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Online Early Monitoring of Students' Level of Mathematical Ability in Engineering Mathematics Subjects

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ABSTRACT

Proper mastery of engineering mathematics is one of the key success factors for students in the field of engineering. Delays in identifying students who are weak in mathematics can result in their having difficulties in learning subsequent mathematics courses. Therefore, a method of monitoring students' ability in the Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM) in the subject of mathematics was developed in the form of an online system, namely, TCExam. TCExam contains a maths readiness test for the subjects of Vector Calculus and Linear Algebra. A total of 60 questions in the form of multi-objective questions are prepared based on important topics needed to be mastered by students. Also included in the TCExam are survey questions on factors among students in selecting a university. The TCExam is implemented for students during the first week of the semester. This system will provide maths readiness test results directly to the lecturers and the data will then be analysed using the Rasch Measurement Model to obtain a reliability value as well as test quality and students' level of ability. The high value of Item Reliability of 0.98 explains that the level of reliability of the readiness test questions is very high. Results from the Rasch analysis also reflect that students' level of mathematical ability is poor, indicating that the maths readiness test is needed at the early stage of their enrolment into university to identify weak students much earlier so that specific monitoring measures can be made to help these students.

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INTRODUCTION

Mathematics is an important subject and a prerequisite for almost all undergraduate courses at universities, especially for engineering courses. Mathematics serves as a necessary foundation in nurturing future engineers. This is important, given that engineering plays an important role today in the development of activities related to technology, energy, computers, electronic devices and manufacturing processes (Alves et al., 2012). Engineering courses require students to have a strong foundation in basic mathematical concepts. The ability to master mathematical theories is important for solving practical problems. According to Sazhin (1998), the objective of teaching mathematics to engineering students is to ensure that students are able to balance between the practical applications of mathematical concepts and their understanding. It is thus important to balance between theory and practical applications in engineering courses.

However, engineering students' achievement is now showing a deteriorating trend, and this concerns lecturers as well as local and international universities. In 1995, a study conducted by the Engineering Council revealed that engineering students had relatively weak mathematical ability in the subject at undergraduate level (Sutherland & Pozzi, 1995). This group of students had problems in achieving good grades, especially in mathematics. This also led to difficulties in selecting engineering students at the undergraduate level, given the declining level of mathematical ability among students at the pre-university stage. The declining quality of students will have a direct impact on the field of engineering in the future if the problem persists and if it is not properly addressed by the authorities. Research findings with regards to engineering students' achievement in the Faculty of Engineering and Built Environment (FKAB), Universiti Kebangsaan Malaysia also showed a decrease in mathematical ability among engineering students (Zainuri et al., 2009; Haliza et al., 2010; Aziz et al., 2013; Fuaad et al., 2014; Othman et al., 2015).

In an effort to improve student achievement in FKAB, UKM, particularly in the subject of engineering mathematics, provides a maths readiness test for first-year engineering students upon admission. The test is prepared for the first-year engineering mathematics courses, Linear Algebra and Vector Calculus. Previously, the maths readiness test was conducted manually on paper, making it a time-consuming task as answer scripts and data entry needed to be done manually. This problem, in turn, slowed down the process of analysing new students' results, which then made it difficult for lecturers to identify problematic students at the beginning of the semester. In addition, paper wastage was also an issue when the maths readiness test was carried out, given the large number of first-year engineering students. Thus, the main objective of this study was to develop a method of monitoring students' ability in the subject of mathematics in the form of an online system, namely TCExam. The results of this study will facilitate lecturers in expediting efforts to identify the level of students' ability. This study uses the Rasch Measurement Model in the process of question analysis and indetermining students' level of ability in the Linear Algebra readiness test. Unlike previous years, the proposed test is to be conducted online, which will directly reduce operational and materials costs.

The Rasch Measurement Model is a measurement method that uses data from student test results, modifying that data in a 'logit' scale, allowing for a comparison between students' level of ability and item difficulty level to be carried out in the same interval (Rozeha et al., 2007). The analysis of students' results reflects whether or not the questions administered in the readiness are appropriate for students' level of ability. This in turn will assist lecturers to take appropriate action on improving teaching and learning methods to help students who have problems with their foundation in engineering mathematics (Rozeha et al., 2007).

