Article

Descriptive Analytics in an Undergraduate Mathematics Education MOOC Course at a University of Technology: A Review of the Algebra Component

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Abstract

The study explores the learning of algebra in Mathematics 101 offered as Massive Open Online Courses (MOOCs) by using descriptive learning analytics. Delineated benefits of utilising learning analytics include improving course offerings, student outcomes, curriculum development and instructor effectiveness. Quantitative analysis was performed on overall mathematics scores for the population of 158 students. Qualitative analyses were performed on 40 randomly selected students' examination responses to 11 algebra itemised questions to determine if deep, intermediate or surface learning had taken place. The results indicated 63 students passed the overall Mathematics 101 course but only 37 students passed the algebra section of the examination. The qualitative analysis exhibited four items of deep learning, one item of intermediate learning and six items of surface learning. The quantitative and qualitative analyses indicate that a review of the learning material and online pre-test and post-test data is necessary. Improvement of the discussion forum and tracking of students' responses should be frequently monitored by online tutors. It is recommended that a community of inquiry model be established within the ODL context and in discussion forums so that student errors are timeously diagnosed.

Keywords: teacher training; descriptive analytics; algebra; mathematics; deep and surface learning

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Introduction

The use of learning analytics at higher education institutions (HEIs) is common practice to improve the student throughput rate. Learning analytics are descriptive, diagnostic, predictive and prescriptive. Descriptive analytics reviews facts and figures to yield a picture of what concepts were mastered. For this study, we focus only on descriptive learning analytics.

The University of Technology is a contact university and has a student population of more than 26 000 students. Over the past three years, the university has promoted the use of online learning as an additional resource for students.

The Bachelor of Education Degree (BEd) is a four-year degree targeting in-service teachers for training in Natural Sciences, Technology and Economic and Management Sciences. The degree is offered at the School of Education at the Pietermaritzburg campus. Mathematics 101 (MTMC 101) is an introductory course for the further education and training band (FET). The main problem areas were trigonometry and algebra. The majority of students were performing poorly in algebra.

Currently this subject has been flagged as an at-risk subject. Students registering for the course come from diverse social backgrounds and have a range of skills in mathematics. Many students struggle to pass the course in their first attempt due to inadequate pre-knowledge skills (Naidoo 1996).

Learning analytic data on strategies that students choose give instructors an opportunity to learn more about the strengths and weaknesses of the student cohort. These can be used to reorganise learning material to focus on potential problems students may experience with the learning content.

Massive Open Online Courses (MOOCs) provide an opportunity for new knowledge to be accessed by using ODeL. Online tools allow participants to perform various tasks simultaneously and with relative ease at any place where there is Wi-Fi connectivity. Course study can be done according to a personal schedule and participants can exchange ideas with a larger audience and benefit from peer discussions. There is opportunity to create a network of practitioners. Using the community of practice principle, students can engage with the eTutors, lecturer and other students using the discussion forum in WebCT platforms.

Known challenges may include digital literacy skills, time and effort to keep up with the course schedule.

The use of learning analytics to provide student support is a relatively new strategy in the Natural Science Department. Student examination attempts in algebra are qualitatively evaluated using an error categorisation to highlight errors and misconceptions experienced.

The study has provided an opportunity to redesign learning material for a mathematics MOOC for initial teacher training.

Analytics in Massive Open Online Learning Courses (MOOCs) gives course designers the opportunity to source data from digital traces left by learners (Ferguson 2014). Learning analytics is focused on the activity between lecturer and student. According to *The 2011 Horizon Report* (Johnson et al. 2011), it involves modelling to improve teaching and learning situations so learning material can be designed to tailor education to individual needs more effectively. From an educational point of view this means that learning content can be made to be not only student-centred but also centred on the individual.

Sources of data on student progress from assignments, tests, examinations and other forms of assessment provide insight into student learning needs. Course level analytics directed to conceptual development and student networks provides valuable indicators for designers to introduce pedagogical changes to the course design.

Faridhan, Loch, and Walker (2013) suggest a combination of learning analytics and mathematics support to identify how the retention of first-year mathematics students could be improved.

