Development of mathematical mindset scale for mathematics education students

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ABSTRACT

Mathematical mindset is a vital element of one's ability to understand mathematics. Teachers' mindsets affect the way they deliver mathematics to their students, which in turn, will affect students' mathematical mindsets. This paper discusses and proposes a mathematical mindset scale (MMS) for mathematics education students as prospective teachers. The instrument was developed to examine respondents' mindset towards mathematics. There are three-stage processes to finalize the items in the instrument. The first stage is theory collection and preparation of instrument items based on the dimensions of challenge, resilience, effort, learning from critics, and learning from mistakes. The second stage is content validation by a team of experts. The final stage is item selection using confirmatory factor analysis (CFA). The CFA results with a total of 259 mathematics education students produced 11 questions with factor loadings above 0.5. Meanwhile, construct reliability (CR) and average variance extracted (AVE) values are all above the criterion values. The limitations of this research are also discussed further.

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1. INTRODUCTION

Research on mathematical mindset has recently been carried out to explore its influence on students' persistence in solving mathematical problems [1]–[3]. The mathematical mindset concept was originally introduced by Boaler [4] as an alternative learning approach to improve one's mathematical abilities while dismantling myths about learning mathematics. Several researchers have developed instruments related to mathematical mindset [5], [6]. The previously developed instruments were intended to examine students' mathematical mindset scale (MMS), but not for mathematical education students as future teachers.

The teachers' mindset toward mathematics will influence the way they teach [7] and their other aspects of teaching [8]. Teachers can significantly influence students' mathematical mindset [9], [10] which in turn will impact their academic achievement [4], [11]. Rattan *et al*. study [12] shows that the way teachers teach has the ability to 'lock up' students' abilities and prevent them from developing themselves. Therefore, before becoming teachers, Mathematics Education students need to identify their mathematical mindset, because not all mathematics students have growth math mindset.

A study in Indonesia shows that there are two out of three students who believe that intelligence is fixed and cannot be changed [13]. The terrible first impression of mathematics throughout elementary school was one of the causes of students' unwillingness to study mathematics [14]. Some people associate math with anxiety and frustration in elementary school and struggle to grasp sophisticated mathematical concepts or symbols in algebra in middle school [15]. Some students consider mathematics to be unimportant for their personality development. Therefore, they do not have the drive to think mathematically [16].

2. LITERATURE REVIEW

2.1. Triadic of mathematics learning

When mathematics is still seen as something abstract and unrelated to the real world [17], studying it will be considered as full of problem and challenging. However, if someone has positive mental abilities, they will see the challenges as something to tackle and to improve themselves [18]. The process of facing problems is a way to understand the problem we want to solve. This process will later increase curiosity and skills in understanding mathematics [19].

The affective, cognitive, and psychomotor domains are closely related [20] and this relationship is called triadic [21]. Learning mathematics does not only require cognitive abilities but a combination of affective and psychomotor skills [22]–[24]. That true learning is the process of receiving a certain amount of information, then relating it to reality [19], [25]–[27] and then storing it in memory space [28].

Even though mathematics requires good cognitive abilities or mental skills, the affective also influence mathematical abilities. Leder [24] states that discussions about mathematics learning usually include cognitive and affective variables. A positive affective attitude is needed to improve mathematical cognition [23]. Students need a strong motivation to encourage their interest in learning mathematics. On an ongoing basis, learning outcomes can develop aspects of compassion, such as instilling good life values and changing attitudes in a positive direction [29]. In learning mathematics, good cognitive mastery and positive affective abilities can improve psychomotor abilities [20]. Mathematics is a field of knowledge that can be discovered and applied in everyday life [19]. Cultivating a strong positive affective attitude is necessary to encourage enthusiasm for learning in those who study it. Some teachers believe that a positive attitude can improve students' abilities in learning mathematics [22]. Ignacio *et al.* study [23] shows that positive attributions, beliefs, and attitudes toward self-concept are a source of motivation and the key to a person's success in dealing with mathematics.

