Use of Digital Learning Platform in Diagnosing Seventh Grade Students' Mathematical Ability Levels

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Abstract

This paper aims to describe the design and inspection of the quality of a digital learning platform to diagnose mathematical ability levels of seventh-grade students with regard to the topics of Measurement and Geometry. A total of 517 seventh-grade students from 23 schools in four regions, namely north, northeast, central, and south of Thailand were randomly chosen took part as test-takers. The researchers employed a design-based research approach incorporating three stages starting from designing a digital learning platform as an assessment model to diagnose students' mathematical ability levels, up to employing a Multidimensional Random Coefficient Multinomial Logit Model to inspect the quality of the seventh-grade students' mathematical abilities assessment model. The research tool consisted of three subjective questions and 15 multiple-choice questions which were used to develop two five-level construct maps ranging from unresponsive to tactical intelligent for the mathematical procedure dimension, and prolonged intellectual structure for the conceptual structural dimension. The findings verified that there were three forms of evidence to support the quality of the mathematical abilities assessment model. The results of the intersection of a mathematical procedure and conceptual structural dimensions' transition point from levels 1 to 5 as ranging from the lowest to the highest levels at -1.41, -0.69, 0.49, 1.34 and -0.98, 0.14, 0.44, 1.70 respectively. Finally, the empirical findings indicated that the digital learning platform was at a highly appropriate level in terms of its usefulness, suitability, and accuracy except for in terms of feasibility which was at a moderately appropriate level. In conclusion, the digital learning platform can be used to provide substantial information when it comes to diagnosing seventh-grade students' mathematical ability levels.

Keywords: conceptual structural dimension, digital learning platform, mathematical ability level, mathematical procedure dimension, Measurement and Geometry, seventh-grade students

1. Introduction

Huang, Huang and Wu (2014) emphasized the importance of mathematics as a method of real-world importance for numerous additional scientific disciplines. Consequently, it is crucially important in terms of motivating students' knowledge. Since mathematics is a fundamental discipline, mathematical abilities should be 21st Century skills needed to resolve the complications of daily life, both competently and appropriately (Junpeng et al., 2020). In addition, the Organization for Economic Cooperation and Development (OECD) has introduced the Program for International Student Assessment in order to measure 15 years old students' abilities when it comes to utilizing their mathematical knowledge and skills to meet real-life challenges (Jaikla, Inprasitha, & Changsri, 2020). Following this line of reasoning, assessment is used to generate information about students with regard to such aspects as mathematical ability levels in a comprehensive manner to be represented upon by the student and teacher, with instruction being used jointly to create understanding (Kesianye, 2015). In other words, a digital learning platform can be used as a measurement tool to diagnose the student learning requirements after identifying the students' mathematical ability levels, and how they can be addressed to enhance learning. It is understood that there are ways in which digital learning platforms can be considered an integral part of teaching

(Yildiz, 2021).

Junpeng, Inprasitha, and Wilson (2018) defined mathematical ability in terms of a student's competence when it comes to questioning, venturing, and reasoning rationally. This is an aspect of intellectual development in that the student comprehends how to resolve a mathematical problem using suitable approaches and is then able to replicate the method used with regard to other problems up to replicate on the method used to resolve the problem. Moreover, mathematical problem-solving assessment is the most thought-provoking matter, particularly in the topics of Measurement and Geometry (Fouryza, Amin, & Ekawati, 2019) because it contributes significantly to mathematics education outcomes (Junpeng et al., 2018). Junpeng and colleagues explained that students are required to utilize their response to a preceding step to resolve problems in a following step, before finding the ultimate answer thus eliciting their multiple abilities. Subsequently, Redecker and Johannessen (2014) revealed the importance of preparing students with sufficient mathematical abilities for their future career and lifetimes in the current period of fast-tracking transformation in society, predominantly with technological advances corresponding to the post-COVID 19 pandemics period (Yildiz, 2021).

The rationale for chosing to investigate seventh-grade students' mathematical ability levels is because they experienced significant changes in the physical structure, teaching and learning practices, and expectations of school during the transition from elementary to high school schooling, particularly in mathematics subjects (Attard, n.d.). There are several factors such as curriculum, pedagogy, assessment strategies, social interactions, and students' relationships with others which play a critical role in influencing the learning and teaching of mathematics at the seventh-grade level. This is because students are encouraged to engage in their learning activities in such a way to promote their mathematical ability levels (Martin, 2006). Of course, the challenge will not come to an end in seventh grade, but is intended as a vehicle to enhance the quality of the teaching and learning of mathematics in high schools, and has been endorsed by the Office of the Basic Education Commission (2019) in Thailand.