The teaching and learning model used in the MOOC course is based on social and cognitive constructivism. Here individuals are required to organise data to make sense of it. This organisation will lead to further extensions of the learning. When one constructs meaning it will lead to the creation of systems of meaning.

According to research by Dewey (1938), Piaget (1964), and Vygotsky (1986), learning is a process of connecting new ideas with earlier existing understanding. The knowledge base (Alexander 1996) is a scaffold that supports the construction of new learning. Making sense of what is being done is not only an individual activity, it occurs in a complex social system in a particular context.

Learning is an active process that starts with some knowledge and builds on existing ideas through constructions in the mind of the learner. Context and time are essential components of a learning situation. The way we learn gives direction to the way we view concepts and directs the way we can use the learning.

Online educational resources (OERs) may be used in an online educational environment. In their study, Littlejohn and Hood (2017) explored how educators can engage in meaningful learning opportunities, which will facilitate the creation of expertise and knowledge through the use of open education resources (OER). Careful evaluation of study material is necessary for a smooth transition of concepts that students need to be mindful of. This will avoid an unnecessary overload of course material and keep students motivated.

We find that computational weaknesses arise often due to students misreading signs or failing to do basic computations (sometimes because they rely on a calculator). Others find difficulty in sequencing steps or have difficulty in connecting abstract conceptual ideas with reality. Rachal, Daigle, and Rachal (2007) found that students reported learning problems that are related to poor information processing, reading, writing, motivation to study, math, and test-taking skills.

Research into teaching and learning algebra provide valuable insights into student experiences. These can be factored into the learning design to alert students to possible errors and misconceptions in algebra learning (Naidoo 1997).

Digital literacy is a prerequisite for the effective use of technology in a digitally driven learning environment. It encompasses more than just the use of software. It includes the ability to follow or read instructions from graphic interfaces (photo-visual literacy), being able to copy and paste (reproduction literacy), the construction of knowledge through non-linear navigation (lateral literacy) and evaluation of information (information literacy) (Eshet-Alkalai 2004). Digital literacy skills are needed to participate effectively in a technology driven learning environment. These can be developed by peer assistance and networks that students create through participation.

Deep and surface approaches to learning have been used in many contexts (Biggs 1979; Entwistle and Ramsden 1983). To understand the difference between deep, intermediate and surface learning some characteristics of each learning type are reviewed. Deep approaches deal with understanding and making meaning one's own. Weimer (2012) refers to cognitive learning behaviours that deep approaches use. The main trait is attempting to understand material for oneself and making the ideas one's own. Applying this strategy solution to problems will be guided by logical and sequential arguments. With this approach learning allows for analysis and synthesis of ideas to develop long-term understanding of a concept or idea.

Intermediate learning takes place in-between surface learning and deep learning on the learning continuum, where some of the traits of deep learning are lacking and the knowledge base is slightly advanced as compared to the surface learning zone.

The tendency in the surface learning approach is to memorise information and procedures with the main intention of reproducing them. Little or no interrogation of ideas or guiding principles takes place in this learning style. The basic principle used in this approach is superficial retention of ideas or concepts for the purposes of recall rather than developing understanding.

Learning management systems play an important role in helping to build confidence and proficiency in novice students' efforts in algebra. By using the "interleaved worked solution strategy" instructors can provide instructional guidance to foster independent practice. By working through worked examples and doing similar practice examples students can make the transition from novice to expert capabilities in a particular concept. The student's experience needs to be motivating to encourage independent learning.

According to Kuh (2005), good educational practices require all stakeholders to focus on tasks and activities associated with a higher yield in terms of student outcomes. The quality of learning and student success should be owned by everyone in the institution.

The study used descriptive learning analytics to interrogate student examination protocols and to analyse deep, intermediate and surface strategies students use to answer examination questions. Errors and misconceptions students experience in their algebra course are highlighted and discussed.