2.2. Mindset theory

Affective is related to emotion, feelings, and the heart [22], [30] and is closely related to non-cognitive or psychological trait. One of the psychological traits that has recently begun to be considered is mindset. Dweck [31] states that mindset is a malleable belief. Research on the brain reinforces the theory that the human brain is malleable and can be filled with various experiences [32]. Mindset is closely related to mental health symptoms [33]. Mindset refers to the implicit views that people have about basic human characteristics [34]. Mindset, known as a person's belief about his ability, is something that remains or develops [35]. Mindset is also defined as a belief that is usually not expressed in words [36]. Mindset is not an inanimate object that has remained since humans were born. Mindset can change and develop following trainings [31].

Fixed and growth mindsets are the two mindsets that Dweck distinguishes [31]. A person with a fixed mindset thinks that their strength, intelligence, and other traits of greatness have already been established from birth, without the need for training and learning. Failure is viewed as evidence that a person is unqualified and will never be successful. A person with a growth mindset will view failure as an opportunity to continue growing and learning [31], [37], [38]. The idea that personal qualities, especially intellectual ability, are malleable and developable is known as a growth mindset [39].

2.3. Mathematical mindset

Some people strongly belief that mathematics is a subject that can only be mastered by someone with ‘natural’ mathematical abilities [40]. Mathematics is often considered a male-only subject. Some stereotypes state that minorities and women are not suitable for the world of mathematics [4], [41]. Following this line of thinking, if women have to put a lot of effort to understand mathematics, the effort is considered as evidence that women do not have 'natural' mathematical abilities. The more difficult a lesson is, the more stimulated the brain to think and add new neuron networks [4], [19], [41]. Dweck also states that mindset can predict math and science achievement over time. This ensures that one's mathematical abilities can develop. Female students and those who are considered to have weak intelligence can master mathematics [41].

Daly *et al.* [42] explained that the mathematical mindset is based on two assumptions about mathematical intelligence. The first assumption is someone who thinks that mathematical ability is obtained from genetically inherited intelligence. The second assumption is someone who thinks that math skills can be improved by doing exercises. The latter is called a growth mindset in mathematics. A growth mindset in mathematics is an affective aspect that is required to drive enthusiasm and motivation into mastering mathematics [43], [44]. Mathematics learners who have a fixed mindset tend to be afraid of facing difficult math problems [6], [41], [42]. Meanwhile, learners with a growth mindset will feel challenged and driven by the problems they face [32], [44].

Ayebo and Mrutu [45] suggest that effort, usefulness, difficult problems, understanding, and steps are the factors that form the mathematics belief scale. Meanwhile, Im and Park [5] refer to the seven positive norms proposed by Boaler [19], namely: i) everyone can learn mathematics to the highest level; ii) mistakes are valuable; iii) questions are important; iv) mathematics is about creativity and making sense; v) mathematics is about connecting and communicating; vi) a deep understanding is more important than speed of work; and vii) mathematics class is a space for learning, not a place to show off. Saefudin *et al*. research [6] uses the dimensions of mathematical skills and intelligence, challenge, obstacle, effort, criticism, and the success of others. This research developed MMS by referring to five dimensions: challenge, resilience, effort, learning from critics, and learning from mistakes. Thus, this research aims to find items that can provide information about the mathematical mindset tendencies of mathematics education students through confirmatory factor analysis (CFA).

3. RESEARCH METHOD

The design of this research is non-cognitive instrument development research using CFA. Based on the domain sampling approach, CFA has historically been used to build and enhance reflectively assessed constructs [46]. CFA aims to ensure that the items that have been prepared following the dimensions of the variable [47]. There are five dimensions in the mathematical mindset instrument in this research, they are challenge, resilience, effort, learning from critics, and learning from mistakes. Each dimension consists of five statement items to anticipate the occurrence of failed statement items. This instrument uses a five-type Likert scale, which continuum from strongly disagree to strongly agree. Each dimension was initially represented by five statement items, for a total of 25 items in the instrument.

