IMPACT OF e-LEARNING INTERVENTIONS ON THE PERFORMANCE OF FIRST YEAR UNIVERSITY STUDENTS IN MATHEMATICS

T. Omar Sheikh,
Cape Peninsula University Technology
email: sheikht@cput.ac.za

Abstract

The focus of this study was to evaluate the impact of selected e-learning interventions in addressing under-preparedness of first year university students in mathematics. The guiding model in selecting the interventions was the integrated framework for computer-based learning proposed by Hung (2003). Using this model, appropriate interventions, based on the different contexts of learning and instruction were identified. Diagnostic tests, reflecting the content domains of the Senior Certificate mathematics Papers, were used to identify the mathematics needs of the students. A one-way ANOVA revealed significant differences in performance among the content domains F(6,42)=2,40, p=0,050. Post hoc comparisons using the Tucker HSD test indicated that the mean score for Number patterns (M= 77,99 , SD=14,44) was significantly different than Statistics (M=48,36 , SD=12,69). Weekly mathematics laboratory sessions were run to address the needs. Under-prepared students' difficulties, and details of instructional approaches are discussed. The study found that the e-learning environment can provide a positive experience at the crucial transition period between high school and first year at university and enhance performance.

Rationale

A significant proportion of students entering universities have difficulties in mathematics at the first year level (Jacobs, M. de Bruin , G.P, 2009). They come from diverse backgrounds and their experiences in mathematics are varied. It is a difficult task to know what one can assume as a starting point for the first year mathematics curriculum (Cox, B, 2003). Contemporary school leavers appear to be poorly skilled and under-prepared for the challenges of university education in Science and Mathematics (Jansen, 2007).

Under-preparedness is of particular concern in applied sciences and engineering where the mathematics skills are needed for solving problems. The lecturer needs strategies to present first year content and, at the same time address the gaps and needs of the under-prepared as they unravel during instruction. In most cases, a quick review of what students are expected to know from their high school mathematics, is inadequate. While intervention programmes are well-researched, funded and established in universities in the West, there are few programs that focus on the needs of the under-prepared in higher education in South Africa (Louden et al., 2000). Hence, the need to identify what mathematics

conceptions, skills and processes learners bring to the mathematics lectures and the intervention and remedial strategies needed to overcome under-preparedness.

Research questions

Most institutions of higher learning administer a range of tests to learners on entry. These are useful to pinpoint the gaps and needs of the under-prepared and to design appropriate interventions. The focus of this study was to identify the mathematics domains in which students are struggling and provide supplemental support through e-interventions. Specifically the study will address the following research questions:

1. What are the mathematical needs of under-prepared university students?
2. Do the mathematics interventions support and remedy the identified needs?
3. What factors influence the effectiveness of the mathematics interventions?

Literature Review

Several research studies have highlighted the steady decline over the past decade of basic mathematical skills and of the level of preparedness of students accepted into institutions of higher learning. (Cox,B , 2003, Jacobs 2009, ; M, de Bruin , G.P, 2009). Research has also highlighted student difficulties with the concepts of functions (Clement, 1985; Tall , 1997) , limits (Oerhtman, 2002, Bezuidenhout, 1998) and derivatives (Ellison 1993).

Fuchs et al (2005) found that computation and problem solving represent distinct domains of mathematical cognition in the under-prepared and that we need to consider these separately for diagnosis and instruction. Cognitive research has focused on the relation between mathematical ability and visualisation (Duval, 1999). Presmeg (1992) found that the difficulties of iconic visualisers compared to schematic visualisers are widespread and robust.

Several studies have highlighted the role of technology in learning mathematics. Hughes-Hallet (1991) used and recommended a graphical approach, and Palmiter (1991), and Kendal and Stacey (2001) used computer assisted learning. Artigue, M (2002) distinguishes between the epistemic, pragmatic and heuristic contributions of technology in the learning of mathematics. She emphasises the ease with which learners using computers can move between different representations of mathematics objects, paving the way for more advanced concepts.

Several studies (CAI) have pointed out the factors affecting the efficacy of interventions. De corte, E (2006) conducted an intervention study in higher education using the CLIA framework which emphasises cognitive skills (orienting, planning, self testing and reflecting) as well as affective skills (self judging, valuing, coping and attributing). Student performance operating in this framework improved.