METHODOLOGY

Research Sample and Data Collection

This study involved a total of 355 first-year students from FKAB, UKM, which consists of students from four departments, namely, the Department of Civil and Structural Engineering (JKAS), the Department of Chemical and Process Engineering (JKKP), the Department of Mechanical and Materials Engineering (JKMB) and the Department of Electrical, Electronics and Systems Engineering (JKEES) for the 2014/2015 session. A total of 13 testing sessions were conducted in two computer laboratories at the faculty, which can accommodate between 20 and 35 students at a time. The readiness test was conducted for three to four sessions a day in each department and it took four days to be completed.

Research Instrument (Mathematical Readiness Test)

This study used the readiness test questions as a means of measuring the level of mathematical ability among students at the beginning of the semester, which could assist lecturers in identifying students who have difficulties at an early stage of the course, during admission. The research instrument was a set of mathematical readiness tests that was validated using the Rasch Measurement Method. The questions were uploaded in the TCExam online system. A total of 60 multi-objective questions were given based on important topics that needed to be mastered by engineering students. Students had to answer two sets of mathematical readiness tests: Vector Calculus (30 questions) and Linear Algebra (30 questions) and one online questionnaire regarding university selection. The sttudents were given one hour to complete each set of questions. Data on the student results were then downloaded from the TCExam system and analysed using the Rasch Measurement Model to determine the level of their mathematical ability. For this research, the data of test results that were obtained from the mathematical readiness test (Linear Algebra 2014/2015 session) were analysed using the the Rasch Measurement Model. The reliability of the mathematical readiness test (Linear Algebra) was measured from the value of the Item Reliability and Cronbach Alpha.

TCExam

TCExam is an open-source system for electronic tests, also known as Computer-Based Assessment (CBA), Computer-Based Testing (CBT) or e-examination, and it enables lecturers to digitalise and distribute tests, quizzes, examinations as well as questionnaires to target groups in an easier and faster manner. The system, developed in 2004 and translated into 24 languages, is widely used around the world by universities, schools and government and private companies.

The TCExam coordinates all phases of evaluation: authoring, scheduling, delivery and reporting automatically. It is easy to use as users can access the TCExam system using the Internet web through engines such as Mozilla Firefox or Internet Explorer. The advantage of the TCExam compared to the traditionally written examination system is that the system will speed up the administration and the scoring process will be more efficiently done compared to traditional methods that require lecturers to check students' answers and enter their data manually one by one into Excel. The system further reduces 'human error' in the data entry process. The TCExam simplifies the process of assessment, reduces cost and improves the quality and reliability of the test.

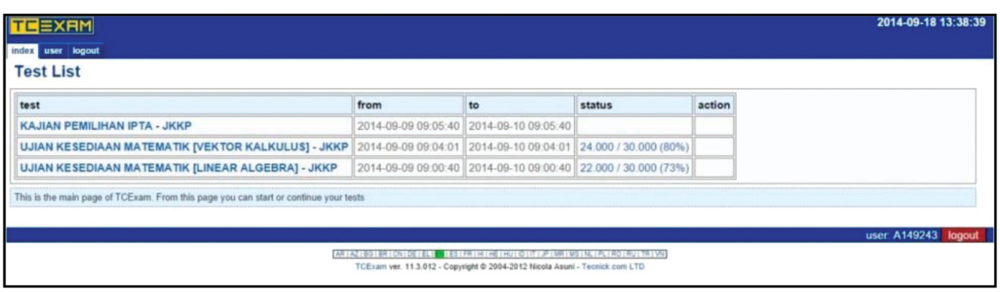


Figure 1. Interface showing the list of tests for students.

In this study, three sets of questions were uploaded into the TCExam system, namely IPTA Selection Study, Mathematical Readiness Test (Vector Calculus) and Mathematical Readiness Test (Linear Algebra). Figure 1 shows the interface when students logged in using their respective IDs and passwords. The ID and password were given prior to the exam in the computer laboratory. This was to prevent students from other departments/ sessions from accessing the questions from outside the computer lab. For this study, the three sets of questionnaires were segregated according to department in order to avoid confusion and question leaks as all four departments involved were taking the test at different times. The results of the exam were revealed immediately after the session.

