Validating a Research Instrument: Diagnostic Test for First Year University of Technology Engineering Mathematics Students

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Abstract—**Poor performances by first year engineering mathematics students at tertiary institutions in South Africa continue unabated due to a variety of reasons. It is sometimes assumed that the students entering a university have the necessary preliminary knowledge to proceed with the university curriculum. However, when we teach or assess students we find that students have gaps in their school knowledge. Identifying first year engineering students' basic mathematical competencies and knowledge gaps have become a prime focus of many tertiary institutions in South Africa. Improving these mathematical skills early in the students' studies is an onerous task. This paper reports on an e-learning research instrument designed for first year engineering students in mathematics. The research instrument was designed to identify areas of weaknesses and strengths thereby isolating 'at risk' students at an early stage of their first year mathematics course at a university of technology. The online test compiled of basic mathematics questions was peer reviewed and validated by mathematics lecturers from a mathematics department at a university of technology. Lecturers personally took the online test. A general questionnaire was completed and then each question analysed to ascertain its appropriateness. We found that there was consensus for the criteria of language clarity, question relevance, notation and terminology but discrepancies in cognitive levels. Validation of items in respect of clear language, appropriateness of the questions for the test as well as appropriate use of notation and terminology was confirmed**

Index Terms—**first year engineering mathematics students, research instrument**

I. Introduction

The transition from secondary school to university is a challenging and somewhat confusing experience for first year university of technology students. Students who leave grade 12 perform poorly in Mathematics at tertiary institutions, which is a serious concern in South Africa [1], [2]. Whilst many factors contribute to this confusion, the impact on students' mathematics performance is further exacerbated by the mathematics gap prevalent in students who recently completed their schooling. Both local as well as international universities have funded numerous interventions and diverted many resources towards addressing the mathematics gap. Such initiatives traditionally involved contact sessions or additional lessons further encroaching on students' time. Another way of addressing the issue is providing off campus assistance to students via E-Learning initiatives. Interventions outside of the lectures can improve conceptual understanding and competencies in these prior learning areas [3], [4]. Online assistance complements lectures and has the potential to improve students' competencies in basic mathematics thereby closing the divide between high school and tertiary mathematics. Identification at an early stage in students' mathematical studies is critical in remediating the mathematics knowledge gap. Reference [5] and [6] explored the successes and weaknesses of e-learning through a project funded by their university known as the Mathematics Pathfinder Project. All students registered for the Mechanical and Industrial Mathematics 101 course wrote a pretest on basic mathematical competencies, which were prior learning requirements for Math101. An essential instruction of this test required students not to use calculators. Students who achieved a mark of less than 50%, were identified as 'at risk' and subsequently inducted into the project. Based on the data and analysis thereof, the researchers recommended that all first year engineering students enrolled for Mathematics 101 attempt the pre-test as a process of early identification of 'at risk' students. In order to implement the recommendation it became necessary to interrogate the pretest.

The aims of the study were to:

- Validate the pretest.
- Conduct the pretest online for all first year engineering Maths 101 students

For this stage of the exploration we ask: *How valid is the online pre-test that first year engineering students have to write in order to identify gaps in their understanding in basic mathematics*?

II. Related Literature

In order to implement the recommendation it became necessary to interrogate the pretest. The researchers drafted preliminary questions for the pretest based on their high school Mathematics experience as well lecturing Mathematics 101 and 102 at a university of

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technology. The item development occurred over a period but was never ratified or subjected to any form of validation. Two crucial decisions concerning the test were then taken, viz., to ensure that the test was conducted online and secondly to validate the test. This study thus has a dual purpose. Firstly to ensure that the pretest is available on a suitable e-learning management system and accessible to students at the institution and secondly to validate the test.

A. *E-Learning*

In the first part of the Pathfinder project mentioned previously, the sustainability of e-learning with first year engineering mathematics students was investigated by considering a framework for sustainable learning. The term 'sustainable' was used by [7] to incorporate terminology, strategies and related issues in the area of e-learning. In this study, they considered the domains of the research area illustrated in Fig. 1, for information.

