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Window into First Year Students' Preparedness: Basic Arithmetic and Algebra

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ABSTRACT This paper reports on the results of a diagnostic quiz for basic arithmetic and algebra. The quiz items were based on elementary knowledge and skills expected of first year students to perform essential mathematical tasks and to communicate the results of such tasks. The quiz was taken online voluntarily by 428 first year students who were registered for a calculus module at a South African university. The multiple choice items in the quiz focused on: Operations on numerical fractions; Operations on algebraic fractions; Operations with monomials; Operations with exponents; Operations with logarithms; Linear equations and linear inequalities. Results indicated that a significantly large number of the respondents did not have the necessary level of preparedness to successfully study the calculus module that they were enrolled for. The percentages of students lacking the relevant knowledge and skills for the indicated sections are documented in the results section of the paper.

INTRODUCTION

Maharaj and Wagh (2014) outlined a pre-course diagnostics for first year university students studying calculus. An online quiz based on their work was made available to students. This paper focused on the outcome of the quiz and proposed a mechanism for remediation to address the under-preparedness of the students opting for a course on differential calculus. The research first analyzed the results of the diagnostic quiz on basic arithmetic and algebra based on the work of Maharaj and Wagh (2014). Based on the findings, a remediation strategy was formulated to bring students to the desired level of preparedness for the differential calculus course.

Objectives

In this paper the researchers addressed the following research question with reference to students studying at the University of KwaZulu-Natal (UKZN). *What is the level of competence of first year university students in basic arithmetic and algebra?* This question was investigated with regard to those students who enrolled for the main stream mathematics' module, *Introduction to Calculus*, offered at UKZN during the first semester of 2014.

Literature Review

This focuses on mathematical under preparedness, major areas of under preparedness and support structures.

Mathematical Under Preparedness

Evidence of the under preparedness of incoming first year students to study university mathematics has been documented in various reports (for example, London Mathematical Society, Institute of Mathematics and its Applications and Royal Statistical Society 1995; Department of Basic Education 2013, 2015) and also by various researchers (for example, Sander and Cleary 2004; Gill and O'Donoghue 2007; Jennings 2009; Faulkner 2011; Maharaj and Wagh 2014; Ally et al. 2015; Maharaj et al. 2015; Maharaj and Wagh 2016). In the literature, the under preparedness of such students in the context of European countries is often referred to as the *mathematics problem* (London Mathematical Society, Institute of Mathematics and its Applications and Royal Statistical Society 1995; Gill and O'Donoghue 2007; Faulkner 2011) while in Australia the term *first year experience* (Jennings 2009) is used. The descriptions of *mathematics problem* according to O'Donoghue (2004) include: Mathematical shortcomings of entering students; Mathematical deficiencies of entering students; Pre-requisite mathematical knowledge and skills; Mathematical preparedness/under-preparedness; Mathematics at the school/university interface; Issues in Service mathematics teaching; Numeracy/Mathematical literacy. This *mathematics problem*, *first year experience* or under preparedness contributes to an ever increasing number of students who fail to continue in their studies of university mathematics. In turn this results in huge financial losses to universities and the state.

This mathematics' under preparedness affects students in various fields of study at universities. The reason for this is that an increasing number of areas of science, technology, management and commerce use mathematics as the only effective language for the analysis of their problems and also for the communication of their results and ideas (London Mathematical Society, Institute of Mathematics and its Applications and Royal Statistical Society 1995). This report also pointed out that the *mathematics problem* is extremely serious for the following three reasons: it is not a case of some students who are less well-prepared; many 'high-attaining' students seriously lack in fundamental notions; for any modern economy a sound education in mathematics is important, both for the mass of ordinary students and for the mathematically more able.