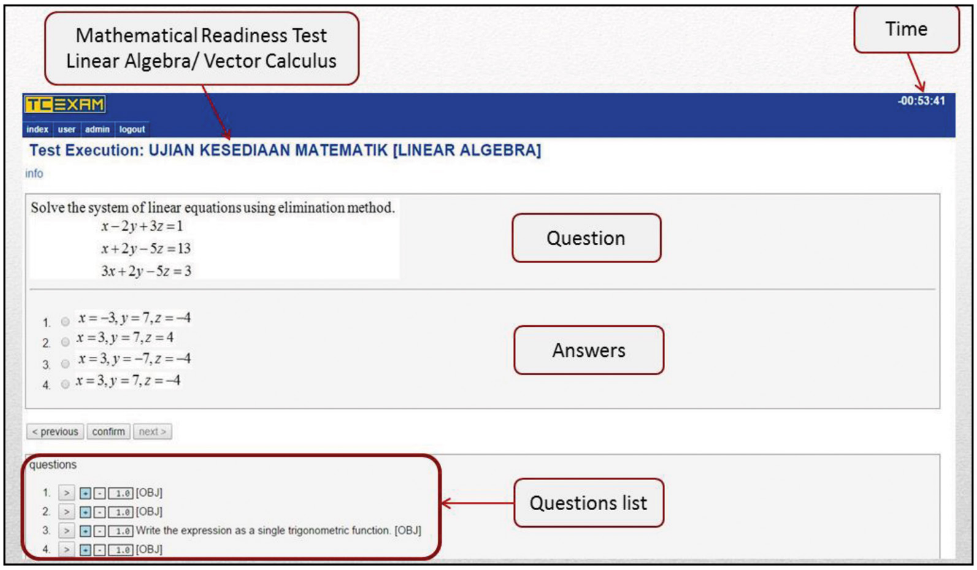
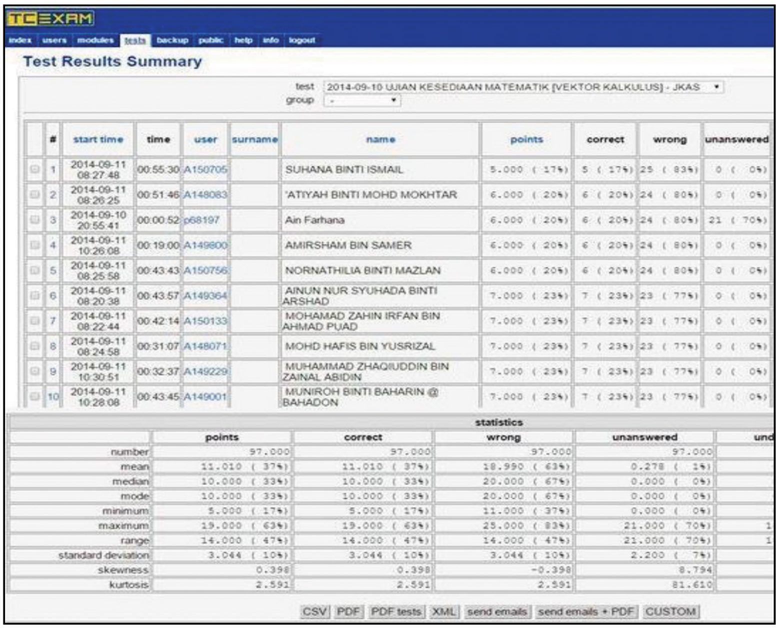


Figure 2. Interface displaying the questions.

Figure 2 shows the interface seen by the student when answering the questions online. Details such as the names and the test time can be seen at the top of the screen. For the mathematical readiness test set, the questions and answers administered to the students were randomly assigned to each student. The question menu can also be seen in Figure 2. This menu facilitated students in checking their answers and in detecting unanswered questions.

The TCExam results were then analysed using the Rasch Measurement Model. Figure 3 shows an output example of the readiness test results generated by the TCExam. The results for each student can be seen along with detailed questions if the lecturer wanted to gauge parts where students experienced problems the most. The percentage of students' scores can also be seen in Figure 3.