The research question is to determine to what extent students understand the algebra concepts in the MOOC Mathematics 101 course. The study objectives include the following:

- evaluating the students' Mathematics 101 examination scores;
- evaluating the students' Mathematics 101 algebra scores;
- Analysing whether students' understanding of the algebra concepts is based on deep, intermediate or surface structures.

The study applied the positivist paradigm. A mixed-methods approach was used to collect data. The quantitative method involved the analysis of the mathematics scores and the algebra scores. The qualitative method was beneficial in providing a deeper insight into the students' understanding of the algebra concepts using deep, intermediate and surface structures as instruments.

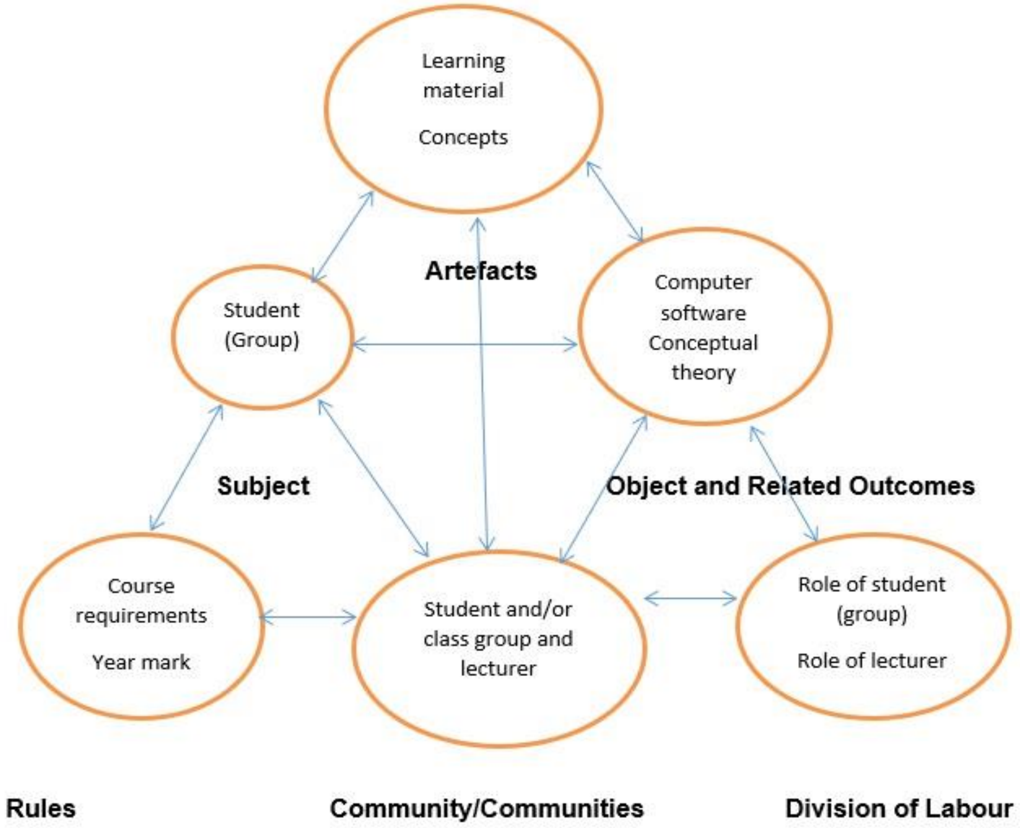
Activity Theory

Activity theory has been used extensively in various ODL studies as an analytical tool. Lim and Hang (2003) used it to explain ICT integration in Singapore schools.

Hasan and Kazlauskas (2014) give a simplified version of activity theory as developed by Vygotsky: "Who is doing what, why and how?" According to Vygotsky (1986), human reasoning is best explained through practical activity in a social environment.

The core of an activity is concerned with the subject (student) and the object (the task).

Activity theory will be used to elicit and explain the limitations of the course and will give an indication of what must be included in the course design to improve conceptual understanding to minimise errors and misconceptions.



The collective activity system used in this project is shown in Figure 1.