Other factors impacting on the efficacy of the interventions include the following: mathematical domain (algebra, problem solving, etc), the timing of the intervention (early interventions reduce anxiety), the length of the interventions (affect the range and depth of skills addressed) as well as the instructional method (constructivist, behavioural).

Particular settings, such as mathematics laboratory sessions, the use of calculators and graphing tools, have an important role in the instructional sequence. A mathematics laboratory session can be used as a context for students' initial context-dependent thinking, and then become a *model for* more independent learning. (Gravemeijer, 1997). The activities lead the student through levels of thinking from concrete to abstract, knowledge to comprehension and application as well as problem solving. The instructional tools advance the complexity of the task, enable different representations and potentially raise the sophistication of the student's thinking. Instruction focuses on engaging the student in independent, sustained thinking. (Wright, et al., 2006).

There are several implications of the literature review on the current study. Effective interventions require flexibility to meet individual differences. They need to offer a spectrum of services including interactive mathematics tools, immediate feedback and counselling. The enhanced visualisation and representation that technology offers in the teaching and learning of mathematics is invaluable. The mathematics laboratory interventions designed for use in this study present text, concepts and skills, and have embedded interaction items as well as practice, quiz and self testing features. The focus of the mathematics laboratory sessions was to enable the learner to move easily between algebraic, verbal, graphical and tabular representations. The transition from instructor dependent learning to independent learning is less traumatic as technology opens the possibility of 'own time, any place, anywhere' learning with built-in immediate feedback features.

Theoretical framework

The conceptual framework adopted for this study is the integrated framework for computer based learning proposed by Hung (2003). According to Hung, theories of learning including the behaviourist, cognitivist, constructivist and social constructivist models play an important role in identifying e-intervention tools for addressing the needs of the under-prepared. Rather than treating the learning theories as discordant entities, we use and apply appropriate computer-mediated tools and instructional technologies, based on the different contexts of learning and instruction. Tools for e-learning identified by Hung are shown in Figure 2.

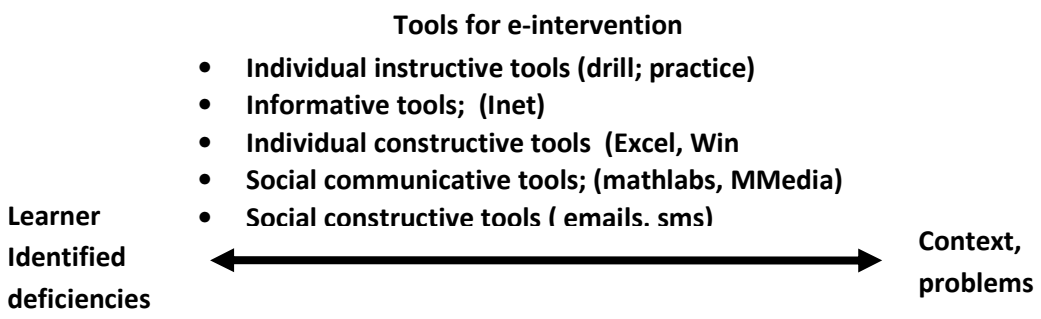

Figure 1 Tools for e-intervention identified by Hung (2003)

As Figure 1 shows, the individual instructive tools include closed-ended, tutorial type, direct individual instruction systems that allow for drill and practice, common in the behaviourist theories of learning. *Informative* tools such as the Web based blackboard, and the internet provide necessary materials and resources for students to construct their knowledge**.** *Individual constructive tools* include spreadsheets, word processors, mathematics software and simulations. These can support guided inquiry and can be used constructively fo exploring new concepts. S*ocial communicative tools* include video conferencing, laboratory management systems, multimedia, e-mailing and similar systems, which enable communicative processes between users. *Social constructivist tools* are simulations, sms and e-mails, that support learning through social constructivistic processes. A common feature of all constructivist programs is that they shift authority and responsibility for constructing new knowledge to the student. In e-learning there are cognitive and affective learning benefits from this shift. Cognitively, students are able to hold instructional content in short-term memory longer when they directly control media. This is crucial to building links between new information and prior knowledge.

