the problem is located. Makonye (2020) posited that solving applied mathematical problems, particularly in financial mathematics is a complex process, especially for problem solvers who come from cultural contextsthat do not emphasize the time value of money (TVM) principle and interest. As a result, to describe how groups of PSMTs in a rural university in South Africa solvednon–routine mathematical problems in financial mathematics, we expanded Kilpatrick et al.'s (2001) algebraic activities by adding contextual activities. Contextual activities caterto the missing but critical aspects of mathematical proficiency as described by Kilpatrick et al. (2001). Hence, contextual activities entail knowledge of financial principles, such as the time value of money (TVM) principle; ways of calculating interests and financial conventions, such as the use of 360, 365, or 366 days in financial markets; and knowledge of current financial practices, an awareness of mathematical limitations when solving problem is applied contexts(such inapplicability of rounding conventions in context).

Solving Context-Based Problems

As an applied branch of mathematics, financial mathematics often embeds problems in a financial context, and as such the problems are referred to as context–based problems (wijaya, 2018). Context refers to the situation in which the problem is embedded. In applied mathematics, context may be classified as comaflouge or authentic contexts. A comaflouge context refers to situations in which the procedures, algorithms, or operations needed to solve the problem are easily identifiable whereas authentic contexts refer to realistic contexts i.e. problems originating from the real world or fantasy setting which may involve personal, scientific, occupational, and public information.authentic contexts demand that problem solvers integrate and use their mathematical knowledge in new ways to solve the problem. Authentic contexts offer problem solvers an opportunity to deal with missing, superfluous, or implicitly stated information when solving a problem.

Severalproblem-solving heuristicshave been developed to guide the problem-solving process. George Poyla's seminal work in 1945 pioneered the development of problem-solving heuristics that underpin mathematical problem-solving to date. His model had four steps namely; understanding the problem, devising a plan, executing the plan, and looking back (reflection) (Poyla,2014). Since then numerous heuristics have been developed.for example, by inserting an exploration stage between understanding the problem and devising a plan Schoenfeld (1985) developed a five-stage problem-solving heuristic. Zalina (2005) developed a model with three stages by combining executing the plan and looking back.While heuristics guide the problem–solving process, they do not guarantee the correctness or existence of a solution to the problem. Similarly, Blum and Ferri (2009) developed a problem-solvingmodel with seven stages. Blum and Ferri's model differs from others in that it applies to contexts outside the mathematical realm i.e. it uses real-world contexts as the starting point of mathematical problem-solving. Blum and Ferri's (2009) problem-solvingmodel was deemed appropriate for this study because it takes into account the context of the problem. This model brings together algebraic activities and problem-solving heuristics and recognizes that mathematical problem-solving in financial mathematics is a continuous and cyclic process between the real world and the mathematical world.



Blum and Ferri (2009):Modelling Cycle

Financial Mathematics Within The South African School Curriculum

The South African mathematics school curriculum is divided into five content areas: Number and number relationships; functions and algebra; space, shape, andmeasurement and data handling and probability(Department of Basic Education, 2011). Financial mathematics is placed under number and number relationships in the General Education and Training band (GET) and under functions and algebra in the Further Education and Training band (FET). Department of Basic Education(2011) argues that learning mathematicians in the GET should solve problems that involve whole numbers, percentages, and decimal fractions in various financial contexts. In the FET, learning mathematicians are required to apply knowledge of geometric series in solving financial problems involving annuities with or without a formula.Unlike other topics in mathematics which have their content, financial mathematics recontextualizes content from other areas of mathematics such as percentages, sequences and series, and measurement. Hence financial mathematics could be thought of as applied mathematics. This view is shared by Khalo and Bayaga (2014) who argued that financial mathematics is an application topic within the school curriculum that deals with contexts involving issues with national or global significance which learning mathematicians are expected to make sense of and resolve mathematically. Further, they opined that these contexts include financial documents, tariff systems, income, expenditure, profit/loss, budget, interest, banking, loans, and investments. In, South Africa Financial Mathematics is allocated about 10% of the mathematics marks in the National Senior CertificateExamination. On the other hand, Khalo and Bayaga (2014) contended that Financial Mathematics is allocated 35% of the marks in Mathematical Literacy in the National Senior CertificateExamination. The inclusion of Financial Mathematics in the National Senior CertificateExamination indicates that Financial Mathematics is a valuable component of the school curriculum in South Africa. Despite the significant allocation of marks, National Senior Certificate diagnostic reports for the period 2011 – 2019 show that learning mathematicians do not perform well in this area of mathematics.In support, Cobbinah and Bayaga (2017) argued that any curriculum conveys the policies that enable the country to measure the quality of its education against international standards and it influences classroom practices. It seems teaching mathematicians need to go beyond a knowledge of mathematics to adequately contribute to the eradication of the relatively low learner performance in this area of school mathematics in the National Senior Certificate Examination and the low levels of financial literacy among South Africans. This study extends the work of Kilpatricket al, (2001) on algebraic activities by introducing contextual activities as a competence that should be acquired by learning mathematicians. This is done by responding to the following question;