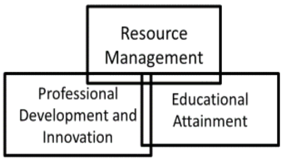


Figure 1. Domains of sustainable e-learning

The report by the researchers found that the availability of e-learning resources and data analysis all satisfy the demands of the three domains of sustainable learning. The domain of resource management was necessary and this pre-test was a starting point in this domain.

Researchers in the Pathfinder Project further explored the domain of educational attainment by asking whether e-learning support materials could address the mathematics gap and improve the mathematical skills of first year engineering maths students. This was carried out by analyzing the pretest and posttest results of a purposefully selected sample of first year engineering students identified as at risk in the project. Students who achieved a mark of less than 50% in the pretest were deemed to be 'at risk' and subsequently inducted into the programme. The pretest included questions that would test basic mathematical competencies of students entering a university of technology and the results would indicate the areas of weakness. During the project, a sample of twenty-five first semester Maths students were selected to participate in the project. The researcher controlled the various phases of the project until completion. By aligning and analysing the data obtained in the pretest and posttest, the researchers recommended that all first year engineering students enrolled for Mathematics 101 attempt the pre-test as a process of early identification of at risk students. Results from the project indicated that the pre-test was an appropriate instrument that could be used to identify 'at risk' students.

The studies indicated above laid the foundation for this case study in that it provided grounds to conduct an online diagnostic test for first year engineering mathematics students. This led to the pretest transforming to a 'diagnostic online pretest', which would be completed by all incoming first year engineering mathematics students who will undertake the test at a pre-determined time to identify 'at risk' students early in the semester.

B. *Validity*

The three main types of validity include content-related validity, criterion-related validity and construct-related validity. This study focussed on content-related evidence of validity. Several definitions of content validity appear. Reference [8] describe it as 'the degree to which the elements of an evaluation instrument are representative of the construct of interest', whilst [9] understand it as 'the degree to which a sample of items represents an adequate operational definition of the construct of interest'. In summary, a test has content validity if it measures knowledge of the content of which it is designed to measure. The items of the test should exhibit appropriateness, correctness and usefulness in its design [10].

The content validation process varies according to the construct it measures. In this study, mathematical test items formed the basis of the construct and hence an appropriate procedure was utilised in the validation process. A two-step procedure of obtaining content validity followed, viz. item construction followed by expert judgement.

Stages in the process of obtaining content validity evidence:

1) *Item construction*

The researchers compiled the questions used in the quiz when leading the pathfinder project mentioned earlier. A test blueprint was developed identifying the basic mathematics conceptual and procedural errors that students typically make in first year mathematics. The sections identified included numeracy, exponents, surds, ratio and proportion, algebraic expressions, algebraic fractions, linear and quadratic equations, functions and trigonometry. The researchers used the cognitive levels used for high school learners since the majority of first year students just completed their schooling and were now attempting a first mathematics course at university. Thirty questions formed the test with a duration of sixty minutes. The number of questions per section is tabled below (Table I):

TABLE I. TOPICS IN WHICH CONCEPTUAL AND PROCEDURAL DEFICIENCIES WERE FOUND

Section	No. of questions
Numeracy	2
Ratio and Proportion	1
Exponents and surds	2
Algebraic simplification	5
Algebraic fractions	5
Equations	5
Functions and graphs	5
Trigonometry	5

The researchers used a bottom up approach in compiling the test. Based on fundamental errors and misconceptions that the researchers' encountered, specific questions were drafted that would identify basic mathematics flaws. These questions were then categorized in the sections tabled above and suitably placed in the four cognitive levels described in [11]. These levels include L1 (knowledge), L2 (routine procedures), L3 (complex procedures) and L4 (problem solving).