Research Design

The instructional design used in this study involves identifying the mathematics needs and projecting a potential learning trajectory for the under-prepared learners. An intervention program is a structured plan for providing instructional materials and activities to support learning. In this study, e-learning modules, tutorials and mathematics laboratory worksheets were used to support the under-prepared learners. See Appendix . An appropriate instructional sequence of tasks and activities that foster development along the trajectory was developed. The research design is outlined in Figure 2.

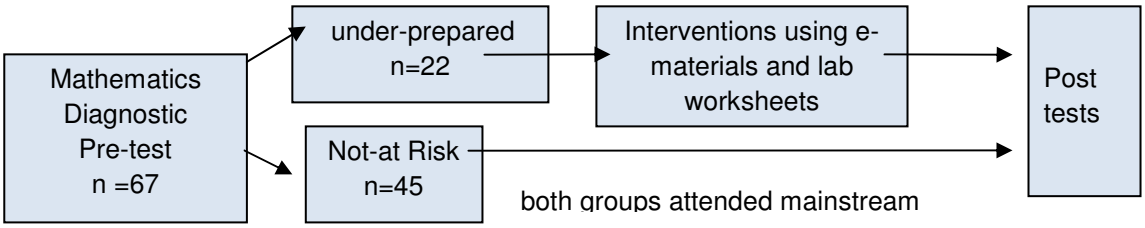

Figure 2 Research design used in this study

Research Methodology

Two mathematics diagnostic tests, were administered to the 67 students who joined the National Diploma in Mathematical Technology program. The majority of the students had obtained a 4 (50% – 60%) in the Senior Certificate Mathematics examination in the previous year. The first test consisted of 24 multiple choice questions answered without the use of a calculator. The majority of items in Test 1 were level 1 (knowledge) and level 2 (routine procedure) questions like "The period of $y = 2 \sin 3x$ is…" and "If $y = 2\sqrt{x}$, then

dy/dx =….. Test 2 had 49 items categorised under seven content domains: Number patterns,(8 items) Algebra (7 items), Analytical Geometry (5 items), Trigonometry(6 items) , Calculus(13 items), linear programming (5 items) and Statistics(6 items). In Test 2 learners had access to a Formula sheet and were allowed the use of calculators.

The post-test focused mainly on content that learners were underperforming in. The post-tests were administered after the interventions that lasted 4 weeks. Throughout the study, all students, including the 'not at risk' attended the mainstream lectures.

E-interventions

Twenty two students, who scored below 50% in the diagnostic tests, participated in the interventions. The interventions consisted of weekly mathematics laboratory sessions held in addition to the mainstream lectures. The first session was an instructor-led session, where learners logged in and learnt to navigate their way through the mathematics software and the content modules. The software used was a graphical package called Winplot and the e-modules used were PPlato Math Support Modules. The packages were produced using LaTeX and converted into PDF files. The learners loaded the software and specific content modules on their flash drives and could work with them on any computer after the laboratory session. The content modules had built in hyperlinks that gave feedback to their selected responses. In addition, worksheets were used for targeted interventions. See Appendix A2. Learners were encouraged to work out their solutions on paper and check their answers. The lecturer's role was that of a facilitator. Post tests were used to evaluate the effect of the interventions on the performance of the learners.

Data Analysis

The first research question was to identify the mathematical needs of the under-prepared. The diagnostic tests administered to all 67 students provided valuable screening data. Details of the data analysis follow.

Figure 3 shows student performance on the 24 items in the first diagnostic test. Students did not use calculators in this test. The Kuder Richardson test reliability index for the test was 0,63. A test reliability cut-off of 0,60 is common in exploratory research. The measure of reliability indicates the likelihood of obtaining the same results if the test is repeated. Following current research trends, if more than 60% of the learners got an item incorrect, the content was earmarked for review. Most of the items in this test were 1-step or 2- step, knowledge or routine procedure questions.

Item analysis of the test showed that students found Items 8, 10, 11 and 22 difficult. Items 17 and 21 had poor item-test correlation values (< 0,1) and the item difficulty values, adjusted for guessing, were below 0,1.