Why do pre-service mathematics teachers who select an appropriate financial mathematics formula and apply correct mathematicsnot always getthe correct answers?

Research On Financial Mathematics

Problems in financial mathematics differ from other problems in mathematics in that they are textual and involve contexts outside mathematics such as everyday financial contexts. Pournara (2011) posits that solving problems in financial mathematics requires more than knowledge of mathematics. For example, the problem solver may need knowledge of how financial markets and banks operate. Pournara contends that there is a misalignment between solving financial problems at school and the practices of the major banks in South Africa. Clarifying banking practices that are not emphasized at school but are dominant in banking, Parramore (2011, p. 211) added that:

- *Interest is charged or credited on a daily basis, usually on the balance of the account at the end/beginning of the day.*
- *The balance of the account is adjusted for withdrawals and deposits, but not for interest, at the end of each day.*
- *The interest charges or credits are recorded separately. The accumulated interest is consolidated with the account at specified intervals.*

In solving financial mathematics problems, mathematical procedures need to be carried out with care and their results should be interpreted in context to make sense. For example if five people share an inheritance of 6 cars. The mathematical operation performed is division. Applying this operation gives 1.2 cars per person which does not make sense in the real world. Garder (2004) adds that forlearning mathematicians to be successful in solving problems in financial mathematics they should be proficient in the time value of money principle. Time value of money simply describes the relationship between time and money. This principle is based on the fact that money in hand is better than money promised at some time in the future if there are no inflationary or deflationary effectson the economic system since a rand in hand could be invested to generate interest (Xudong & Mingxing, 2014).

According to Pournara (2013b, 2014), in most countries, financial mathematics is part of financial literacy and it requires teaching mathematicians who have relevant knowledge of mathematical concepts and the conventions of the banking world. What one needs to understand is that financial mathematics at school does not always portray the actual practice of the banking sector, though it is a precursor for the former. For example, when the compounding period is not mentioned, at school it is taken to be annual but the banking sector assumes monthly compounding (Pournara, 2014). Jalbert (2004) contents that learning mathematicians experience difficulties in identifying and applying the correct time value of money technique in solving financial mathematics problems. This view is supported by National Senior Certificate (NSC) diagnostic examination reports compiled by the Department of Basic Education for the period 2011 – 2017 on learning mathematicians' performance on financial mathematics problems. Thereports show that difficulties stem from learning mathematician's inability to choose the appropriate formula from the given formula sheet, in adequate language, low levels of mathematical and technology knowledge, lack of practical knowledge of how loan repayments are handled on a daily basis and substituting incorrect values in the formula(Department of Basic Education, 2011c, 2012, 2013, 2014, 2015, 2016, 2017).A Study conducted by Khalo and Bayaga (2014) with South African 10th graders taking Mathematical Literacy sustained DBE's diagnostic examination reports by finding that learning mathematicians committed numerous errors when solving Financial Mathematics problems. Da Silva and Pournara (2009) expounded that Grade 12 learning mathematicians committed more financial context and representational errors than mathematical errors in solving Financial Mathematics problems. They contended that financial context errors emanated from learning mathematicians' in adequate knowledge of financial concepts or application ofmathematics in a financial context. For example, while 3.7% may be rounded off to 4% in mathematics, this cannot be done in a financial context since the two rates would never give the same returns on an investment. Makonye (2017) conducted a study on seventy (70) second-year prospective teachers at a South African university to explore their understanding of nominal and effective interest rates. He concluded that their use of mathematical formulae was erratic and lacked conceptual understanding. Learning mathematician's difficulties in solving financial mathematics are further compounded by the context. Pournara (2013) argued that to solve Financial Mathematics problems learning mathematicians need to understand the conventions used in finance such as payments or deposits made at the end of the investment period do not earn interest during that period. This brings into focus the timing of the payment or deposit when solving mathematical problems in Financial Mathematics.