Figure 1: Model of collective activity system (adapted from Engeström [2000, 963])

Methodology

The target group is the first-year Mathematics 101 (MTMC 101) cohort at the School of Education, University of Technology, consisting of 156 students aged between 18 and 28 years. There were 67 male students and 89 female students. Forty students' algebra responses to the questions were randomly selected. The algebra component forms 25 per cent of the final examination. The main focus is quadratic equations and applications, exponents, surds and logarithms (limited to the application of the laws). The algebra component of the final examination is qualitatively analysed using deep, intermediate and surface learning as instruments.

All students are registered concurrently for the Skills and Life Orientation course that prepares them for using a computer to access online courses that use the University ICT services, which hosts the learning management system (LMS). Training is directed at computer basics, which include terminology, computer technology, computer literacy, e-learning, Wi-Fi and the internet. Students practised logging into the online classrooms and were shown how to do posts in the discussion forum. Autonomous learning was encouraged by dividing them into groups.

Problems based on concepts are posted on the discussion forum for students to engage with as a group. Two compulsory tutorials are done weekly where students are given the opportunity to work in smaller groups to attend to their weaknesses.

Students were given links to follow for additional examples and explanations using videos available on YouTube.

The tasks are given in Table 1.

Table 1: Algebra tasks

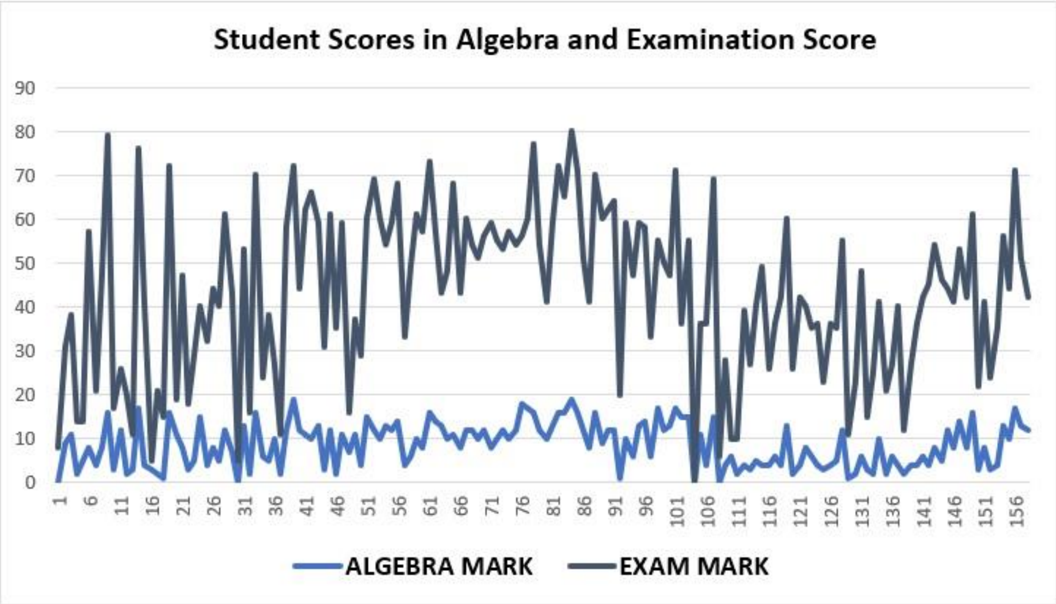
a) Solve for x: $x^2 - x - 12 = 0$
b) Solve for x: $x(4 - x) < 0$
c)Solve for x: $x(x + 3) - 1 = 0$ Express your answer in simplest surd form.
d)Solve for x: $x = \frac{a^2+a-2}{a-1}$, if $a = 888\,888\,888\,888$
e) Solve for x and y simultaneously: $y + 7 = 2x$ and $x^2 - xy + 3y^2 = 15$
f) Simplify: $\sqrt{3}.\sqrt{48} - \frac{4^{x+1}}{2^{2x}}$
g) Solve for x: $2^{x+2} + 2^x = 20$
h) The roots of a quadratic equation are: $x = \frac{3 \pm \sqrt{-k-4}}{2}$ For what values of k are the roots real?
i) Simplify: $\log 8 + 2 \log \frac{1}{5} - 5 \log 2$
j) Solve for p: $2p^2 - 3p - 2 = 0$ (Use the method of completing the square.)
k) Solve for x: $\frac{3}{x+3} - 1 = \frac{2x}{x-2} - \frac{5(x+2)}{(x+3)(x+2)}$

A pilot study was performed during 2016. Problem questions were modified and the qualitative instruments were refined. Pilot testing enabled assessment of the questions' validity and the reliability of the data collected.