Item 8 asked students to find the turning point on the curve $y = x^2 + 5x + 4$. It could have been answered by constructing a table of points (x ; y) and sketching the curve or recognising that the equation represents a parabola and using $x = -b/2a$ to find the line of symmetry, or finding the gradient dy/dx by differentiation and

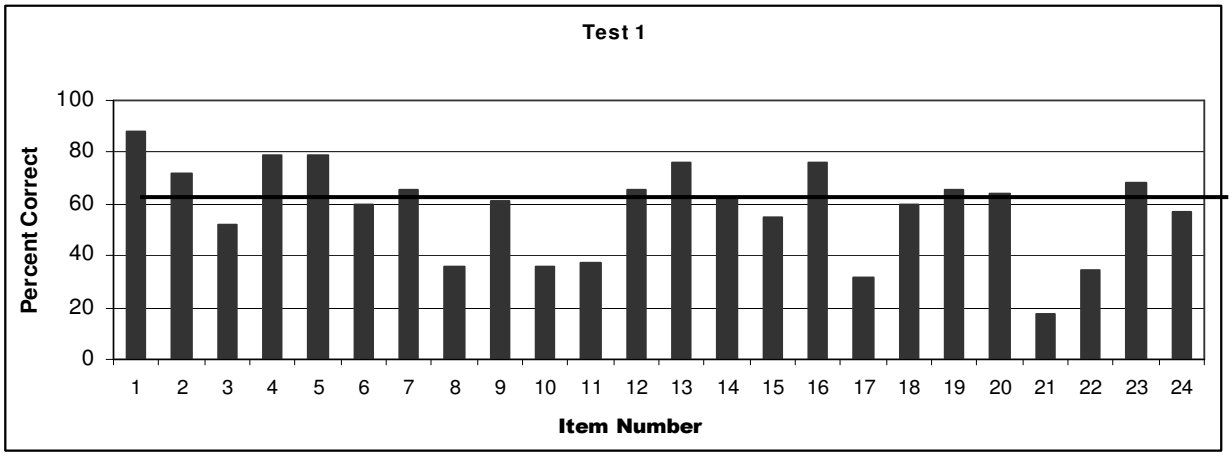

Figure 3 Percentage of students who answered the item correctly (No calculators were used in the test)

locating the turning point by setting dy/dx equal to 0. Only 36% of the students answered this question correctly. Errors in computation, graphical representation and algebraic substitution could have led to incorrect responses.

Item 10 shows that nearly two-thirds of the students had problems with the order of operations in a calculation. Could this be attributed to the over-reliance on a calculator to perform basic calculations? This has negative implications when students attempt to simplify expressions like $4x - 8x \div 4(x + 2)$ in algebra.

Items 17 and 21 have poor discrimination indices. The strong students fared just as badly in the item as the weak students. Finding cos 120° turned out to be very difficult (18% got this correct). Errors in applying Pythagoras Theorem to a 1, 2, √3 triangle, and applying sign conventions incorrectly are common. Figure 4a.

Items 11 and 22 were mensuration problems. In item 11, the surface area of the closed cylinder required students to disaggregate the curved side into a rectangle and the two circles at the top and bottom. Figure 4b. They then had to find the sum of the areas. Common errors include not relating the length of the rectangle to the circumference of the circle, confusing a diameter with the radius and incorrect substitutions. Often students use memorised formulae and substitute without thinking.