Methodology

Design of the study

A case study design with multiple units was used to generate data for this study. This design allowed the researchers to compare how the various groups interpreted and solved the problems. The sampling employed in this study was purposive sampling (Cohen et al., 2011), since it was based on the assumption that these pre-service teachers possessed various mathematical problem-solving strategies and could wrestle with algebraic activities during problem-solving. The researchers further assumed that their mathematical knowledge is evenly matched across the groups and reasonably sound based on the number of mathematics modules they have passed since enrolling for the degree.

Participants And Context Of The Study

Participants were drawn from a pre-service teachers' Bachelor of Education programme at a South African university. The participants were in their final year of a 4-year Bachelor of Education programme, majoring in mathematics education.In this institution, final-year students choose three major subjects per semester from a collection of eight modules (mathematics, physical sciences, life sciences, and technology). Hence, final-year students have a choice of taking one, two, or no mathematics per semester. The participants in this study had completed at least four semesters of 'mathematics content' and two semesters of subject pedagogy 'mathematics method'.

The institution in which this study was conducted is one of other rurally based universities in South Africa. As a result, most students enrolling in this institution come from less-resourced schools and mostly poor communities. Because of these factors, most of the students in this programme had entered the institution with the bare minimum of passing marks, such as a 40% in Grade 12 mathematics. As a result, this study reports on the problem-solving abilities of the least privileged PSMTs.

Research Sample

In total 11 PSMTs took part in the problem-solving session. The pre-service mathematics teachers were asked to group themselves in such a way that each group had a maximum of five members. As a result, three groups the D_Group, the M_Group, and the T_group were formed. The D_Group was made up of two participants who were not taking the Financial Mathematics module at the time of data generation. While this was coincidental, it ensured that their thoughts about the problems and the way they intended to solve them were not influenced by those taking the financial mathematics module.

Data Generation

This study reports on the strategies used by the groups to solve four non-routine mathematical problems over a four-week period. The problems were adopted from published articles and textbooks. The three groups solved the same problem while seated in different venues. Two groups (the D_Group and the M_group) were video recorded while the T_Group was audio recorded as they discussed and solved the problems. The video and audio recordings were transcribed verbatim. The written response of each group was collected at the end of each problem-solving session.

Week 1: Problem 1 And Its Description

> A merchant receives an invoice worth R2800 payable in 30 days. The invoice states that if payment is made in 10 days, there will be a 3% p.a. simple discount. If the payment is not made in thirty days, there will be a R30 delinquency charge for every thirty days thereof. Would it be worthwhile for him to borrow from a bank that charges interest at 5% p.a. simple interest in order to take advantage of the discount? Justify your answer mathematically.

This problem is based on hire purchase. The problem required PSMTs to make assumptions and use them to solve the problem. For example, PSMTs needed to be explicit about how much was borrowed from the bank and for how long. PSMTs had to explicitly deal with the time value of money (TVM) principle and unit conversion. The problem demanded that PSMTs connect the problem context to the problem solving strategy and to identify the relevant information essential in solving the problem (WiJaya, 2018). Figuring out how much was borrowed and how much would the savings be provides not only the motivation for PSMTs to engage with the problem but also a relevant context in which the stakes are high.