Results

The 2017 final examination scores and the scores of the algebra section in the examination were compared in terms of two line graphs.

Graph 1 shows the overall examination scores and the algebra scores.



Graph 1: Exam scores and the algebra section of the exam scores

The results indicated 63 students passed the overall Mathematics 101 course but only 37 students passed the algebra section of the examination. A hypothesis test performed on the mathematics scores and algebra scores at 95 per cent probability indicates that the scores are independent.

Table 2 displays the deep, intermediate and surface learning strategies used by the candidates.

Table 2: Percentages of deep, intermediate and surface learning per item

Item	Deep Learning	Intermediate Learning	Surface Learning
A	84%,	5 %	11%
B	23%,	69 %	8%
C	69%,	8 %	23%
D	35%	12 %,	43%
E	54%	0 %	46%
F	31%	0 %	69%
G	62%	3 %	35%
H	12%	23 %,	65%
I	12%	0 %	88%
J	0%	42%	58%
K	0%	19%	81%

Discussion

The algebra scores were lower than the actual mathematics scores. Hypothesis tests performed at a 95 per cent probability suggest both scores possibly evolved over two independent population groups.

In Item A, the majority of the students displayed deep learning approaches. It appeared as if many had a sense (or understanding) of what they were doing. The equation to be factorised was given in standard form (product of factors).

In Item B, a very large percentage of students displayed intermediate understanding of inequality for quadratic equations. This could possibly indicate that conceptual reinforcement and remediation might be necessary to develop a deeper understanding of inequality of linear and quadratic equations. Writing inequalities correctly requires students to be able to make sense of their final solutions. Confusion between “<” and “>” signs were apparent (see Exemplar 3 and 4). Some students did not know what to do, so they expanded the factorised form of the expression and did not know what to do further.

In Item C, a larger percentage of students displayed surface learning traits. Here the expression had not been given in standard form and students showed cognitive strain to produce the correct factors. Comparing this item (C) to another item (A), we see that the non-routine presentation of the question was challenging to the deep approach students as well.

Item D was poorly answered. More students demonstrated surface learning than deep learning (43% were surface responses and 35% were deep responses). Since a value was given to be substituted into the expression, students just substituted the given value without making sense of the value of the expression. The surface learning students in the sample failed to simplify by doing factorisation.

In Item E, just over half the candidates displayed a deep approach to the solution. The surface strategy was characterised by participants' inability to do binomial expansions correctly after doing the correct substitution. In order to remedy such situations pre-concepts need to be reinforced. In this instance, "multiplication of binomials" or the application of "squaring a binomial" are pre-knowledge skills to solve simultaneous equations in quadratic form. Surface learning approaches just depend on recall and candidates do not focus on learning strategies since they limit themselves to the essentials needed to pass an examination. Assessment and practice examples must focus on leading students to at least the intermediate phase.

In Item F, the majority of the candidates demonstrated surface learning abilities. The concepts "surds" and "exponents" need to be dealt with more by focusing on the laws and their applications to help students reinforce their base knowledge. Although some of these problems can be approached by using a rote strategy, meaning-making skills depend on multiple applications of the laws. The surface abilities also give the impression that students are not spending enough time to be thorough with these concepts. Another possibility is that the laws are taken for granted because when practising them individually they seem to be easy.