It seems from the literature that the under preparedness of students entering university to study mathematics is a universal problem. In South Africa the University of Pretoria (UP) introduced an extended study programme to create opportunities for students who were identified as at risk academically and/or did not meet the entry requirements for the engineering degree (Jennings 2009). That university found that students could be at risk due to the following reasons: limited educational background; unrealistic expectations of engineering study; an inability to cope with demands of tertiary education; a lack of motivation; limited career information; the transition from a secondary to a tertiary teaching; learning environment (Steyn and Du Plessis 2007). It should be noted that some of those reasons could classify a student as at risk even in courses that do not relate to mathematics. To address the issue of underprepared students UP used questionnaires and quizzes to gain information on the students' level of preparedness for tertiary study and to identify possible weaknesses in the students' knowledge (Steyn and Du Plessis 2007). More recent studies by Ally et al. (2015) and Maharaj el al. (2015) reported on the use of e-learning to address the *first year experience* in the South African context and their effect on student success. Those studies suggested that e-learning could serve as an important form of student support to address the *mathematics problem* with first year students. The study by Ally et al. (2016) concluded that student performances with regard to educational attainment could be improved by using suitable e-learning methods.

Major Areas of Under Preparedness

The London Mathematical Society, Institute of Mathematics and its Applications and Royal Statistical Society (1995) noted that the serious problems perceived by those in higher education are: a serious lack of essential technical ability to undertake numerical and algebraic calculation with fluency and accuracy; a lack in analytical powers when faced with simple problems requiring more than one step; a changed perception of what mathematics is. The latter refers to the essential place within mathematics of precision and proof. These imply that precision relating to the ability to undertake numerical and algebraic calculation is essential in the study of mathematics. Other studies have also noted the lack of this ability among first year university students. Sander and Cleary (2004) identified a deficiency in basic mathematics skills in first year undergraduate students relating to proficiency in foundational mathematics calculation, in particular the greatest area of weakness was for calculations in the context of fractions. The paper by Gill and O'Donoghue (2007) noted that mathematics' lecturers complained that students displayed: lack of fluency in basic arithmetic and algebraic skills, gaps in or absence of basic prerequisite knowledge in important areas of the school syllabus (for example, trigonometry, differential calculus); an inability to use or apply mathematics except in the simplest or most practiced way (O'Donoghue 1999). Faulkner (2011) argued that in the English education system a decrease in competency such as those, could partially be due to heavier reliance in schools on calculators. In the opinion of the researchers, this could also be one of the contributing factors in the South African context.

Support Structures

To address the problem of underprepared students the paper by Gill and O'Donoghue (2007) noted that diagnostic testing was introduced at the University of Limerick. The reasons for that were: to diagnose those students who were most likely to fail; to make students themselves aware of their level of expertise (or lack of it as was often the case!); classify major areas of weakness in the group of first years as a whole; identify the support that will be needed to help remedy the situation. It was found that 30 percent of first year service mathematics undergraduates required extra support (Gill and O'Donoghue 2007). At the University of Limerick a Mathematics Learning Centre (MLC) was established. The following eight resources and facilities are provided at the MLC: *The Drop-In Centre* - without appointments free one-to-one consultations are provided to students; *Diagnostic Testing* - to identify and inform students who need supplementary help; *Support Tutorials* - set up and taught on a weekly basis of an hours duration in addition to regular tutorials to small groups of students (about 10); *Textbooks* - multiple copies of all the required textbooks for the various mathematics offered at the university are provided; *Computer Assisted Learning (CAL)* - 5 computers are provided for access to CALMAT tutorials; *Examination Revision Programmes* - focuses on the organization of revision programmes for all the main service mathematics courses; *Peer Tutoring* - a mutual benefit programme that makes use of volunteer student teachers who have teaching practice throughout their degree programmes to teach mathematics based on access courses; *Online Support* - the MLC website provides online support help specifically designed for each service mathematics course offered at the university.

Gill and O'Donoghue (2007) reported that: students preferred support that was on a one-to-one consultation basis; there was a distinct, if not decisive, advantage for those students who attend support tutorials over those who do not attend as measured by the results on the next and subsequent university mathematics examinations; unfortunately such attendees were in the minority so some action was needed to reach all those who need help but were not making use of the support structures; analysis of their university database showed that 78.3 percent of those deemed to be in need of help, failed to attend the support tutorials in the first semesters and 78.5 percent in the second semesters. As noted by those researchers it is not always possible to provide support that involves personal interaction. With the increase in student numbers at universities there is therefore a need to invest in online services and to customise these for student use out of hours and also off campus.