Data Analysis

Data were analyzed deductive and inductively. Inductive analysis was applied to all the transcripts. deductive data analysis was carried out on the written group solutions based on the codesdeveloped from the literature (algebraic activities). we chunked the transcripts as we read through each group's solutiontoidentify a suitable code. In some cases, we noted that the predetermined codes did not fit the data. In such cases, we formulated new codes which were amalgamated to form themes.

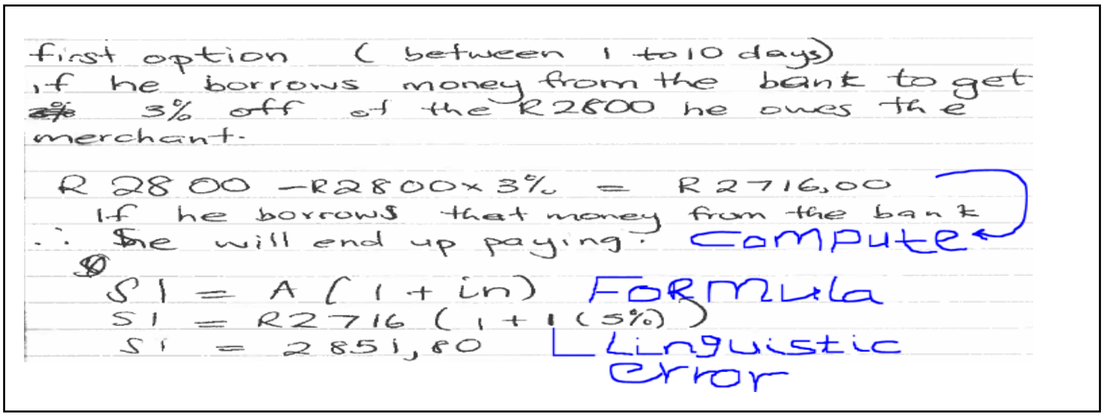
Ethical Considerations

The researchers sought and obtained permission to conduct the study from the university's ethics committee. On receipt of the ethical clearance certificate, we informed the dean and the HOD in writing of our intention to involve final year pre-service mathematics teachers in our study and the duration of this process. Particular attention was paid to any conflict of interest that could arise as both researchers were part of the teaching staff and could have been teaching some of the participants. In this regard, we wrote and issued letters to the pre-service mathematics teachers explaining the purpose of the study, guaranteeing that activities done during the study were not linked to formal assessment and that such activities would take place outside the university's normal working hours and weassured PSMTs that participation was voluntary. Further, we were aware that teaching and researching simultaneously borders on issues of power imbalances. To ameliorate the intrusive effects of the researchers, we also addressed issues around freedom of participation and the anonymity of participants. In this regard, we designed a consent form that all participants signed before the study commenced, stating that all activities would only be used for research purposes. Additionally, participants were informed that they had the right to withdraw at any point without giving a notification or a reason.

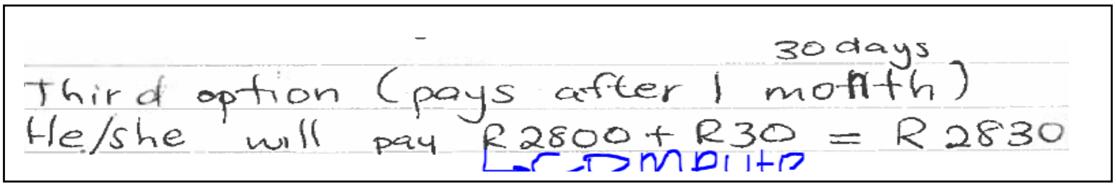
Results

The M_group solved the problem by first reading and transforming the problem into symbolic mathematical statements (see Table 1). They then performed calculations, recalled a formula, and substituted $n = 1$.Finally, this group further engaged in logical reasoning in resolving the problem. they concluded that it would be worthwhile for the merchant to borrow money from the back.