A common error was that $\sqrt{3}.\sqrt{48}$ was written as 3.48. The expression 2^{2x} was expanded to $2^2.2^x$. The rule $(a^m)^n$ and $a^m.a^n$ were interchanged. This indicates that surface abilities dominated the structure of the solution. The multiplication of surds is problematic, $\sqrt[n]{a}\sqrt[n]{a} = a$. The students squared every term without any justification.

The student, in the exemplar above, introduces division by 2 and equates the exponents to the RHS. The student confuses exponents and seems to think exponents with the same base can be equated.

The law $a^m.a^n = a^{m+n}$ is incorrectly used. The student also struggles with addition of terms and exponents.

Some tried to use substitution and others confused the exponent laws. A solution given to the problem $2^{x^2+2} = 20$ shows the failure to recognise the plus sign between the terms on the LHS. The plus sign should have triggered the common factor mental frame but instead the student tried to multiply only the variable and then could not proceed with the solution.

In Item G, which also dealt with exponents, students performed better than in Item I. The concept "exponential equations" was applied better than the related concept "exponential laws." It would appear that the expression in Item G was easier to recognise than that in Item F. The number of candidates using a deep strategy almost doubled and consequently the number using the surface approach halved. A possible reason for this type of student behaviour is that the equation presented was easier to recognise than that in Item F.

In Item H, the majority of the candidates displayed surface learning. The concept "nature of roots" can be applied in different ways. Students were given the roots of the equation and had to relate this to the "discriminant." To extend students' thinking abilities surface approaches are insufficient. Here, the application requires intermediate and deep approaches. To encourage surface learners to attempt such problems they must be given different types of examples to practise so they can reinforce related concepts which may also involve items from another domain like inequalities. The students demonstrate surface learning skills and do not achieve the desired result. The findings in this question are consistent with the diagnostic report of the Department of Basic Education (DBE 2016)

The root of $x = \frac{3 \pm \sqrt{-k-4}}{2}$ was most problematic to the majority of participants. Either the pre-concepts "real roots" and "discriminant conditions" were unfamiliar or students were not able to link what was being asked to an appropriate concept. Answers like $k > -4$ and $k \leq 4$ showed that the concept of the nature of roots was not adequately appreciated.

Item I was poorly done. The "laws of logarithms" tested in this item show that the majority of students had surface structures associated with the laws. Each law must be applied separately to reinforce that law. A combination of the laws will be appreciated if these are adequately reinforced.

The simplification of the logarithm $\log 8 + 2\log\frac{1}{5} - 5\log 2$ yielded answers like $\log 8 + 2\log\frac{1}{5} - 5\log 2 = 3 + 2\log\frac{1}{5} - 5$. The student just dropped off the log operator in the first and last terms. Some students confused $-\log B = log\frac{A}{B}$.

Item J involved the concept of completing the square. "Completing the square" depends on a technique or algorithm for sequential development of the solution. Surface learning candidates depend on memorisation and are unable to solve such problems when the correct steps are not followed. Derivation of the quadratic formula would be an appropriate example to teach students how to complete the square when the coefficients in the quadratic equation are variables. In completing the square problem, $2p^2 - 3p - 2 = 0$, a common error was that the wrong sign was used in the binomial created $\left(p + \frac{3}{2}\right)^2$.

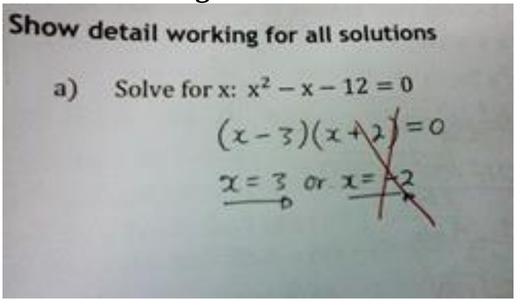
Student protocols were analysed and the marks were used to categorise them according to deep, intermediate and surface learning approaches.

In Graph 1, examination percentage scores show that almost 70 per cent of the group were getting a score of 60 per cent or less. Almost 60 per cent of the group were getting a score of less than 40 per cent. For the algebra scores, the majority of the students obtained a score of less than 20 per cent.