Feedback received from the academic development officer (ADO) of the School of Mathematics, Statistics and Computer Science at the University of KwaZulu-Natal (Mshengu 2014) revealed that the normal support structures that were in place during the period 2010 to 2014 were: tutorials for in-course material; hot seat tutors available for 4 hours a day for five days of the week that the students could consult at their convenience; interviews with at risk students; supplemental instruction (SI) organized by the ADO for students who felt they required extra help. It was noted that the latter two support structures were not well attended. Further a concern was expressed that more of the students who were classified as good or above average were attending the support structures than those who were classified as at risk.

Conceptual Framework

This was guided by the literature review. The main principles on which the conceptual framework was based were:

1. Learning of mathematics is hierarchical in nature (Maharaj and Wagh 2014);
2. There was a need to investigate the informal feedback provided by first year lecturers at the University of KwaZulu-Natal (UKZN) on their perceived lack of pre-requisite abilities of students to study mathematics (Maharaj and Wagh 2014);
3. There is a need to critique and improve the support structures available to students who study first year mathematics at UKZN.

It was decided to do the investigation and critiquing with reference to the *Introduction to Calculus* module offered to first year mainstream students on the Westville Campus of UKZN.

METHODOLOGY

The diagnostics for pre-course differential calculus designed by Maharaj and Wagh (2014) were converted to five multiple choice format quizzes and made available online to students enrolled for the *Introduction to Calculus* module; see Appendix A, quizzes for Sections 1 and 2. During the first lecture and formal tutorial the students were encouraged to take those quizzes in their own time. The module website for *Introduction to Calculus* gave under the topic *Diagnostic Quizzes* links to Pre-calculus Diagnostics and In-course Diagnostics. The taking of any of the quizzes was voluntary. Upon making an attempt to access the Pre-Calculus Diagnostics website the general instruction was available to the student. That instruction indicated that the student was encouraged to take the quizzes provided and that further it would be to his/her benefit to make a note of individual strengths/weaknesses and to then take the necessary remedial measures; get help for example by studying the section on his/her own or consulting a tutor. In the present investigation it was decided to focus on the first quiz that comprised of 23 questions targeting basic arithmetic and algebra prerequisites. The question types are indicated in the Results section.

The data for the student responses to the quiz on Basic Arithmetic and Algebra was obtained from the online learning MOODLE site used by UKZN. That data was collated and analysed for the following broad headings: Operations on numerical fractions; Operations on algebraic fractions; Operations with monomials; Operations with exponents; Operations with logarithms; Linear equations and linear inequalities. This provided answers to the research question. Out of 442 students registered for the module 428 students (about 96%) took that quiz. Some of those students took the quiz more than once; since there were 474 attempts; see Appendix A. It should be noted that the collation and analysis of the data was based on the data for first attempts only; which the MOODLE system was able to generate. The recommendations were guided by the literature review and written feedback communication by email received from the ADO of the School of Mathematics, Statistics and Computer Science at UKZN. This required a study of the available support structure and how that could be improved.

RESULTS

These are presented under the following sub-headings: Operations on numerical fractions; Operations on algebraic fractions; Operations with monomials; Operations with exponents; Operations with logarithms; Linear equations and linear inequalities. The findings are summarized in Tables 1 to 6.

Operations on Numerical Fractions

Table 1 indicates that about 30 percent of those first year students lacked basic competence in the operations of addition, subtraction, multiplication and division on very simple numerical fractions. This suggests that such students should also have difficulty in performing calculations that involve simple algebraic fractions. Table 2 confirms this.

Table 1: Operations on numerical fractions (n = 428)

Questions	*Correct responses (%)*
$\frac{1}{2}+\frac{1}{3}=$	75
$\frac{1}{2}-\frac{1}{3}=$	75
$\frac{1}{2}\times\frac{1}{3}=$	71
$\frac{1}{2}\div\frac{1}{3}=$	72
$\frac{1}{2}\times\frac{1}{2}=$	70

Source: Author

Operations on Algebraic Fractions

It is evident from Table 2 that about 43 percent of the students, who voluntarily took the quiz, lacked the ability to correctly perform basic operations on very simple algebraic fractions. It could be concluded from the study by Jennings (2009) that about 73 percent of their first year respondents (enrolled for a specialist mathematics bridging course) and 43 percent (enrolled for the calculus and linear algebra course) could not add two algebraic fractions. The researchers note that their question type was $\frac{3}{x}+\frac{5}{x+2}$ and this in our opinion is of a more difficult structure than the corresponding type indicated in Table

2. The findings of this paper summarized in Tables 1 and 2 for basic operations with fractions supports those of Sander and Cleary (2004). Those researchers reported that only 26.66 percent of their respondents scored more than 80 percent in questions that involved operations with fractions.