Diagnostic assessment is important for mathematics teachers to allow them to measure their students' understanding of a subject topic or to determine their skills base. Therefore, mathematics teachers typically administer diagnostics in terms of mathematical abilities, using the results to provide remedial instruction or to place students within appropriate level classes. Many mathematics teachers however, use formative assessment procedures to gauge the mathematical ability levels of students (Archuleta, n.d.). According to Shute and Underwood (2006), mathematics teachers need to design tasks in such a way that the information can be interpreted in valid and reliable ways. They further emphasized that a good diagnostic system should be able to accurately infer ability estimates for a student. As a result, the diagnostic process has to begin with the design of an accurate and informative ability model to provide the basis for ability level diagnoses to occur (Shute & Underwood, 2006).

Junpeng, Krotha, Chanayota, Tang and Wilson (2019) constructed and validated progress using digital technology maps to diagnose 1,500 seventh grade students' multidimensional mathematical ability in Number and Algebra topics, using the construct modeling approach. They used four building blocks as their research procedure. Their findings indicated that there were three constituents of evidence of validity, in the form of explicitly internal structure, test content, and response processes. The reliability values with regard to the mathematical procedure (MPC) and conceptual structural (CSC) dimensions were 0.84 and 0.80 respectively. The majority of the seventh-grade students were found to be at mathematical ability level 2, namely, 44.95 percent and 61.57 percent in MPC and CSC dimensions respectively. Besides, the digital technology mapping approach they developed was found to be at the most appropriate quality levels in terms of usefulness, suitability and accuracy aspects, as evaluated by 10 experts. Their research has successfully contributed to helping mathematics teachers to use digital technology to improve students' mathematical ability levels.

Phaniew, Junpeng and Tang (2021) conducted research to plan and validate a measurement model to establish standards when it came to gauging ability levels in the topics of Measurement and Geometry. They created a measurement model for such standards by employing a Multidimensional Random Coefficient Multinomial Logit model (MRCMLM). Their findings proved that the validity of the inner structure of the multidimensional model was acceptable, and that the evidence of reliability was consistent with the quality of the assessment model. In addition, they managed to establish assortments for the assessment model that were consistent with the findings from the Wright map.

Junpeng et al. (2020) validated a digital tool used to diagnose 1,504 seventh-grade students' mathematical ability levels with regard to Number and Algebra. They employed a design-based method to generate a diagnostic device consisting of four parts, namely, a register system, input data, a process system, and a diagnostic feedback

report. Their findings indicated that the internal structure of validity is constructed on a comparison of model fit and the Wright map. Moreover, the evidence of reliability and item fit are yielding with the quality of the digital tool, as reflected in the analysis of the standard error of measurement and the infit and outfit of the items. Their research implications confirm that the digital tool they developed can offer rich information, especially to those students who display middle and extraordinary mathematical ability levels.