2) Expert judgment of items constructed

Expert judgement is a fundamental method used to determine whether a test has content validity. The study was conducted this year (2017) in the Mathematics Department at a University of Technology in South Africa. Seven lecturers in this department undertook the online diagnostic test and simultaneously completed a paper-based Question validation excel worksheet designed by the researchers. In addition, lecturers answered an online Feedback Questionnaire after the diagnostic test. Lecturers assumed the role of students in completing the online test. The diagnostic test consisted of multiple choice questions, matching and answer selection questions. Validation of the items in the test is based on the expert knowledge of the lecturers as well as their vast experience in teaching and lecturing at a high school as well as a university.

III. Methodology

In this section the researchers present the research paradigm and research methods used for the data collection. "Methodology refers to the coherent group of methods that complement one another and that have the 'goodness of fit' to deliver data and findings that will reflect the research question and suit the research purpose" [12]. According to [13] research methods are a "range of approaches used in educational research to gather data which are to be used as a basis for inference and interpretation, for explanation and prediction".

A qualitative approach was used in this paper. Data was collected from seven mathematics lecturers from a university of technology. An online research instrument was uploaded on to a learning management system known as moodle. Moodle provides a variety of teaching tools that can be incorporated in pedagogical paradigms that a researcher wishes to implement. The two tools used in this paper include the quiz and the feedback features, both providing alternatives to paper based testing and feedback. The quiz activity enables a user to create quizzes comprising questions of various types, including multiple choice, matching, short-answer and numerical. The quiz can be set so that multiple attempts are permissible, with the questions shuffled or randomly selected. A time limit may be set. Basic mathematics questions were compiled and stored in a question bank, which then served as a conduit to formulating a quiz to the user's specification. The online diagnostic test was composed of 30 questions as described previously.

Lecturers' then completed the online diagnostic test found on the moodle platform of the university website. A detailed information guide containing appropriate notes were distributed to assist lecturers in accessing and logging into the site. Lecturers' then performed the following tasks: completed the diagnostic test online, completed the validation excel worksheet and simultaneously answered the feedback questionnaire online.

A. Diagnostic Test

The quiz feature of the moodle site allows the user to compile a test quiz once a question bank was established. Suitable categories were formed, based on the questions identified as common and basic conceptual and procedural errors made by students. Questions were then uploaded into the categories. The distractors for each question were carefully considered whilst compiling multiple choice and matching type questions. The number of questions per category ranged from a minimum of five for ratio and proportion to a maximum of twelve for algebraic equations. The researchers were mindful that all the questions in each category were in the same cognitive bracket. After the question bank was completed, the diagnostic test quiz was compiled. The researchers used the random feature of the quiz to generate a random question from each category depending on the number of questions identified for each category. As a result, a quiz opened by one user may not contain the same questions as another user. The quiz was then set up consisting of thirty questions as described previously. This included inter alia the timing of the quiz, i.e. when and how long the quiz would be opened online for the lecturers to complete. The number of questions that display per page was set in the layout feature whilst the question behaviour was set to shuffle within questions resulting in the distractors positioned differently each time the quiz is attempted. Appendix 1 shows a sample of questions that the online test generates.

B. Validation Checklist Worksheet

An excel worksheet was designed for lecturers use when answering the test. As mentioned, items should display appropriateness, correctness and usefulness for the intended purpose. Each question had to be viewed, answered and analysed with respect to the following criteria: language clarity, question relevance, terminology and notation as well as cognitive level.

A brief description of each follows:

- Language Clarity – Is the question clear, unclear or ambiguous? Phrasing questions correctly avoids confusion and directs the user to answer the questions for the intention that it was set. In this case the lecturer is required to indicate if the language is clear and does not detract from the mathematics that is required to answer the question.
- Question relevance – Is the question relevant for a basic mathematics diagnostic test.
- Terminology and Notation – Appropriate or inappropriate. Notation is an integral feature of mathematics. Inappropriate notation could lead users to follow a different procedure or use incorrect concepts.