Table 2: Operations on algebraic fractions (n = 428)

Questions	*Correct responses (%)*
$\frac{1}{x}+\frac{1}{x^2}=$	57
$\frac{1}{x}-\frac{1}{x^2}=$	62
$\frac{1}{x}\cdot\frac{1}{x^2}=$	64
$\frac{1}{x}\div\frac{1}{x^2}=$	62
$\frac{1}{x}\cdot\frac{1}{x}=$	65

Source: Authors

Operations with Monomials

Table 3 gives the findings on operations with monomials. It could be concluded that about 42 percent of the respondents had difficulty with foundational knowledge and skills relating to the addition or subtraction of very simple like terms of the type ax^3, for a a natural number. The findings indicated in Table 1 suggest that more students would experience difficulty with the addition or subtraction of such monomials if the numerical coefficient a in like terms of the type ax^3 takes on values that are integers or fractions. The same could be true when factors of the form ax^n; for a and n taking on values that are integers or fractions; are multiplied or divided.

Table 3: Operations with monomials (n = 428)

Questions	*Correct responses (%)*
$2x^3.3x^5 =$	61
$2x^3 + 3x^3 =$	58
$2x^3 - 3x^3 =$	64

Source: Author

Operations with Exponents

Note that Table 4 indicates that 39 percent of the respondents had difficulty for the basic calculation based on the simplification of the expression $2x^3.3x^5$. This required the application of the product law for exponents, namely if two powers that have the same base are multiplied then the result is the same as writing down the base and raising it to the sum of the indices of those powers. Table 4 indicates that 47 percent of the respondents had difficulty when raising a power to a power. In the first structure observe that the power is represented by a base which comprises of the product of the natural number 2 and the factor x^3. Basic knowledge and skills required relate to the identification and application of the following laws for exponents, $(ab)^n = a^n.b^n$ and $(b^n)^m = b^{nxm}$. Observe that for the second structure in Table 4, $(2^{x+1})^3$ classified as raising a power to a power, the index of the base comprises of two terms. Application of the law for exponents requires that the distributive property for multiplication over terms would need to be identified and then attended to.

Table 4: Operations with exponents (n = 428)

Questions	*Correct responses (%)*
$(2x^3)^2 =$	53
$(2^{x+1})^3 =$	53

Operations with Logarithms

An observation of the summary in Table 5 reveals that about 68 percent of the respondents had difficulty with operations involving basic logarithmic structures. In the study by Jennings (2009) where the question on logarithms required the evaluation of the expression, $\log_3 9+\log_4 2$, it could be concluded that 90 percent of the specialist mathematics bridging students and 73 percent of students enrolled for calculus and linear algebra had difficulty. The simplification of the logarithmic expression $\log_{\sqrt{2}} 2$ indicated in Table 5 requires similar knowledge and skills as that for the evaluation of a logarithmic expression that appeared in the study by Jennings (2009). These include identifying and applying in the correct context the change of base law for logarithms, for example $(\log_b a) = (\log a) \div (\log b)$

where the new base is 10, expressing the numbers on which the logarithm is operating as a power and then identifying and applying the appropriate law (for example ($\log 9 = \log 3^2 = 2 \log 3$); followed by the identification and division of the same factors in the context of fractions. This indicates that the logarithmic expression that appeared in the quiz at UKZN compares favorably with the question that appeared in the study by Jennings (2009). As is evident from Table 5 the questions on logarithms for the current paper were based on more basic knowledge and skills required for operations with logarithms; for example the identification and application of the addition and subtraction laws for logarithms.

Table 5: Operations with logarithms (n = 428)

Questions	*Correct responses (%)*
$\log_{\sqrt{2}} 2 =$	49
$\log_a 2 + \log_a 5 =$	53
$\log_a 2 - \log_a 5 =$	41
$7 \log_2 a = \log_2$ ____	48
$\dfrac{\log 16}{\log 8} =$	32
$\log 2 + \log 5 =$	33

Source: Authors

Linear Equations and Linear Inequalities

The results in Table 6 indicate that 46 percent of the respondents lacked the necessary pre-requisites required for solving simple linear equations or inequalities. This is rather surprising since students in South African schools encounter linear equations and inequalities regularly during their study of mathematics from grades 7 onwards. If this is true then one of the possible implications is that the learning of the knowledge and skills amongst such students was and is still possibly not focused on understanding.