2. Method

2.1 Research Procedure

In this research the researchers employed a design research method (Vongvanich, 2020) consisting of three stages. In the first stage, the researchers conducted semi-structured interviews to investigate the conditions and needs of users. These involved two mathematics teachers, two computer engineers, and three experts in educational measurement and evaluation. The findings obtained from the first stage were used to design a digital learning platform as a prototype to diagnose seventh-grade students' mathematical ability levels as part of the second phase. In other words, this prototype takes the form of a feedback information system that can automatically diagnose mathematical ability levels through a digital learning platform. The final stage was used to test and refine solutions in practice by implementing the prototype in schools, allowing the researchers to introduce the new design principles, thus completing the innovative assessment process. **Figure 1 elucidates the research procedure of the entire research, but this paper reports the findings of the final phase.**
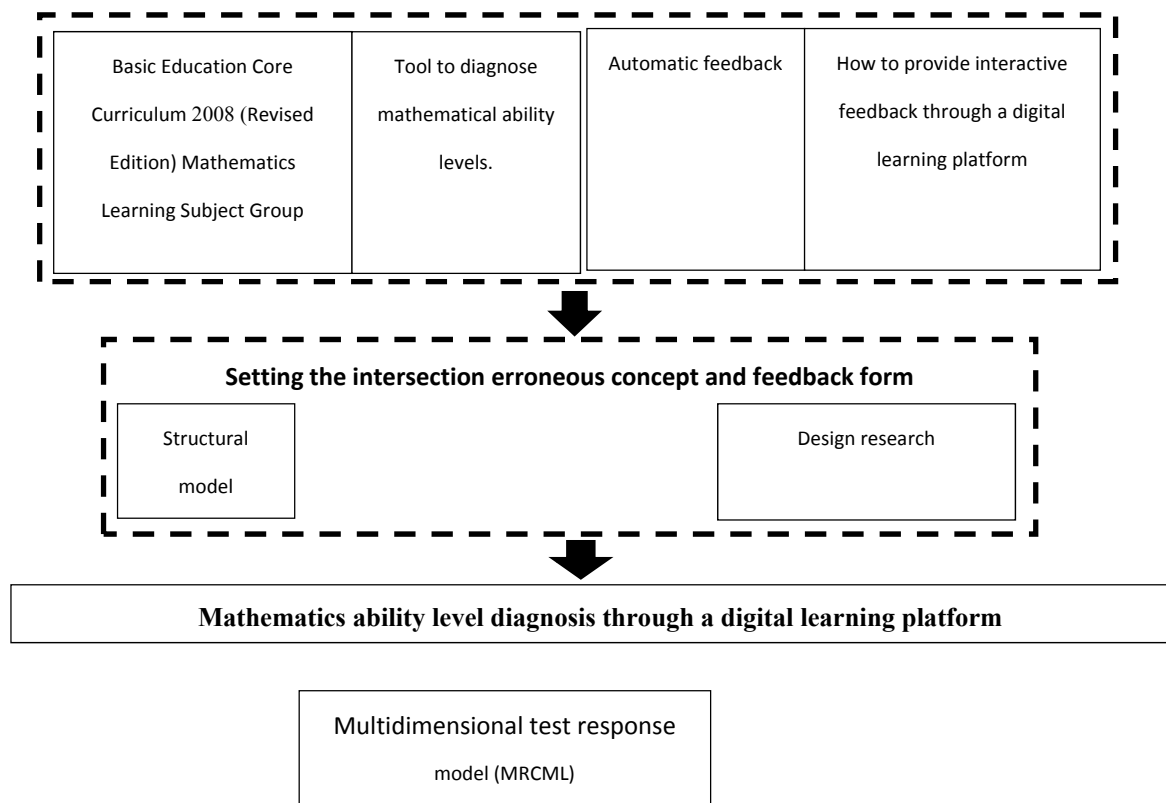

Figure 1. Research procedure

2.2 Test Takers

The researchers employed a probability cluster sampling technique to divide the population into four clusters (regions), namely north, northeast, central, and south Thailand. The entire cohort of 517 seventh-grade students from 23 schools in the four regions, were arbitrarily chosen to take part in the test as they display homogeneous characteristics and have an equal chance of being a part of the sample. The researchers took into account the students' mathematical ability levels, school size, and school context to make sure they were representatives of all seventh-grade students in Thailand. This sample size fulfilled the requirements recommended by Custer (2015) as well as by Jiang, Wang and Weiss (2016), that the obligatory sample size for the estimation of item

parameters in the multidimensional model of the Rasch-family models is 400 to 500, in order to deliver precise parameter estimates.

2.3 Research Tool

In this research the researchers adopted Junpeng et al.'s e-MAT Testing (2020) procedure as a diagnostic tool for evaluating the students' mathematical ability levels, and for reporting their learning assessment using information technology. Specifically, e-MAT Testing is a real-time online toolkit using a direct-response web application interactive support available iOS Android and Windows systems. The research tool is an empirical standardized mixed-format test indicating its accuracy, suitability, and feasibility when it comes to applying the interpretation of the original innovative design.