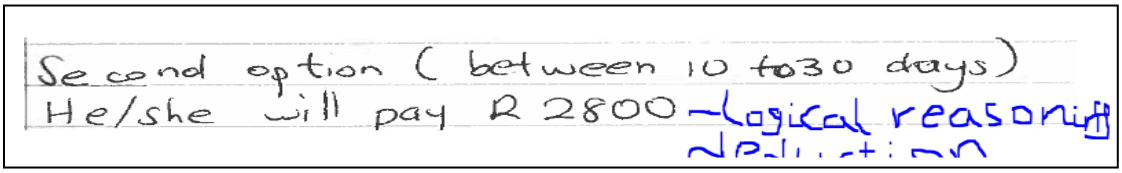
Table 1



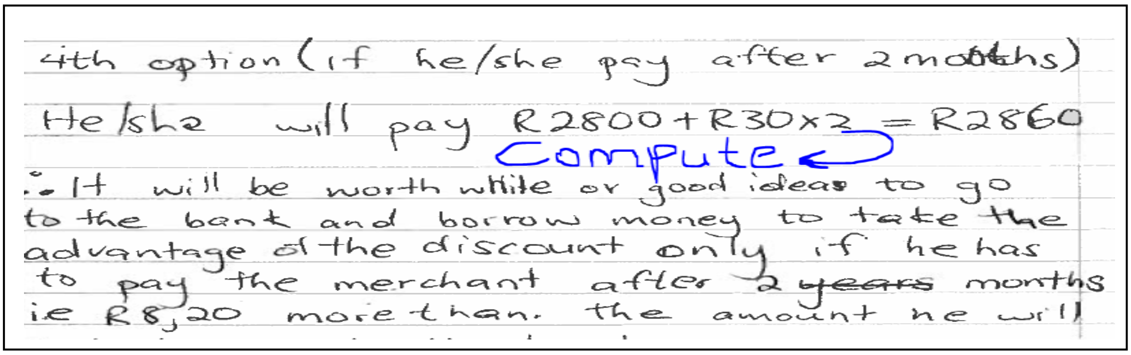
first option (between 1 to 10 days)
if he borrows money from the bank to get 3% off of the R2800 he owes the merchant.
R 2800 − R2800×3% = R2716,00
If he borrows that money from the bank
∴ she will end up paying: Compute
SI = A (1 + in) Formula
SI = R2716 (1 + 1 (5%))
SI = 2851,80 Linguistic error



Third option (pays after 1 month 30 days)
He/she will pay R2800 + R30 = R2830
Compute