DISCUSSION

The literature indicated that the *first year experience* or *mathematics problem* (which refers to the under preparedness of first year students to study university mathematics) was and still is a global concern (Sander and Cleary 2004; Gill and O'Donoghue 2007; Jennings 2009; Faulkner 2011; Maharaj and Wagh 2014; Ally et al. 2015; Maharaj et al. 2015). It seems that this under preparedness contributes significantly to the lack of student success and throughput at universities. In the South African context the DoBE (2015) diagnostic report indicated that generally the algebraic skills of their candidates (who wrote the grade 12 mathematics examination) was poor and as a result many of them performed at an unsatisfactory level. This was because they were not proficient enough to do the basic mathematics from grades 8 to 10, which resulted in poor performance in grade 12. The same argument applies to the study of university mathematics. If students do not have the basic knowledge and skills that they should have acquired during their schooling years to study university mathematics then one should expect them to perform poorly. For example, in this paper it is reported that about 42 percent of the participants failed to correctly add like terms of the form ax^3, in the context where a represents a natural number. This implies that at a significant number of the participants in this study would struggle in solving problems that require pre-requisite knowledge and skills based on the addition or subtraction of like terms. The implication here is that a lack of required knowledge and skills become stumbling blocks for students. These barriers result in student difficulty to make progress with their university studies in mathematics.

Table 6: Linear equations and linear inequalities (n = 428)

Questions	*Correct responses (%)*
$2x + 5 = a$	54
$2x + 5 \geq 3$	57

Source: Authors

The paper by Maharaj et al. (2015) reported on student responses to common errors including those based on inequalities, algebraic processes involving fractions and exponents. All of those sections still seemed to be problematic for many of the participants of this study. The reader is referred to the analysis relating to Tables 2, 3, 4 and 6 which confirm that many of the participants had difficulty with calculations based on basic knowledge and skills relevant to those sections. It should be noted that in this paper the inequality was linear in structure compared to the inequality reported on in Maharaj et al. (2015). In that study the inequality had, what could be classified as a quadratic structure. One would normally expect students to have difficulties in solving inequalities with a structure that is more complicated than the one with a linear structure. So it was surprising to detect that about 40 percent of the participants could not correctly solve the linear inequality given in Table 6.

Compared to the study by Ally et al. (2015) the diagnostic quiz items designed for this paper was simpler. The items designed by Ally et al. (2015) for a pre-test on basic knowledge and skills were used to determine the areas of weaknesses and strengths of their students. That pre-test items were cognitively more demanding and required more compression by their students to unpack what was required. The items for the present paper were formulated to be as simple as possible, so that students understood what was required and the response of the average student was expected to be almost instantaneous. The reader is referred to Tables 1 to 6, to get an insight into what the focus was on and the level of preparedness of the participants. Since the participants were science students, for which there was a stringent pre-requisite enrolment requirement relating to their grade 12 final mathematics result, the expectation of the researchers was that most of the students would get the items correct. The statistics in Tables 1 to 6 indicate that was a false expectation. Of particular concern was the low correct response percentages for items on operations with logarithms indicated in Table 5. For example only about a third of the participants could simplify the logarithmic expression, $\log 2 + \log 5$. It should be noted that online diagnostic quizzes is one form of student support that could be used to address the global issue of *first year experience* or *mathematics problem*. However, this needs to be within a framework of coordinated student support structures as discussed by Maharaj and Wagh (2016) for students to obtain greater benefit. In a developing country like South Africa there are a significant number of students who still want face to face consultations with a view to addressing their shortcomings. The aim of setting up the online diagnostic quizzes was to provide a means for students to identify their strengths and weaknesses, if any. Then the student was expected to take the necessary remedial measures to overcome the identified weaknesses. For example, this could be further studying or consulting with a hot seat tutor. The ADO at UKZN, Mshengu (2014) indicated such a support structure for the mathematics students was available.