2.4 Data Collection

The digital learning platform of the prototype automatic feedback system consists of five sections, namely data acquisition, processing, display, automatic feedback, and assessment report. There are five formats in the form of presenting positive feedback, retrying, providing examples, giving detailed error warnings, and providing advice or information. The data acquisition section involves the input of the test results from the first phase which are then transferred into the automatic feedback system. The data acquisition section consists of: (i) the intersection and the score range of its intersection allowing converting to scale and raw scores; (ii) the descriptions of the mathematical ability level for each dimension; (iii) misconceptions of each option or question; (iv) students' development in terms of the five feedback formats, and (v) the correct answers to each question. The data acquisition section is useful for the students as they can check their test scores automatically, while the teachers can use the data as guidelines for grading purposes.

The processing section involves an automated scoring process and is used to manage the students' answers with regard to the multiple-choice questions and the subjective questions. The system will immediately provide automatic feedback for incorrect answers to multiple-choice questions in order to guide students with the provision of additional learning sources. Moreover, students can check their answers to the subjective questions, either in real-time or non-real-time feedback. The display section utilizes the information received from the data acquisition section by focusing on the algorithm program procedures which display the interpretation results on the screen. For example, the display section will sum up the raw scores for all questions and compare the total raw scores against the scale score. This leads to a diagnosis of the students' mathematical ability stages in each dimension.

The automatic feedback section shows how the system can lead to students' self-improvement to a higher mathematical ability level using descriptions or video clips that link to related knowledge and information. In addition, the system will allow students to import data into the new data entry section and it will repeat the above functions. The students will receive an immediate report after they have completed a test. The assessment report section is designed to report the results in an individual and easily understandable form. The assessment report is comprised of personal data, information and statistics, and assessment data with regard to the students' mathematical ability levels.

3. Results

3.1 Mathematical Ability Levels of Seventh-Grade Students Using Construct Maps

The mathematical ability assessment tool used in this research has two MPC and CSC dimensions. According to the progress maps shown in Junpeng et al.'s (2019) research, as shown in Figure 2 there is a five-level ascending order from unresponsive to tactical intelligent for the MPC dimension. On the other hand, the researchers made use of the SOLO taxonomy as a model to recognize, designate, and enlighten the CSC dimension, namely non-response, pre-structural, uni-structural, multi-structural, and prolonged intellectual structure (Briggs & Collis, 1982). Figure 2 shows the two construct maps of mathematical ability levels for seventh-grade students' test results, developed by researchers.

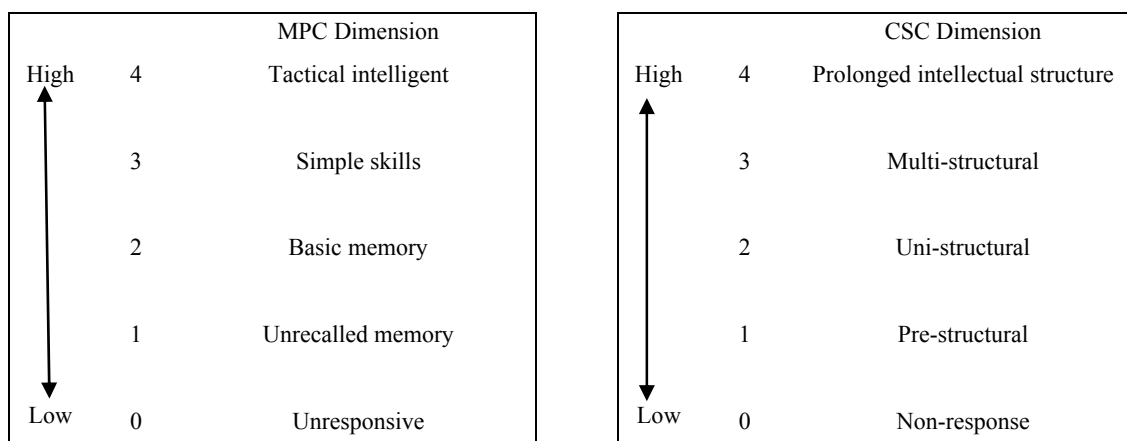| MPC Dimension		CSC Dimension	
High 4	Tactical intelligent	High 4	Prolonged intellectual structure
3	Simple skills	3	Multi-structural
2	Basic memory	2	Uni-structural
1	Unrecalled memory	1	Pre-structural
Low 0	Unresponsive	Low 0	Non-response

Figure 2. Construct maps

In addition, the researchers designed the mathematical tasks according to the standards and indicators of the Core Curriculum of Basic Education 2008 of Thailand (Revised in 2017) in Substance 2, Measurement and Geometry. A total of 18 items in a mixed format was developed, encompassing three subjective questions and 15 multiple-choice questions. The test questions were distributed equally among the MPC and CSC dimensions, giving nine questions for each dimension, using construct modelling (Wilson, 2005) as a foundation for progress, and for the quality inspection of the research tools.