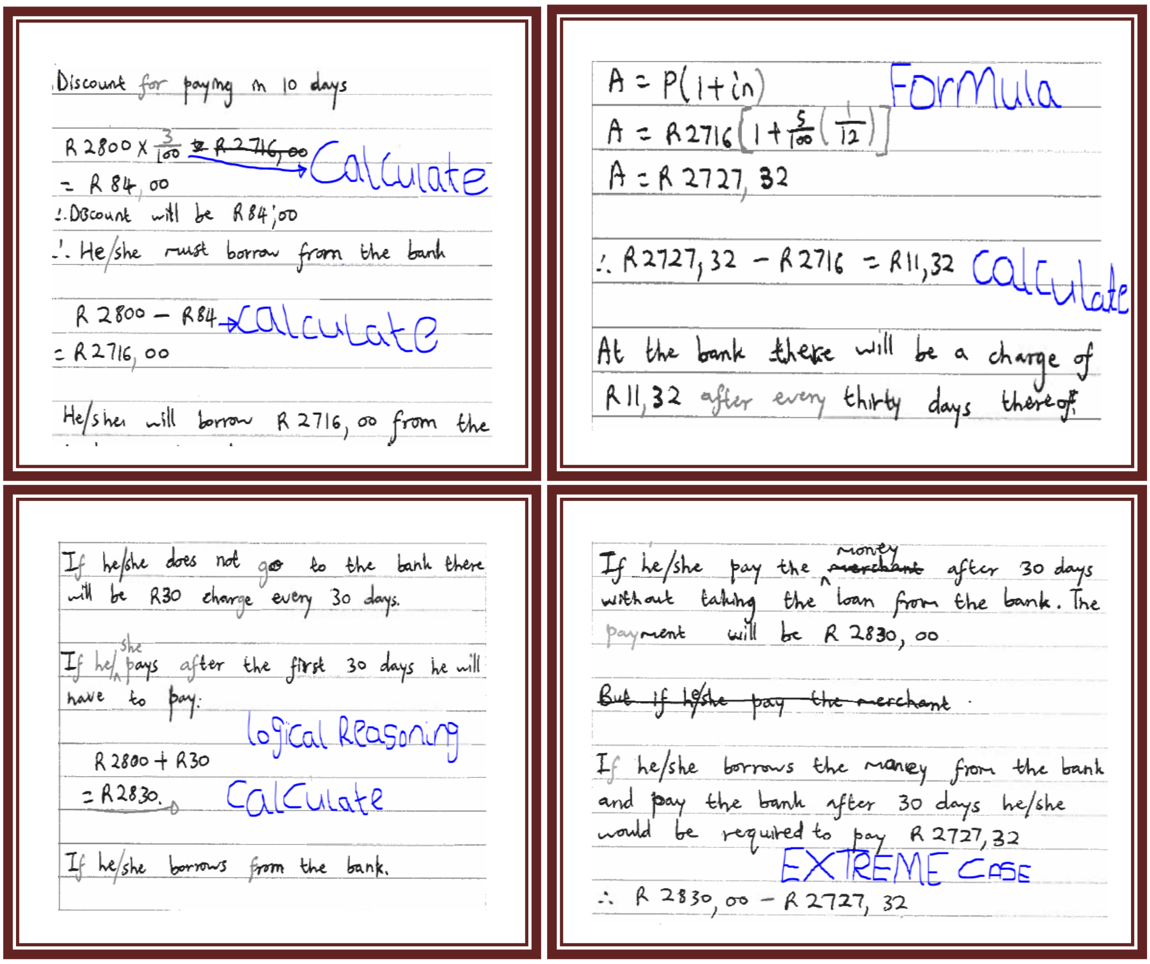


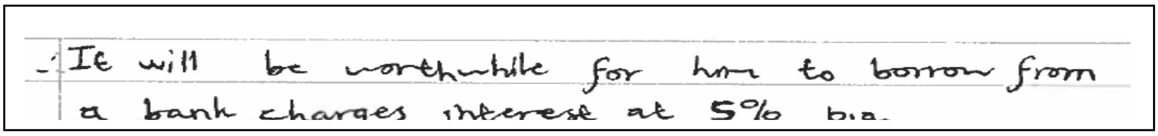
Second option (between 10 to 30 days)
He/she will pay R 2800 — Logical reasoning application



4th option (if he/she pay after 2 months)
He/she will pay R2800 + R30×2 = R2860
Compute
∴ It will be worth while or good ideas to go to the bank and borrow money to take the advantage of the discount only if he has to pay the merchant after 2 ~~years~~ months ie R8,20 more than the amount he will

The T_group solved the problem in a similar manner to the M_group but they substituted $n = \frac{1}{12}$. They also concluded that it would be worthwhile for the merchant to borrow from the bank.





The last group to solve the problem was the D-group. This group listed the known quantities first. they then wrote a formula for finding accumulated amount under simple interest into which values were substituted. The substitution made by the D-group differed with the previous groups in that they substituted $n = 30$ and they never calculated the value of the discount. The common threat across all the groups is the choice of a formula and use of 30 days though with different interpretations.