- Cognitive levels - These levels include L1 (knowledge), L2 (routine procedures), L3 (complex procedures) and L4 (problem solving). Lecturers completed this section based on their mathematical content knowledge.

After coding these criteria, a general comment line was inserted below each question. Here lecturers could comment on the question or provide any advice for the question.

C. *Online Feedback Questionnaire*

The aim of this questionnaire was threefold: firstly to test the new feedback feature of moodle, secondly to elicit lecturers overall analysis of the diagnostic test and thirdly to further explore the capabilities of the feedback feature. The feedback feature allows the user to set questions requiring information, long and short text answers as well as numeric and multiple-choice types. The researchers adapted the question type to record numeric answers, yes/no cases, multiple choice as well as longer test answers. The questionnaire contained ten questions of a general nature. Questions can be edited, templates can be saved, answers can be analysed collectively and actual responses can be viewed. If utilised correctly the feedback module in moodle can be an essential feature in a researchers' arsenal eliciting a wealth of information when required. Appendix 2 shows the online depiction of the feedback questionnaire

IV. Data Analysis and Discussion

Data collected from the validation checklist worksheet and the online feedback questionnaire will form the basis of the analyses and discussion. However, three separate discussions ensue because of the comment lecturers completed after each question.

A. *Question Validation Summary Table*

A quasi-statistic approach was used for the collection of data. A summary of the completed validation checklist worksheet appears in Table II. Each question shows the total number of responses for language clarity, question relevance, terminology and notation as well as cognitive levels.

TABLE II. Question Validation Summary Table Abbreviations: A – Appropriate I – Inappropriate

Question No.	Language Clarity			Question relevance		Terminology and Notation		Cognitive levels			
	Clear	Unclear	Ambiguous	A	I	A	I	L1	L2	L3	L4
1	7			6	1	6	1	2	5		
2	7			7		7		4	3		
3	7			7		7		3	3	1	
4	7			7		6	1		7		
5	7			7		7		3	1	3	
6	6	1		7		6	1		4	3	
7	7			7		7		1	6		
8	7			7		7		1	6		
9	6	1		7		7			7		
10	6	1		7		7			6	1	
11	6	1		7		6	1		7		
12	6	1		6	1	7		4	3		
13	7			7		7		2	4	1	
14	6	1		7		7		2	4	1	
15	7			7		7		4		3	
16	7			7		6	1		6	1	
17	7			7		6	1	2	5		
18	7			7		7		1	6		
19	7			7		6	1		5	2	
20	7			7		7		2	5		
21	7			7		7		2	5		
22	7			7		7			3	4	
23	7			7		7		3	4		
24	7			7		7		5	2		
25	7			7		7			3	4	
26	7			7		6	1		3	3	1
27	7			7		6	1		4	3	
28	7			7		7			4		3
29	7			7		7			5	2	
30	7			7		7				4	3

For the criterion of language clarity only questions 6, 9, 10, 11, 12 and 14 did not receive all seven lecturers approval. These questions had a single word before each mathematics problem, viz. 'expand' or 'simplify'. Six of the seven lecturers thought that these questions were clear whilst only one checked the 'unclear' box. Lecturers thought that no question was ambiguous at all. Only two questions, viz. questions 1 and 12 received an inappropriate mention by a lecturer for question relevance. Thus for these two questions, six thought the questions were relevant for the test whilst only one lecturer indicated disapproval. Question 1 involved finding values of a numerical expression by removing brackets while in question 12 an algebraic fraction to be simplified. Subsequent checking of question 12 revealed that the answer was not included in the multiple choices. One lecturer indicated inappropriateness for each of the following questions with respect to notation and terminology, viz. questions 1, 4, 6, 11, 16, 17, 19, 26 and 27. Coding for cognitive levels proved to be an onerous task for respondents, clearly showing in the results. Lecturers voiced their concerns when submitting the validation table indicating that they had difficulty in completing the cognitive levels table. This concern clearly showed in the coding since only three questions, viz. question 4, 9 and 11 was allocated the same level by all seven lecturers. Lecturers coded some questions across two levels whilst some questions had coding across all three levels.