After the 517 seventh-grade students took the mixed format test, the researchers calculated their scores, with the correct answers for each multiple-choice question being given one mark and zero marks for the wrong answer. On the other hand, multiple ratings from 0 to 4 marks were used to calculate the scores for the subjective questions. A precise guide was utilized to measure the MPC and CSC dimensions of the seventh-grade students. This scoring guide ranged from 0 to 4 for both MPC and CSC dimensions, demonstrating unsuitable, partly suitable, most suitable, and highly suitable in terms of ability. Therefore, the scoring guide was utilized for all assessments relating to any of the dimensions. Figure 2 illustrates the scoring guide for diagnosing students' competence in terms of the five ability levels in the MPC and CSC dimensions.

3.2 Quality Inspection of the Seventh-Grade Students' Mathematical Abilities Assessment Model

The educational and psychological testing standards suggested by AERA, APA and NCME (2014) were used to test the quality of the digital learning platform in the form of a prototype automatic feedback system used to measure seventh-grade students' mathematical abilities. The findings verified that there were three forms of evidence to support the quality of the mathematical abilities assessment model, indicating that it met the principles at an adequate level. The primary piece of evidence in terms of validity of the inner structure was identified in parallel with the empirical data (χ^2 = 11.54; df = 2; p = 0.01). In addition, the assessment model was consistent with the data because the G^2 value of the multidimensional model was less than of the unidimensional model, as illustrated in findings with regard to the Likelihood-Ratio. Therefore, a multidimensional model was found to be more accurate and reliable than a unidimensional model. Hence, the multidimensional model is suitable for the scoring determination of the ability levels of seventh-grade students in MPC and CSC dimensions. The final piece of evidence was the quality of item fit which utilized the multidimensional form of partial credit model by ConQuest 2.0 (Wilson, 2005) to check the suitability of every question. The correctness of every question (INFIT MNSQ) was between 0.79 to 1.27. The outcome of the INFIT MNSQ value achieves the adequate principles range of 0.75 to 1.33 as proposed by Adam and Khoo (1996). Therefore, the researchers concluded that the seventh-grade students' mathematical abilities assessment model is an accurate and high-reliability measurement model.

3.3 Item Fit to Formulate the Mathematical Abilities Assessment Model

The mean threshold of mathematical ability level for every dimension was utilized to articulate the mathematical abilities assessment model. Table 1 demonstrates the transition points which were calculated from the mean of the item thresholds in every level for MPC and CSC dimensions. Next, the researchers articulated the valuation standards by manipulating the transition in conjunction with the criteria range on the Wright map for separate ability levels. The identical level of the MPC dimension and CSC dimension was identified by the mathematical mean threshold of the mathematical ability level.

Table 1. Findings of item fit statistic analysis

Dimension	Item	Difficulty	Threshold Level			
			1	2	3	4
MPC	5	-1.64	-1.64			
	6	-0.63		-0.63		
	7	-0.18			-0.18	
	8	0.13			0.13	
	9	-0.75		-0.75		
	10	0.09			0.09	
	13	0.52				0.52
	17	0.56	-1.48		1.30	1.90
	18	0.52	-1.10		1.09	1.59
Mean			-1.41	-0.69	0.49	1.34
CSC	1	-1.23	-1.23			
	2	-1.20	-1.20			
	3	0.38			0.38	
	4	2.32				2.32
	11	-0.66		-0.66		
	12	0.16			0.17	
	14	0.38			0.37	
	15	0.29			0.28	
	16	0.58	-0.51	0.93	1.02	1.07
Mean			-0.98	0.14	0.44	1.70