TCEXAM

index users modules tests backup public help info logout

Test Results Summary

test 2014-09-10 UJIAN KESEDIAAN MATEMATIK [VEKTOR KALKULUS] - JKAS

group -

#	start time	time	user	surname	name	points	correct	wrong	unanswered
1	2014-09-11 08:27:48	00:55:30	A150705		SUHANA BINTI ISMAIL	5.000 (17%)	5 (17%)	25 (83%)	0 (0%)
2	2014-09-11 08:26:25	00:51:46	A148083		'ATIYAH BINTI MOHD MOKHTAR	6.000 (20%)	6 (20%)	24 (80%)	0 (0%)
3	2014-09-10 20:55:41	00:00:52	p68197		Ain Farhana	6.000 (20%)	6 (20%)	24 (80%)	21 (70%)
4	2014-09-11 10:26:08	00:19:00	A149800		AMIRSHAM BIN SAMER	6.000 (20%)	6 (20%)	24 (80%)	0 (0%)
5	2014-09-11 08:25:58	00:43:43	A150756		NORNATHILIA BINTI MAZLAN	6.000 (20%)	6 (20%)	24 (80%)	0 (0%)
6	2014-09-11 08:20:38	00:43:57	A149364		AINUN NUR SYUHADA BINTI ARSHAD	7.000 (23%)	7 (23%)	23 (77%)	0 (0%)
7	2014-09-11 08:22:44	00:42:14	A150133		MOHAMAD ZAHIN IRFAN BIN AHMAD PUAD	7.000 (23%)	7 (23%)	23 (77%)	0 (0%)
8	2014-09-11 08:24:58	00:31:07	A148071		MOHD HAFIS BIN YUSRIZAL	7.000 (23%)	7 (23%)	23 (77%)	0 (0%)
9	2014-09-11 10:30:51	00:32:37	A149229		MUHAMMAD ZHAQIUDDIN BIN ZAINAL ABIDIN	7.000 (23%)	7 (23%)	23 (77%)	0 (0%)
10	2014-09-11 10:28:08	00:43:45	A149001		MUNIROH BINTI BAHARIN @ BAHADON	7.000 (23%)	7 (23%)	23 (77%)	0 (0%)

statistics

	points	correct	wrong	unanswered	und
number	97.000	97.000	97.000	97.000	
mean	11.010 (37%)	11.010 (37%)	18.990 (63%)	0.278 (1%)	
median	10.000 (33%)	10.000 (33%)	20.000 (67%)	0.000 (0%)	
mode	10.000 (33%)	10.000 (33%)	20.000 (67%)	0.000 (0%)	
minimum	5.000 (17%)	5.000 (17%)	11.000 (37%)	0.000 (0%)	
maximum	19.000 (63%)	19.000 (63%)	25.000 (83%)	21.000 (70%)	1
range	14.000 (47%)	14.000 (47%)	14.000 (47%)	21.000 (70%)	1
standard deviation	3.044 (10%)	3.044 (10%)	3.044 (10%)	2.200 (7%)	
skewness	0.398	0.398	-0.398	8.794	
kurtosis	2.591	2.591	2.591	81.610	

CSV PDF PDF tests XML send emails send emails + PDF CUSTOM

Figure 3. TCExam test results.

The statistical analysis provided by TCExam includes mean, median, mode and standard deviation, and all these can be used by lecturers. The Semester 1 Mathematical Readiness Test for 2014/2015 session was conducted in the computer lab of the Faculty of Engineering and Built Environment (FKAB), Universiti Kebangsaan Malaysia, as shown in Figure 4.

Figure 4. TCExam test environment.

RESULTS AND DISCUSSION

This section focusses only on the analysis of the mathematical readiness test (Linear Algebra). Questions in the mathematical readiness test and student results were analysed using the Rasch Measurement Model to obtain the reliability value as well as test quality and students' level of ability. The value of the Cronbach Alpha of 0.6 indicated that the mathematical readiness test questions were acceptable. Based on Figure 5, the value of the Item Reliability of 0.98 indicated high reliability of the readiness test questions. This is an important indication that the set of questions were able to measure students' mathematical ability in a more precise manner. Figure 5 shows the maximum and minimum values of the items in the mathematical readiness test questions which also reflect the item's position in the logit unit. The position of these items is based on their level of difficulty. The maximum item is located at +1.46 logit and the minimum item is at -2.55 logit.