There were 259 participants who were willing to complete the instrument (20.6% male and 79.4% female). Data collection was carried out using Google Forms. All of the respondents were Indonesian (Jakarta) students from the Mathematics Education Study Program. There is no particular reason why the number of male respondents is less than female respondents. This instrument was given randomly to all grade levels and all genders. However, the number of female teachers is generally greater than males [48]. This is perhaps a result of traditional belief that is still very strong in Indonesia, that being a teacher is considered a profession that is more interesting for women. However, research shows that it does not always the case as may men found to be passionate in teaching [49].

This research is divided into three stages. The first stage is the stage of preparing the instrument based on the dimensions of the mathematical mindset theory. The second stage is the expert validation test. At this stage, the MMS was tested for content validation by five experts [50]–[52]. After that, the value of V Aiken’s index was calculated. The last stage is testing the MMS on participants, followed by items selection using CFA. The CFA is also used to assess the reliability and validity of the measuring approach [53]. Selection was only carried out on items that produced factor loadings above 0.5 [54], [55]. After item selection, construct reliability (CR) and average variance extracted (AVE) were calculated to determine the level of reliability. CR values must be greater than 0.7 to be considered high [56]. The AVE can be used to gauge convergence validity by averaging a construct's indicator reliability. The criterion for the AVE value is that it must be above or equal to 0.5 [56].

After obtaining the model, a goodness of fit check is carried out to assess the fitness of the model. The goodness of fit criteria for root mean square error of approximation (RMSEA) is 0.06 or less to indicate a close fit and less than 0.07 indicates an adequate fit [57]. Other criteria are the Tucker-Lewis index (TLI), comparative fit index (CFI), and the normed fit index (NFI) if more than 0.9 is defined as fit [58].

4. RESULTS AND DISCUSSION

After constructing the MMS items, content validation was carried out with several experts. An expert validation test known as content validity is to ensure that the items in the instrument sample the complete range of the attributes under study [59]. The evaluation of an instrument’s content representativeness or relevance is known as its content validity [51]. For this reason, several experts are tasked with checking whether the statement items are following the dimensions. Table 1 presents the results of expert validation using the V Aiken’s index. Five experts provided assessments regarding the statement items in the MMS, where the number of suitable experts ranged from 3 to 5 people [51]. The content validation with V Aiken’s index was calculated with (1) [60].

$$V = \frac{s}{n(c-1)} \quad (1)$$

Information:
V= validity value (range from 0 to 1)
n= the number of experts who made the assessment
c= the number of value choices
s= r–lo, where r= the value chosen by the expert/ratter and lo= the lowest value

Table 1. Expert validation results of V Aiken's index

Item	Ratter					Ss	V
	I	II	III	IV	V		
1 – 25	123	87	100	125	71	381	0.762

Source: Processed data

Based on the results of V Aiken's index (Table 1), the MMS instrument is classified as having high validity of content. However, it still needs to be tested for construct validity and reliability using SPSS 21 and AMOS 22, to find out whether there are items that need to be removed or corrected. The Kaiser-Meyer-Olkin (KMO) and Bartlett tests were used to determine the suitability of the sample size and the adequacy of the correlation matrix [54], [61]. The KMO value must be greater than 0.5 to be considered a research factor, but the significance value on Bartlett's test of sphericity must be less than 0.05 to indicate the existence of a significant correlation between variables [62]. Since the KMO measure of sampling adequacy value was 0.884 and Bartlett's test yielded $\chi2$ (300)=1852.889, p<0.000 as presented in Table 2. It means that the data can be continued to the next analysis, i.e. selecting items that have a factor loading above 0.5. Meanwhile, items that have a loading factor below 0.5 will be removed. After removing items below 0.5, a model was obtained that met goodness of fit. The model of MMS is shown in Figure 1.