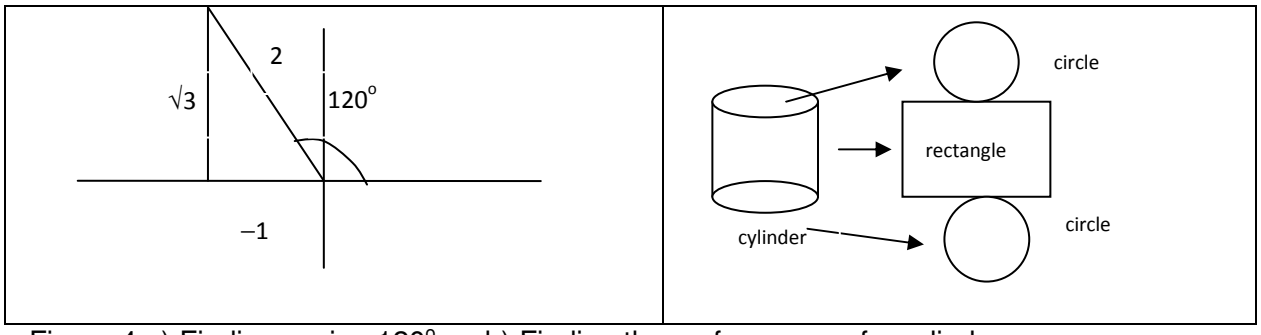

Figure 4 a) Finding cosine 120° b) Finding the surface area of a cylinder

In general, it seems that students have difficulties in basic computation (order of operations), algebra (graphing, inequalities), trigonometry and mensuration.

Pretest –Post-test comparisons

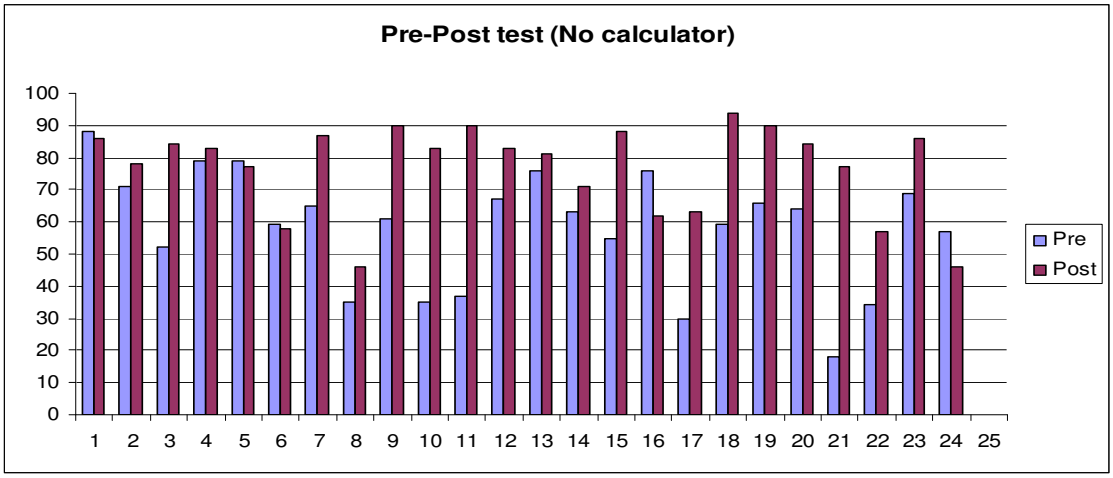

Figure 5 Pretest- Post test comparisons by items

The pre-test post- test comparisons by items on the first diagnostic test showed a slight improvement on most test items. The gains on item 8 on finding the turning point of a parabola were marginal (35% in the pre-test and 46% on the post-test). The equation of the parabola in the post test was $y = 2x^2 - 4x - 4$ which gives an easy to substitute x value of 1.