SUMMARY OF 30 MEASURED Item

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	153.2	356.0	.00	.12	1.00	-.1	1.00	.0
S.D.	67.3	.0	.96	.01	.05	1.1	.07	1.1
MAX.	316.0	356.0	1.46	.17	1.13	1.8	1.21	1.9
MIN.	58.0	356.0	-2.55	.11	.90	-3.0	.88	-2.5

REAL RMSE .12 TRUE SD .95 SEPARATION 7.59 Item RELIABILITY .98
MODEL RMSE .12 TRUE SD .95 SEPARATION 7.66 Item RELIABILITY .98
S.E. OF Item MEAN = .18

Figure 5. Summary of item statistics.

Figure 6 shows the summary for the Person statistics. If the item's logit indicates the level of difficulty of the questions, then the Person's logit shows students' level of mathematical ability. Good students have the highest logit while poor students have the lowest logit and are located at the bottom part of the PIDM figure. According to Figure 6, the maximum Person value in this study was +2.15 logit while the minimum Person value was -3.07 logit.

SUMMARY OF 356 MEASURED Person

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	12.9	30.0	-.32	.42	1.00	.0	1.00	.0
S.D.	3.9	.0	.68	.04	.16	1.0	.24	1.0
MAX.	26.0	30.0	2.15	.77	1.59	3.3	1.92	3.5
MIN.	2.0	30.0	-3.07	.40	.61	-2.6	.52	-2.2

REAL RMSE .43 TRUE SD .52 SEPARATION 1.20 Person RELIABILITY .59
MODEL RMSE .42 TRUE SD .53 SEPARATION 1.26 Person RELIABILITY .61
S.E. OF Person MEAN = .04

Figure 6. Summary of Person statistics.

The analysis then focussed on evaluating students' ability in the mathematical readiness test. The value of the Person's average of 0.32 given in Figure 6 shows that the level of student ability in the mathematical readiness test was weak and below expectations. This can be seen in the Person and Items on a Distribution Map (PIDM) as shown in Figure 7, which indicates items and the Person's position according to their respective logit values. The comparison between these two can be made when both are adjusted using logit. The item's position in PIDM determines the question's level of difficulty while the Person's position in turn determines students' level of ability. The higher the position of the item, the more difficult the questions will be, and the lower the position of the item, the easier the question will be to the students. As for Person, higher position in the diagram indicates that the students are good. Figure 7 shows the item's mean located at+0.00 logit. This is based on the Rasch theory that states that every student has a 50:50 chance to answer the question correctly. Thus, the further the position of item from the item's mean, the probability of the students answering the question correctly also varies, according to the question's level of difficulty. In other words, if the item is at the top of the diagram, then the question has a high degree of difficulty; thus, the probability that the student would answer the question correctly is low.

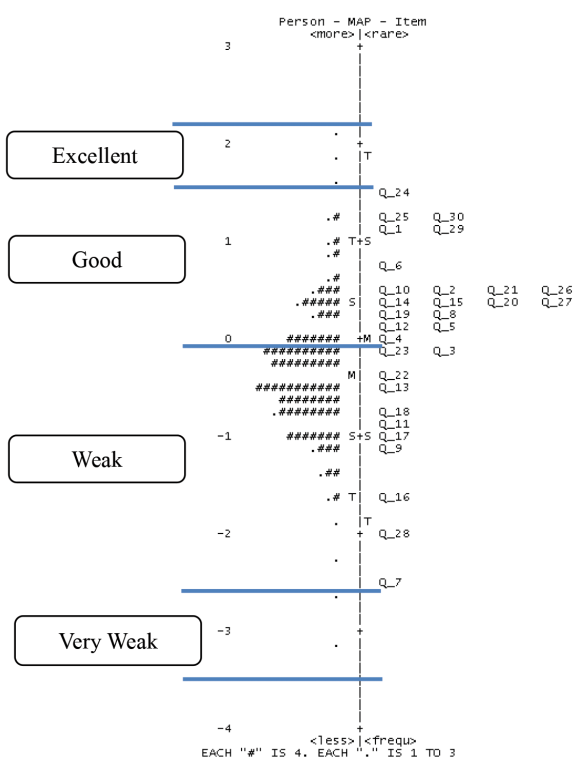


Figure 7. PIDM figure for the mathematical readiness test (Linear Algebra).