B. Question Validation Sheet: Comments per Question

Table III below shows comments by lecturers for questions. Questions 3-7, 11, 13, 15, 19-25, 27 and 28 had no comments.

TABLE III. LECTURER COMMENTS

Question Number	Comment
1	Lecturer S preferred the use of the word 'number' instead of 'value'. Lecturer M – not sure what is tested
2	Lecturer M- addition of fractions known to be difficult'.
8	Lecturer S – 5x+5y should be included as a distractor
10	Lecturer S – 'x' not printing clearly
12	Lecturer A – rephrase question as 'Simplify if possible.'
14	Lecturer S – Question should be, 'Simplify.'
16	Lecturer D – question should read, 'A root of the equation…'
17	Lecturers D and N – reword the question as, 'If α and β are roots of the equation,……' Lecturer S thinks α and β are typed too close.
26	Lecturer D – reword question as follows: 'Find the value of ……for all values of ϴ.'
29	Lecturer S - one of the options should be 3/17.
30	Lecturer T – question could be confining.

A feature of most comments is the phrasing and re-wording of questions. The mathematical integrity and appropriateness of the question does not surface in the comments. This tacit approval of the questions in the diagnostic test further consolidates the validity.

C. Online Feedback Questionnaire

Questions appearing in the feedback questionnaire are found below, followed by a discussion based on lecturers' responses.

Question 1. Teaching/lecturing experience

This ranged from a minimum of 14 years to a maximum of 31 years. Collectively, the nine lecturers had a total experience of 153.5 years teaching mathematics at school and/or lecturing. All lecturers' hold higher degrees in Mathematics. This vast experience further solidifies the validity of the research instrument. It can be inferred that lecturers are well aware of the basic mathematics problems and the gap that exists between school and first year engineering mathematics.

Question 2. Do you feel the diagnostic test questions cover basic mathematics sections that are lacking in first year university of technology students mathematical ability?

All respondents answered positively further strengthening the validity of the test. The sections identified included numeracy, exponents, surds, ratio and proportion, algebraic expressions, algebraic fractions, linear and quadratic equations, functions and trigonometry.

Question 3. Indicate any additional sections that should be included.

The following additional sections were suggested: basic geometry, simultaneous equations and graphical interpretation.

Question 4. Which devices were used to complete the test?

5 lecturers used their stand-alone office PC's whilst 2 used other devices.

Question 5. Did you experience any difficulty in completing the test with the devices?

No lecturer experienced any difficulty completing the test online, although one lecturer had issues with logging in which was a function of the university IT department.

Question 6. If 'yes' to the previous question, explain the difficulty experienced.

None

Question 7. Did the Mathematics display clearly on the device?

All answered positively.

Question 8. What Mathematical skills would you prefer students develop.

The following were suggested.- making connections, more reasoning type questions, 100% procedural fluency, problem solving and applications of basic mathematics.

Question 9. Duration.

All lecturers believed that the duration of 1 hour was sufficient.

Question 10. Follow up to Question 9.

None since all believed the test duration was correct.

The positive responses to all questions in the feedback questionnaire further strengthens the validity of the diagnostic test. Additional basic mathematics sections were noted and the test duration kept at sixty minutes as validated by the lecturers.