Table 2. Results of sample adequacy test with KMO and Bartlett's test

Sample adequacy test		
Kaiser-Meyer-Olkin measure of sampling adequacy		0.884
Bartlett's test sphericity	Approx. Chi-Square	1852.889
	Df	300
	Sig.	0.000

Source: Processed data by SPSS

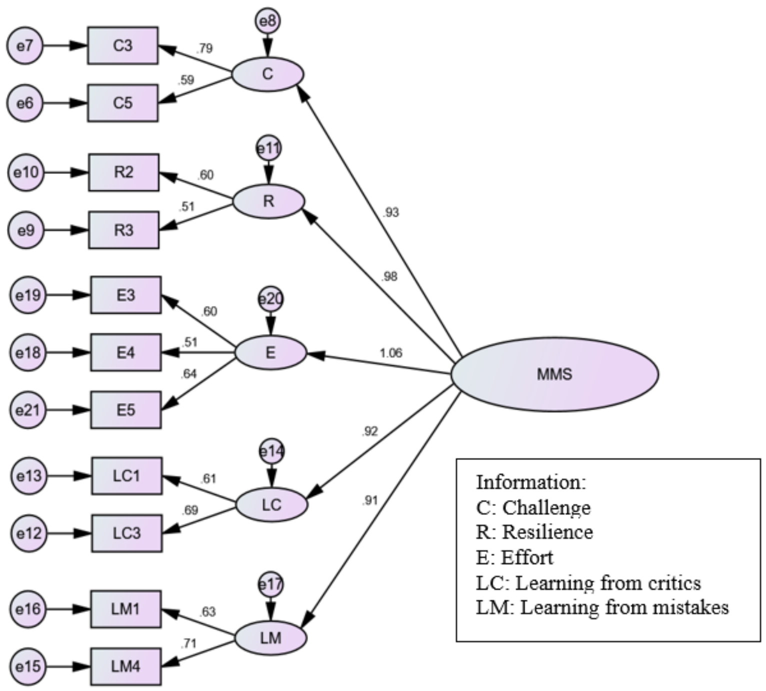

Figure 1. Model of mathematical mindset scale

Later on, the CR value is 0.984 and AVE 0.925. CR must be better than 0.7, and AVE must be greater than 0.5, for MMS to be considered very reliable [56]. Based on the results of the CFA test with AMOS, 11 items passed the test as shown in Table 3. The goodness of fit in this model meets the requirements with X^2/df=2.090, RMSEA=0.065, RMR=0.025, goodness of fit index (GFI)=0.95, adjusted goodness of fit (AGFI) =0.908, Tucker-Lewis index (TLI)=0.928, normed fit index (NFI)=0.908, and comparative fit index (CFI)=0.95. Figure 1 shows items whose factor loadings are above 0.5. The dimensions of challenge, resilience, learning from criticism, and learning from mistakes are conveyed by two items. Meanwhile, the dimension of effort is represented by three items. The statement items that passed can be seen in Table 3.

Table 3. Dimensions, items, and factors loading

Dimensions	Items	Factor loading*
Challenge	C3. No matter how much math intelligence I have, I will be able to improve it.	0.787
	C5. If other people can master mathematics, then I can too.	0.590
Resilience	R2. I am aware that I do not have talent in mathematics, but I will do everything I can to become an expert in mathematics.	0.600
	R3. Even though the lecturer thinks my efforts will be useless, I still want to prove that mathematics is a science that anyone can master.	0.510
Effort	E3. I will keep asking anyone until I can really understand mathematics.	0.598
	E4. Even though my friends say that studying without having mathematical talent will be useless, I think otherwise.	0.511
	E5. Mastering mathematics is not an easy job, but there are opportunities to learn and understand it little by little.	0.636
Learning from critics	LC1. Even though I've been told I'm not intelligent many times, I will keep asking questions until I finally understand mathematics.	0.605
	LC3. The mathematics lecturer's criticism of me challenged me to prove that I could be better.	0.687
Learning from mistakes	LM1. A bad grade in mathematics challenges me to continue to master it.	0.626
	LM4. Even though my teacher said that I had no hope in mathematics, I wanted to keep trying.	0.707

*AMOS result

Mindsets can be formed from challenge, resilience, effort, learning from critics, and learning from mistakes. The challenge dimension describes the difference in attitudes between those with a growth math mindset and those individuals with a fixed math mindset. Ayebo and Mrutu [45] stated that if students believe they cannot solve the problem in a short time, those with fixed math mindset will choose not do it. The opposite will be done by students with a mathematical growth mindset. They will be increasingly challenged to solve math problems, no matter how difficult it is [4], [31]. They understand failure as a process of forming mentalities and abilities so that they can become experts [31]. Hard work is one of the factors that shape a growth mindset [31], [45].