Figure 7 shows the position of four groups of students based on their level of ability by logit. These groups were classified as very weak, weak, good and excellent. Based on Figure 7, 70.2% of the students (250 out of 356 students) were below the item's mean; +0.00 logit indicated that the students' level of ability upon answering the mathematical readiness test was below expectations. These groups of student were labelled as very weak and weak. These two groups of students found the maths readiness questions administered to them quite challenging, and this can be seen in the position of 18 items that were above the students' level of ability in Figure 7. These 18 items were located above the logit of the item's mean, +0.00 logit.

However, a few important observations with regards to the students' level of ability were observed. Four students who had a high level of ability were placed in the excellent group. Their level of ability exceeded the readiness test questions' level of difficulty administered to them. This indicated that these readiness test questions did not measure the overall level of ability of all four students because for them, the questions administered were quite easy. Upon closer examination, overall, the marks for these students were seen to be more than 80%, with less than six wrong answers out of 30 questions. This was different for the very weak students as they had a very low level of ability and were located under the easiest item. This indicated that the readiness test administered to them was not able to assess their ability as the questions were too difficult for them. Overall, the results of these readiness tests was less than 10%, with only two to three questions answered correctly. These students must be given special attention.

Next, the students' level of ability according to their logit was broken down by their pre-university CGPA groups (university entrance CGPA) as shown in Table 1. As can be seen in Table 1, the group of students who obtained a CGPA of 3.75-4.00 during their pre-university studies recorded the highest number of students, but only 40% of them belonged to a group who had a high level of ability based on their readiness test (Linear Algebra) results. The majority of them belonged to the weak group and are located below the Item's Mean= + 0.00, based on their mathematical readiness test, even though this group was expected to perform better than the other two groups based on their pre-university CGPA. Interestingly, 26% and 14% of the students who belonged in the group of CGPA 3.50-3.74 and 3.00-3.49, respectively, performed well in the mathematical readiness test. It shows that CGPA at the pre-university level does not necessarily reflect good mathematical readiness.

Table 1
Students' Level of Ability in Readiness Test (Linear Algebra) Grouped by Pre-University CGPA

CGPA	Below Item's Mean =+0.00 logit		Above Item's Mean =+0.00 logit		Total
3.75-4.00	96	60%	64	40%	160
3.50-3.74	82	74%	29	26%	111
3.00-3.49	72	86%	12	14%	84
Total	250	70%	105	30%	355

The results obtained via the correlation analysis also indicated the same results. Correlation analysis is a statistical technique to quantify the dependence of two or more variables. The correlation coefficient (r) value lies between +1 and -1. Any value of r more than 0.5 or close to 1.0 shows a strong positive correlation, which means that the values of both the variables increased simultaneously, showing linear dependence. The results showed a very low value of correlation, r=0.224, which explained the weak correlation between the students' CGPA during their pre-university studies and their level of ability in the early stages of the semester when they entered the undergraduate courses in the university. This reflects the need to conduct a mathematical readiness test to determine students' level of ability at the beginning of the semester and not depend solely on their results of their pre-university studies.

SUMMARY

Results from the analysis reflected that the students' level of mathematical ability was low and that they were weak in the subject, indicating that the maths readiness test was needed at the early stage of their enrolment into university. This is further supported by a weak correlation between the students' CGPA in the pre-university stage and the readiness test results, which indicated that lecturers should not solely depend on students' results during pre-university. This study showed that there were some students who needed further help with certain important topics.

Overall, the TCExam system can assist lecturers in simplifying and accelerating the process of marking and assessing students' maths readiness. Material cost and time can be reduced while quality and reliability can be enhanced with the use of the Rasch Measurement Model.

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