3.4 Scoring Criteria and Determination of Seventh Grade Students' Mathematical Ability Levels

The findings of the intersection of the MPC dimension's transition point from levels 1 to 5 were reported from lowest to the highest level at -1.41, -0.69, 0.49, and 1.34 respectively. Conversely, the intersection of the CSC dimension's transition point from levels 1 to 5 was reported from lowest to highest as -0.98, 0.14, 0.44, and 1.70 respectively, as elucidated in Figure 3.
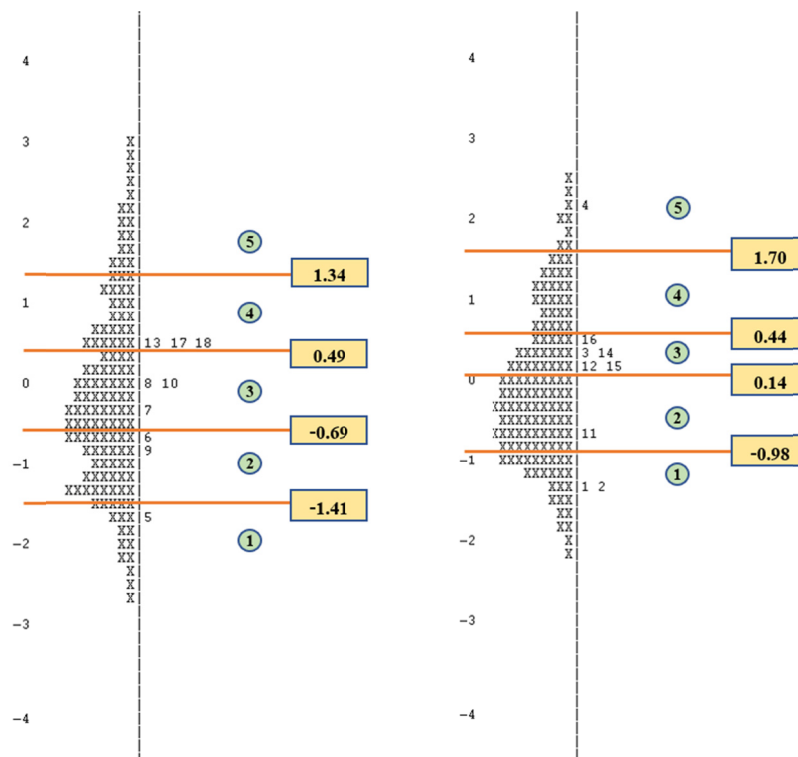

Figure 3. Determination of mathematical ability levels of the MPC and CSC dimensions

3.5 Findings of Multidimensional Test Response from the Seventh-Grade Students

The mathematical ability standards of the assessment model were set by the after the researchers doubled confirmed with criterion zone identified from the Wright map. Therefore, the researchers determined a sum of five score assortments. These were transformed into scale and raw scores from the estimation of the mathematical competency parameters. Table 2 demonstrates the complete findings of the 517 seventh-grade students' mathematical ability level in terms of the MPC and CSC dimensions. The findings show that none of the test-takers was at the lowest mathematical ability level in either the MPC dimension or the CSC dimension. This implies that they were at the higher ability level than the minimum level.

Table 2. Findings of determination of mathematical ability standards

Dimension	Competency level	Intersection θ	θ range	Scale scores	Raw scores
MPC	Tactical intelligent (5)	1.34	>1.34	>63.40	8–13
	Simple skills (4)	0.49	0.49<θ<1.33	54.90–63.30	7
	Basic memory (3)	-0.69	-0.69<θ<0.48	43.10–54.89	6
	Unrecalled memory (2)	-1.41	-1.41<θ<0.70	35.90–43.19	3–5
	Unresponsive (1)		<-1.41	<35.90	0–2
SLO	Prolonged intellectual structure (5)	1.70	>1.70	>67.00	8–12
	Multi-structural (4)	0.44	0.44<θ<1.69	54.40–66.99	7
	Uni-structural (3)	0.14	0.14<θ<0.43	51.40–54.39	6
	Pre-structural (2)	-0.98	-0.98<θ<0.13	40.20–51.39	3–5
	Non-response (1)		<-0.98	<40.20	0–2

3.6 Findings of Empirical Assessment

The empirical assessment findings on the quality of the digital learning platform were assessed by two seventh-grade mathematics teachers, two computer engineers, and three experts in educational measurement and evaluation to determine its accuracy, suitability, feasibility, and usefulness. As illustrated in Table 3, the empirical findings indicated that the digital learning platform was at the highly appropriate levels in terms of its usefulness, suitability, and accuracy, with the exception feasibility was only at a moderate appropriate level. The highest average scoring related to the usefulness of the digital learning platform (mean score = 4.89; *SD* = 0.58). This implies that the platform can respond well to the students' needs. In addition, student feedback can be used to diagnose the students' mathematical ability levels. Consequently, it is useful in terms of improving their learning outcomes. This was followed by the suitability aspect (mean score = 4.83; *SD* = 0.23). This indicates that the assessment procedure, the extensiveness of the assessment descriptions, and the assessment system itself, are found highly appropriate match the assessment guidelines.