CONCLUSION

The findings of this paper with regard to students enrolled for the main stream mathematics module, *Introduction to Calculus*, during the first semester of 2014 at UKZN revealed that a significant number of students lacked required essential knowledge and skills relating to basic arithmetic and algebra. The researchers summarise the percentage of students who had difficulty in answering questions relating to the following sections: (1) Operations on numerical fractions 30 percent; Operations on algebraic fractions 43 percent; Operations with monomials 42 percent; Operations with exponents 47 percent; Operations with logarithms 68 percent; Linear equations and linear inequalities 46 percent. Since the entry requirements for the main mathematics module at UKZN is much higher than those of the other service mathematics modules, the implication is that the situation with students taking those service modules could be much worse. This would have to be investigated further.

RECOMMENDATIONS

One of the recommendations of this paper is that first year mathematics lecturers should undertake a diagnosis of the basic knowledge and skill pre-requisites required for the study of university mathematics. This will help to pinpoint their students' strengths and weaknesses. It is recommended that support structures should be planned to address the identified weaknesses. This is very important since the study of mathematics is hierarchical in nature. With particular reference to the study of mathematics by first year students at UKZN, based on the feedback received from the ADO, the following are recommended: (1) mechanisms need to be explored to increase student participation in support structures that are provided to them; (2) the calculation and awarding of the duly performance (DP) certificate of a student which determines whether he/she qualifies to write the examinations should take into account minimum requirements for lectures and tutorials. It is recommended that their performance with regard to online quizzes should be a component included in the calculation of their class mark that contributes to the awarding of their DP certificates.

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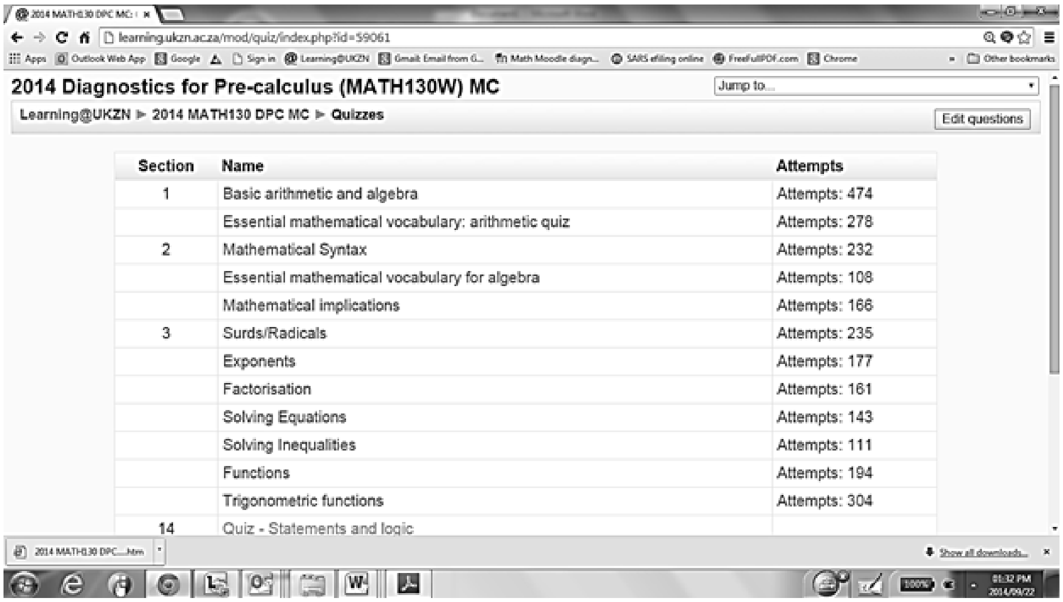
APPENDIX



Section	Name	Attempts
1	Basic arithmetic and algebra	Attempts: 474
	Essential mathematical vocabulary: arithmetic quiz	Attempts: 278
2	Mathematical Syntax	Attempts: 232
	Essential mathematical vocabulary for algebra	Attempts: 108
	Mathematical implications	Attempts: 166
3	Surds/Radicals	Attempts: 235
	Exponents	Attempts: 177
	Factorisation	Attempts: 161
	Solving Equations	Attempts: 143
	Solving Inequalities	Attempts: 111
	Functions	Attempts: 194
	Trigonometric functions	Attempts: 304
14	Quiz - Statements and logic	