V. CONCLUSION

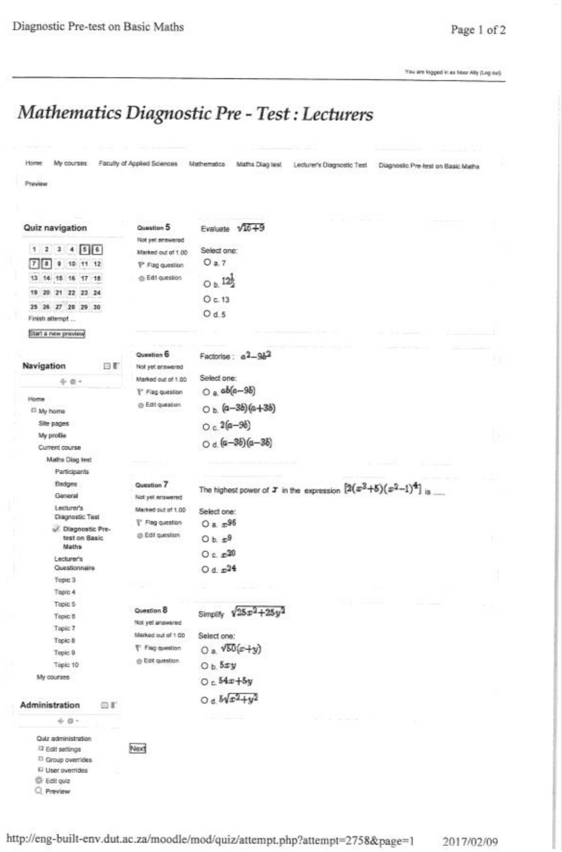
The focus of the study was to validate a diagnostic online pretest that first year engineering mathematics students would attempt so as to identify students considered 'at risk' at an early stage of their studies. The online diagnostic will test the level of understanding in numeracy, exponents, surds, ratio and proportion, algebraic expressions, algebraic fractions, linear and quadratic equations, functions and trigonometry. Content validity was performed by experts in the form of mathematics lecturers based in the mathematics department in a university of technology who wrote, coded and commented on the online diagnostic test items. Analysis revealed consensus for the criteria of language clarity, question relevance, notation and terminology but discrepancies in cognitive levels. Validation of items in respect of clear language, appropriateness of the questions for the test as well as appropriate use of notation and terminology was confirmed. Although lecturers' assessment of cognitive levels differed, the general theme that emanated from their coding indicated approval of all questions in the test. Comments given and discussion from the feedback questionnaire provided further suggestions.