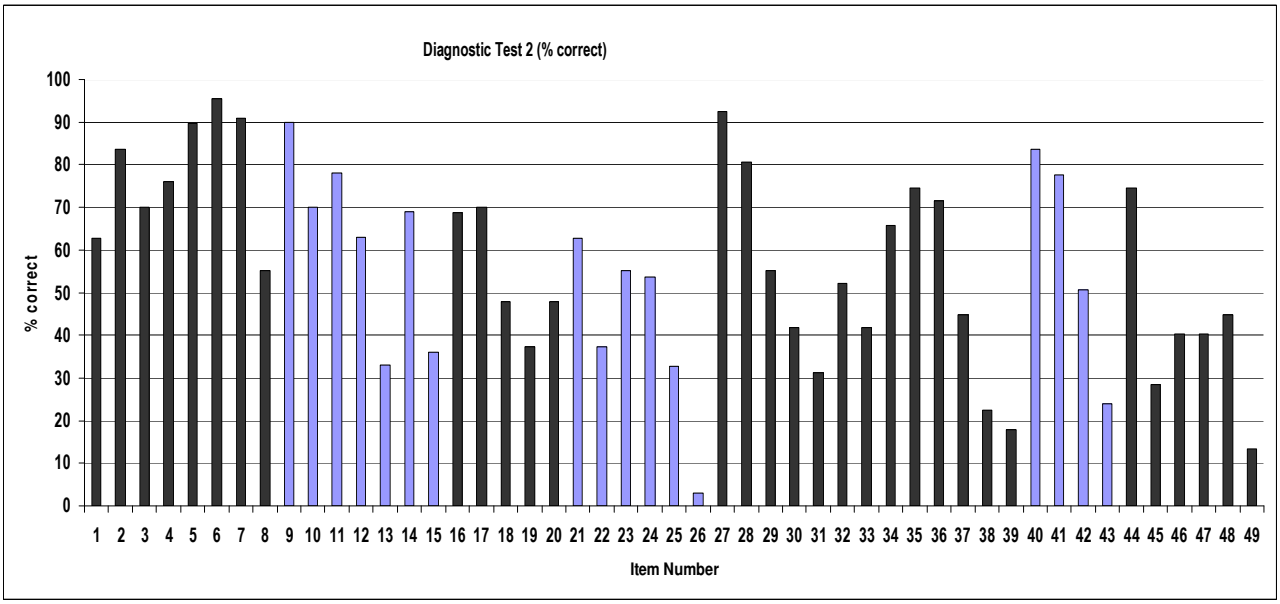

Figure 6 Performance on Pre-test 2 with items under different content domains

(**Number Patterns (1-8) Algebra (9-15) Anal Geom (16 – 20) Trig (21 – 26) Calc (27-39) Lin Prog (40-43)**
Stats (44-49))

The second diagnostic test had 49 items grouped under seven content domains similar to the Senior Certificate Mathematics papers. The results are displayed in Figure 6. The graph shows under-performance in nearly half of the items in the test.

The largest proportion of incorrect responses were in Trigonometry (5 out of 6), and Statistics (5 out of 6). The performance in Analytical Geometry (3 out of 5) and Calculus (6 out of 13) was poor.

A one-way ANOVA, used to test for differences between the means of the content domains, revealed significant differences [$F(6,42) = 2{,}399$, $p = 0{,}044$] . Post hoc comparisons using the Tucker HSD test indicated that the mean score for Number patterns (M= 77,99 , SD=14,44) was significantly greater than for Statistics (M=48,36 , SD=12,69). A complete ANOVA analysis performed in SPSS is presented in the Appendix (Table A1).

Underperformance in algebra (Items 13, 15, 19, 43), trigonometry (22, 25) , calculus (30, 37, 38) and Statistics (45 – 49) is evident. Closer scrutiny of the items in which the students under-perform reveals the following:

- All these items are at cognitive level 3 (complex procedures) or level 4 (solving problems). They involve multiple steps in their solutions.
- Algebraic understanding requires multiple skills including symbol manipulation, simplifying, factorising, completing the square, solving equations, graphing equations and inequalities.
- Students have difficulties in solving word problems and there is a lack of understanding of relationships between variables,
- There are difficulties in graphing relationships between variables and moving between symbolic, tabular and graphical representations. Items 20, 23, could be solved graphically.

In conclusion these findings suggest that incoming students need intervention and guidance in content domains such as Statistics, Algebra, Trigonometry and calculus. In addition, lack of skills in reading graphs, problem comprehension and representation, as well as in problem solution need to be addressed.

Impact of the interventions on student performance

The second research question investigated the effectiveness of the interventions. Only students in the intervention group who had attended all the tests and the laboratory sessions were included in the data analysis. This reduced the intervention sample size from 22 to 18. For the students receiving e-intervention, t-test comparisons reveal significant differences between pre-test scores (M=37,67, SD = 6,76) and post test scores (M=50,67, SD =12,04) $t(17) = 4{,}57$, $p = 0{,}05$

Factors affecting intervention

The third research question addressed the factors affecting effectiveness of e-learning interventions. Data to address this question was gathered by the researcher through observations of student engagement during the laboratory sessions. The factors that stood out most include the following:

- Students' prior computer experience and, in particular, keyboarding and navigation skills must be considered. Skills such as switching on, logging in, using the software and exiting from the program are important first steps and need to be developed.
- Lack of access to computer facilities outside class time limits the benefits of the software and the e-modules. In particular, the non-resident students cannot make full use of the IT facilities.
- Not all students switch easily to learning through exploration and discovery. The didactic switch needs to be gradual.
- Language factors have a major impact on e-learning. Complex wording such as "Each equation has a parameter, *A* that you can change easily. Explain using graphs, what happens when you take A through negative, 0 and positive values for these functions: $f(x) = Ae^x$, $f(x) = A\,\ell n\,(x)$, $f(x) = A\cos(x)$" need translation into simpler language.
- The length of the intervention is an important factor in the success of e-interventions. Remediating higher cognitive level deficiencies takes time.