Discussion

All the groups drew on the same ready-made mathematics (formulae) to solve the problem. Further, all the groups did not get the expected answer although they executed their transformational activities (substitution, computation, etc.) and representational activities such interpretation, translation, formulation of equations, etc. (Kilpatrick etal., 2001) fluently. PSMTs differed in their interpretation of the n used in the formula for simple interest. The M-group substituted a 1 for n. This meant that the money was borrowed for a full year while the T_group substituted $\frac{1}{12}$ which implied that the money was borrowed for one (1) month i.e. 30 days which was correctly converted to years. The D_group substituted 30 thus implying that the money is borrowed for 30 years.

The groups seem to have ignored the TVM principle in carrying out their calculations and further had different meanings of the n in the formula. The meaning of n was necessary and critical to calculating the value of debt and to resolve the problem successfully. The error in the value of n seemed to emanate from PSMTs inability to define the variable n as used in the simple interest formula. During the interview a member of the T_group had this to say regarding n:

Interviewer: so like, okay, okay so this man goes to the bank to borrow money, when does he borrow the money? For how long does he borrow this money according to your analysis from the group? For how long was he borrowing the money, the money?
Representative: we thought he is borrowing it for 30 days
Interviewer: you said for 30 days?
Representative: yes
Interviewer: did you think of this person not borrowing on the first day? what would have happened if he did not borrow the money on the first day? how will that affect your answer?
Representative: I think it can cause problems at the bank
Interviewer: okay, how?
Representative: because the days will no longer be a month now
Interviewer: mmmmh
Representative:yeah, if it will still be within 10 days there is no problem with the discount. Let's say he borrows on day 5, there will be 25 days left maybe there will be a problem from the bank with these 25 days
Interviewer: so you think the bank only lends money for a full month?
Representative: no, the way we thought that day maybe it is below 30 days we do not know what to put in the term there, in the n if you are using a formula
The interview extract highlights the discord between school mathematics and the actual banking practices and the difficulties that PSMTs grappled with as they attempted to interpret the problem. Pournara (2013) posits that banks calculated interest daily while at school daily calculations of interest are unheard of. The use of a formula seems to hidethe actual practice of calculating interest which is fundamental to understanding why the formula works. The prospective teacher does not see the problem in the calculation but anticipates that the bank will have a problem if the bank was to calculate interest for less than 30 days.PSMTs' inadequate knowledge of the TVM principle only allows them to see interest over a long period of time.

PSMTs insistence on the value of n being a full month (30 days) is a precursor of their lack of knowledge of the time value of money principle (Jalbert, 2004, Gardener, 2004). PSMTs do not seem to realize that borrowing money over a long time enriches the creditor as more interest is earned while impoverishing the borrower. Taking this point further, Makonye (2020) argued that learners who come from cultures that do not hold a time value of money principle have difficulties responding to problems that require the use of the TVM principle. Solving contextualized mathematical problems seemed to interfere with PSMTs understanding of the problem.For PSMTs to translate textual information in the problem into an equivalent symbolic mathematical statement, PSMTs needed to identify and relate data to the knowns and unknowns in the problem (Poyla, 2014). For this to happen PSMTs need to have contextual mathematical competences (ability to recognize and use mathematics efficiently across context). PSMTs inability to solve the problem seemed to emanate from their lack of contextual activities of algebra particularly how money generates interest. This finding is in line with Makonye (2020) who found that learning mathematician who come from cultures devoid of (western) financial practices such as interest and TVM have problems in learning financial concepts as described by teaching and learning support materials.

Conclusion And Recommendation

When analyzing PSMTs written work we realized that PSMTs did not have a problem in deciding which formula was suitable for the problem. However, none of the groups was able to calculate the correct number of days the merchant was to borrow money from the bank. While PSMTs were aware that money has to earn interest, they failed to apportion the correct time. This difficulty seemed to originate from PSMTs' lack of knowledge of banking practices instead of their knowledge of mathematical procedures. Inadequate knowledge of financial principles, let them into making an incorrect assumption that banks calculate interest on monthly basis instead of daily calculations of interest. It is critical that PSMTs are inducted into contextual activities such as financial practices and the time value of money principle early in their learning.

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