The resilience and effort of someone with a growth mindset means that they will not give up easily when they make mistakes or fail. They believe that failure is something that can never be separated from human life [63]. Successful people often make a lot of failures before finding their way. So even with the mindset of mathematics, the most fundamental difference between someone who will eventually be able to master mathematics is their persistence [64]. Those with a fixed mindset hold true the belief that if they are talented, they will not fail or even have to try hard [31]. When they fail, they will assume that it is because they are not talented. Meanwhile, many people who are now known as experts have gone through hours of training [64]. Aditomo [63] mentioned that the dynamics of motivation become even more important when students are faced with setbacks or in a challenging situation. Those with a growth mindset understand that mistakes are natural during the learning process [65].

Apart from responding to mistakes positively, willingness to listen to criticism and filter it for self-improvement is not an easy task. Criticism is something that most people avoid, but students with a growth mindset will look forward to it. The ability to listen to criticism is something that can improve self-quality [65], [66]. Research suggested that teachers praise their students for their effort, not because of their intelligence [67]. Parents and teachers must also understand that talent is not the main thing [68]. Someone who has talent still needs to have continuous passion and persistence. Dweck [41] stated that genius frequently appears to grow over time via sustained work and focus. Students with a fixed mathematical mindset will avoid difficult problems when they know they cannot solve them. Meanwhile, students with a mathematical growth mindset will always move forward, even though they have failed many times. Boaler [19] states that when someone feels confused and has difficulty learning, the nerves in their brain are working to make new connections with other nerves.

Teachers and parents also need to form a growth mindset [69]. Teachers must deliberately create spaces for students to work together, share responsibility, solve problems, and control conflicts [70] to help students develop their mindset. Teachers and students ought to have an optimistic perspective on life and be content with, accept, and appreciate the variety of cultures and individuals [71]. Teachers can also formulate several teaching plans in the classroom to teach students how to communicate effectively [72]. The role of parents and teachers is vital to develop the mindset of students in mathematics. Fixed-mindset teachers tend to labels student only based on their scores [73]. Teachers should understand that there is a huge array of challenges that might cause students to have a low score in their tests. Teachers with a growth mindset will be able to maintain their expectations toward their students and persist to help them to face their difficulties [31], [73].

The psychological aspect, including mindset, undeniably, influences one's cognitive ability or academic achievement. The same goes for math skills. According to previous studies, mathematics can be learned by anyone [4], [41]. A mathematical mindset is also correlated with academic grit [74]. Students who believe that mathematical intelligence can be improved tend to have higher math scores. Conversely, students with a mathematics-fixed mindset, their mathematics scores tend to decrease over time [31]. However, shifting a fixed to a growth mindset requires a long process. In like manner, how mindset affect a person's attitude cannot be seen instantly, but there will be significant changes equivalent with the effort put in the process [63], [75].

This paper presents preliminary research to obtain the appropriate dimensions to build the MMS instrument. However, there are several limitations, such as a small sample size and an unbalanced participant ratio based on gender. The number of female participants was much greater than that of male participants, which might have caused gender-biased research results. We suggest a more balanced gender of samples in future research or research that compares whether gender influences mathematical mindset. Researchers and educators can also conduct experimental research to find out how effective a mathematical mindset is in reducing math anxiety and other learning problems.

5. CONCLUSION

Based on the results of confirmatory factor analysis, there are 11 statement items obtained to represent five dimensions, i.e. challenge, resilience, effort, learning from critics, and learning from mistakes with CR value is 0.984 and AVE is 0.925. All the values show the high reliability of mathematical mindset scale. Likewise, with the goodness of fit results, GFI, AGFI, CFI, TLI, and NFI are above 0.9. This indicates that the MMS model is deemed to be fit. This MMS instrument is expected to be able to measure the math mindset tendencies of mathematics education students. Once their MMS is known, lecturers and students can take necessary actions to develop a mathematical mindset to positively impact their future teaching performance. In the future, research needs to be carried out to test the effect of MMS on students' mathematics abilities and academic mathematics achievements.

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