Conclusions

In this study, diagnostic tests were used to identify the needs of under-prepared students. Targeted interventions in the form of weekly mathematics laboratory sessions were used to address the needs. Pre and post test results on both diagnostic tests indicate significant gains for those who received e-interventions. Factors that had an impact on the effectiveness of interventions include previous experience with computers, language factors, and the duration of the intervention.

The findings of this study are significant for educators in high schools and tertiary institutions. There is a need for collaboration and curriculum alignment between the two levels of institutions. Content domains such as trigonometry and calculus where students under-perform stand out and need attention. In addition, practical issues, in the use and application of technology and e-learning in high schools, need attention. There needs to be a shift in emphasis from preparing learners to pass exams to thinking critically and analytically and solving problems.

Further research is needed to determine if the content domains of under-preparedness are stable from year to year and whether they apply equally to institutions that have better intakes. More studies are also needed with larger sample sizes, and randomized assignment to different intervention methods.

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Appendices

A1: Results of one-way ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6401.298	6	1066.883	2.399	.044
Within Groups	18680.490	42	444.774		
Total	25081.788	48			

A2: Selected items from Diagnostic Test 1 in which students under-performed. The response alternatives for each item have been removed.

Item (answered without using a calculator)	% correct
8. The coordinates of the turning point of $y = x^2 + 5x + 4$ are:	36
10. $(4+8) - 8 \div 4 \times 2 =$	37
11. The surface area of a cylinder of height 10 cm and diameter 6 cm is:	37
17. Which of these graphs shows the region: $y < 2x + 5$	30
21 cos 120 is;	18
22. the area of the trapezium shown is	34

A3: Selected items from Diagnostic Test 2 where students under-performed. The response alternatives have been removed.

Item	**Pretest % correct**
13. Solve $\|2x - 8\| = 5$. The solution set is :	37
15. A square with sides of length x has perimeter P and area A. Then A expressed in terms of P, is:	39
19. A circle has the equation $x^2 + 2x + y^2 - 2y = 7$. The centre and radius of the circle are:	43
22. The number of solutions x to $3 \cos 2x = 1$ in the range $0 - 360^\circ$ are	37
25. If $\cos x = -0.5$, what is x in the range 0 to 360°	34
30. What is the equation of the tangent to the graph of $f(x) = 3x^2 - x^3 - 1$ at $x = -1$ (with graph)	33
37 . What is the equation of the tangent to $y = 3 - x^2$ at (1 ; 2) (No graph)	19
38. What are the coordinates of the point on the line $y = 5 - 2x$ closest to (0,0)?	21
43 Given the objective function $P = 2x + y$ and the constraints $x \geq 0$, $y \geq 0$, $y \geq x - 2$, $y \leq 4 - x$ what is the maximum value of P? graph given	26
49 The number of hours 8 students spent studying daily were : 5 7 8 5 6 6 4 3 What is the standard deviation of this data?	16

Appendix A4 Sample e-learning activities

Activity 1. Changing the parameters e-mathematics worksheet

Each equation has a parameter A, B,…that can be changed. Sketch graphs to explain what happens when you take A through negative, zero and positive values eg $y = Ax^2$, $y = Ae^x$, $y = A\,\ell n\,(x)$ $y = A\cos(Bx)$

Activity 2 Guess my equation: Learners enable the type of graph. The software offers a choice between parabolic, polynomial, trigonometric, logarithmic and exponential graphs. After each guess they can check the answer.

Activity 3 Differentiate the functions y below using the chain rule. Use the suggested u substitution (click on the green letters for the solutions).

(a) $y = \ln(x^7 + x)$, $u = x^7 + x$ (b) $y = \cos(\ln(x))$, $u = \ln(x)$