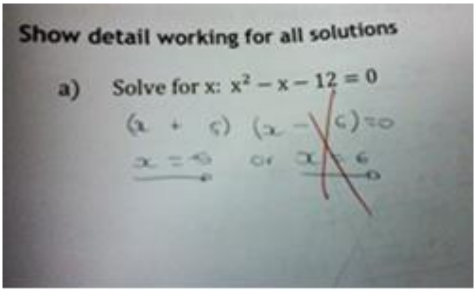
Student Algebra Examination Exemplars

Four exemplars were extracted of student responses from the examination answer books. Two types of exemplars are exhibited that illustrate surface and intermediate learning approaches.

Surface learning:

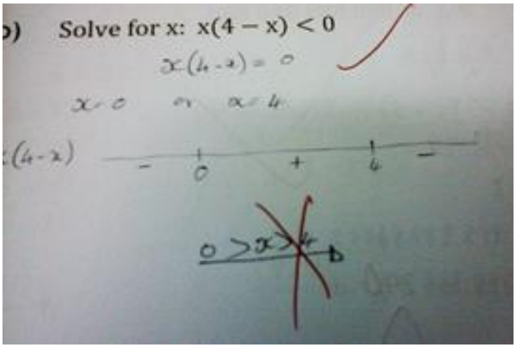


Exemplar 1

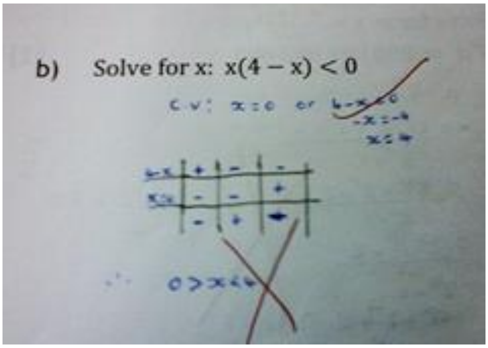


Exemplar 2

Intermediate learning:



Exemplar 3



Exemplar 4

The analyses of students' protocols reveal that surface learning solutions were characteristic of little understanding (Exemplar 1 and Exemplar 2). Students were supposed to check their solutions using techniques like simple multiplication to determine if the factors they chose were correct. It would appear that students still rely on the calculator to find their solutions. No calculators were allowed in this examination.

The analyses of the intermediate protocols (Exemplar 3 and Exemplar 4) indicate that students can find roots correctly but failed to apply the inequality solutions correctly. In Exemplar 4 the pre-concepts regarding both natures of roots and inequalities are poorly applied.

Conclusion and Implications

Student learning approaches were key to the errors they were making in the examination. Deep approaches allow students to build on prior knowledge and link existing ideas to new contexts. On the other hand, those who were producing intermediate scores lacked a strong knowledge base of basic concepts needed to solve the problems. More time must be given to reinforce these concepts at a lower grade at secondary school.

The transition from surface learning to intermediate learning needs reinforcement of pre-knowledge skills. The "interleaved worked solution strategy" may be used to explain steps or concepts to students to improve student understanding. The learning management system (LMS) will promote the principles of activity theory, allowing students to create useful networks to assist their learning.

The e-tutors and lecturers must insist that students check that the factors are correct by using techniques like the FOIL method to multiply the outer and inner terms of the factors and check if the sum or difference gives the middle term of the original expression.

It is recommended that participation in the discussion forum will allow students to construct meaning using peer learning. The discussion forum provided an opportunity for students who were struggling to get additional assistance in the form of student exemplars. Course facilitators and tutors can follow the digital footprints of the users and make constructive comments to aid the learning process. An MOOC environment provides a vehicle for both pre-service and in-service teachers to use technology and to improve their knowledge and skills.

Deep learning must be promoted using technology and the discussion forum in a learning management system. The content knowledge embedded in the LMS must be more interactive. Furthermore, every concept in the content must include pre-concepts at the level at which the student can engage meaningfully.

The LMS must include pre-test and post-test activities. This may alert the tutors and lecturers to areas of concern in the curriculum and content material. Tracking each student may also improve instructor effectiveness.

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