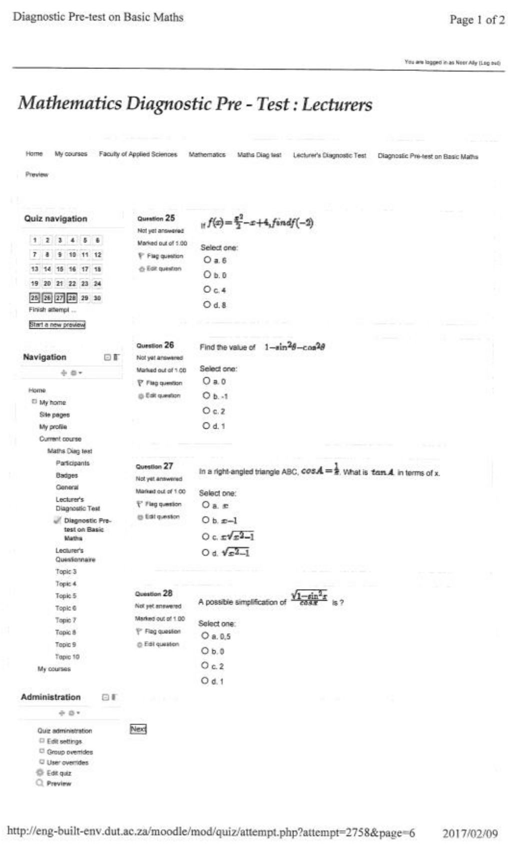
VI. RECOMMENDATION

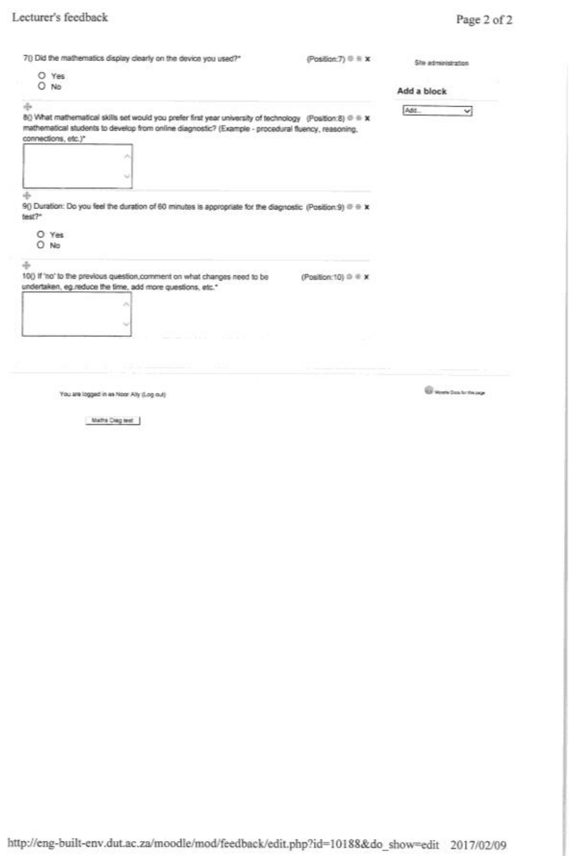
Content validity we accepted in this study as the degree to which the elements of an evaluation instrument are representative of the construct of interest. In summary, a test has content validity if it measures knowledge of the content of which it is designed to measure. The items of the test should exhibit appropriateness, correctness and usefulness in its design. In this study we found that certain items in the pretest had to be adjusted pending the critical suggestions made by experts in the field of mathematics. We now are of the opinion that the pretest would be more effective in use in the main study to be carried out with first year engineering mathematics students. If this exercise of validity was not carried out the study might in the future have certain methodological flaws. It is therefore recommended that other studies of this nature ascertain the content validity of research instruments before being administered. This will also enhance the credibility of the findings one makes in a qualitative study.

APPENDIX A. DIAGNOSTIC PRETEST ON BASIC MATHS

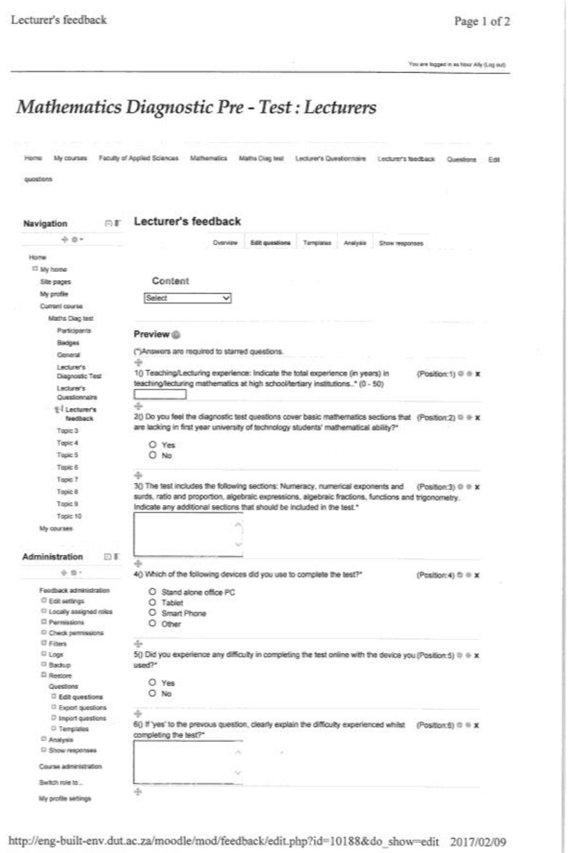
Appendixes, if needed, is numbered by A, B, C... Use two spaces before APPENDIX TITLE.







APPENDIX B. FEEDBACK QUESTIONNAIRE



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