Next, the digital learning platform is able to classify the purpose of the diagnostic measurement precisely at the highly appropriate level (mean score = 4.78, *SD* = 0.58). This indicates that the evaluation procedure of the digital learning platform is accurate, and that the description of the information is consistent with the authentic mathematical abilities of the students. Finally, the feasibility aspect obtained the lowest average mean (4.33) and a standard deviation of 0.57. If we compared the feasibility aspect to the other three aspects of quality, it can be concluded that the feasibility of the digital learning platform was only deemed to be at a moderately appropriate level. This implies that the platform can be used to assess students' mathematical ability levels, while teachers can use it to develop learning management procedures and student development. Consequently, the researchers were of the opinion that the quality of the digital learning platform they developed has reached the quality assurance of the digital learning platform of a prototype automatic feedback system according to the obtained findings.

Table 3. Empirical evaluation results on the quality of digital learning platform

Quality Aspect	Average Score	Standard Deviation	Appropriate Level
Usefulness	4.89	0.58	Highly appropriate
Suitability	4.83	0.23	Highly appropriate
Accuracy	4.78	0.58	Highly appropriate
Feasibility	4.33	0.57	Moderately approprite

4. Discussion

The main aim of this research was to use the seventh-grade students' mathematical abilities assessment model for the topics of Measurement and Geometry, in such a way that mathematics teachers can integrate assessment and instruction. The importance of integrating assessment and instruction have potential benefits for the learning of mathematics, particularly for difficult topics such as Measurement and Geometry. The findings of this research supported Kesianye's (2015) suggestion that with regard to the taught content, including those components of the curriculum which cannot be assessed through the paper-and-pencil techniques, there is a need to use a digital learning platform to enhance student learning. Therefore, a quality assessment model not only focuses on the learning process, but also on the progress made by individual students by what is required, such as an automatic feedback system, to aid progress.

As we are currently in the process of transition to digital transformation in education during the COVID-19 pandemic (Yildiz, 2021), the empirical research with regard to findings on the quality of digital learning platforms may help mathematics teachers to diagnose their students' mathematical ability levels with confidence, as the measurement model has been proved to be either moderately or highly appropriate in terms of its accuracy, suitability, and feasibility, as well as its usefulness. In other words, the research findings are timely and compatible with the digital processor era, within the scope of the contribution of digital transformation in education for both students and teachers during the pandemic period.

The overall findings have confirmed our belief that an accurate digital learning platform measurement model flows from quality evidence. This in turn is obtained from carefully designed assessment tasks that link to a valid students' mathematical ability model and its constituent knowledge, skills, and abilities. The findings of this study correspond to those of past researchers (Huang et al., 2014; Junpeng et al., 2019; Junpeng et al., 2020; Phaniew et al., 2021; Shute & Underwood, 2006; Yildiz, 2021). Moreover, the current education system is moving forward requiring students to possess a higher level of mathematical ability to meet the complex and multidimensional proficiencies needed in the 21st Century. This indicates the need for digital learning platforms to diagnose students' mathematical ability levels, which will be best represented in the form of necessary mathematical knowledge and skills.

Owing to the fact that the MRCMLM that researchers employed is a general and flexible model, the process system of the digital learning platform allowed for the specification of a large number of multidimensional item response models (Draney & Wilson, 2010). In other words, the digital learning platform has used design matrices to specify the relationship between responses to the items and structural parameters for a given measurement situation. Therefore, the digital learning platform can be utilized by mathematics teachers to view students' feedback on the assessment items in a real-time manner (Hwang & Chang, 2011). In conclusion, the researchers would like to suggest that the Ministry of Education, Thailand should provide the necessary in-service training and infrastructure support to promote the use of digital learning platform to diagnose students' mathematical ability levels at both elementary and high school levels.

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