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Exploratory Factor Analysis for Mathematics Identity among Secondary School Students

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ABSTRACT

Currently, there is not widely accepted or universally recognized measure that captures a singular identity for mathematics due to inconsistent measurement methods used in research on this topic The problematic nature of students' relationship with mathematics has prompted researchers to examine the issue through the perspective of identity. This research examined the alignment between the items on the adapted questionnaire related to mathematics identity load on the theorized sub-constructs by conducting instrument validation. Cluster sampling method was employed in this study, involving 213 participants. A questionnaire comprising 19 items was administered to secondary school students. Then, the exploratory factor analysis (EFA) was utilized to categorize the different components present in the questionnaire. Additionally, Cronbach's Alpha was calculated to assess the internal validity and reliability of the questionnaire, ensuring the consistency and accuracy of the instrument. The study revealed that there are three main dimensions which are mathematics recognition, mathematics learning performance and competence, and mathematics career interest that can be classified by 13 items. The result led to formulate a new set of questionnaires. The new set of questionnaires will be distributed for further research to proceed on confirmatory factor analysis (CFA).

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1. Introduction

Over the past few decades, a significant issue in national education has been the declining interest of students in mathematics and the decreasing number of students who view science, technology, engineering, and mathematics (STEM) as a potential area of study or career [1]. Comprehending mathematics is a crucial requirement for most STEM professions, such as statistics, engineering, physics, and life sciences. Even though a strong foundation in mathematics should be

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established during elementary education, a student's readiness for pursuing a STEM degree in college is primarily determined by their mathematical performance in high school. Although young children generally have a positive attitude towards mathematics, studies have revealed a decline in interest over the years, particularly among high school students [2]. As a result, a growing number of researchers have shifted their focus to studying the early mathematics learning experiences in both classroom and informal settings. The aim is to enhance comprehension regarding the formation of a student's mathematical identity [3], [4]. Mathematics identity pertains to the self-perception of students with respect to mathematics, which is influenced by their experiences and engagement with the subject in everyday life [5]. It encompasses students' self-perception and their perception of others' views regarding their engagement in mathematics-related activities [6], [7].

Mathematics identity has become a popular subject in mathematics education research due to its correlation with student confidence, persistence, and positive attitudes toward mathematics [8], [9]. Studies suggest that a strong mathematics identity plays a crucial role in students' persistence and career choices in math or STEM fields [10], [11]. This study aims to create a reliable questionnaire to measure high school students' mathematics identity based on the work [12] and [13]. The questionnaire can be used to improve classroom teaching practices and evaluate informal mathematics programs. The study's research question is whether the questionnaire has empirical evidence to support its validity and reliability.

2. Literature Review

Identity is a complex social construct and generally described as a particular "type of person" that is recognized in a particular environment, either by oneself or with others [14]. Identity formation in STEM has been receiving increasing attention due to growing concerns about students' lack of interest in science [15]. Identity has been defined as a person's perspective on their past experiences and actions in society and the environment around them [16], as well as their present circumstances and potential futures [17]. In 2007, a model for science identity was created by [18], which prioritized performance, recognition, and competence. This model aimed to analyse students' science experiences in both their science education and science-related careers. Another interconnected sub-construct, interest, was later added to this framework [19]. This approach has been successfully utilized to study identity in various fields such as mathematics, physics, science, and engineering [20]–[22]. Research has suggested that a student's motivation to learn and study, their perceived performance and ability, and their belief in receiving recognition from others can predict how long they will stay in school and pursue careers in a particular field [21].

Recent research has placed growing emphasis on the significance of mathematics identity in shaping students' future aspirations and academic achievements. Identity has become a valuable concept in mathematics education, as it helps to understand why students may discontinue studying mathematics without relying on cognitive explanations. Mathematics identity is a crucial construct in mathematics education research for several reasons. Firstly, it is considered a predictor of academic performance and success [8], [24], [25]. It has been suggested that students who possess a strong mathematics identity possess a sense of self-efficacy and curiosity, as well as a growing interest and enthusiasm for mathematics, and a desire to serve as a role model for others in the field [25]. Additionally, the belief that one is capable of mastering mathematics is seen as a significant factor in one's performance, as it is often reinforced by those around them [26]. These theoretical claims are also backed up by empirical evidence. For instance, [8] found that a student's perception of themselves in relation to mathematics has a significant impact on their academic success, as mathematics identity serves as a precursor to action. Seeing one-self as competent in mathematics leads to behaviors that strengthen one's mathematical abilities.

In addition, research studies have shown that mathematics identity is associated with positive future outcomes for students, including their achievement in mathematics [26] and their intentions to pursue STEM careers [10], [21], [27]. For instance, a quantitative study [5] that examined college student's perceptions of their mathematics identity found that specific teaching strategies used by high school math teachers are associated with higher levels of mathematics identity, and that, when compared to non-STEM careers, students who have stronger identities are more likely to be interested in pursuing specific STEM careers. In their subsequent research, [10] measured four constructs related to students' perceptions of mathematics among first-year undergraduate students. The study found that mathematics identity acted as a complete mediator between mathematics mindset and STEM career interest, as well as between mathematics anxiety and STEM career interest.

Previous research has primarily focused on the mathematics identity of college students. Although a study [28] explored how mathematics identity influences the career choices of male and female students in engineering, and another study [12] examined the relationship between career intentions, different mathematics classroom experiences, and mathematics identity, both studies utilized the Factors Influencing College Success in Mathematics (FICS-Math) survey. However, these studies were limited by the survey's questions, which primarily centered around high school math experiences and performance rather than mathematics identity [5], [29]. Despite employing appropriate analysis methods to address this limitation, the items on the survey still offered limited variability. Therefore, the present study aimed to develop a suitable scale that could be used at the high school level and comprehensively measure students' mathematics identity within general mathematics learning contexts in school settings. Thus, the objective of this study was to assess the extent to which the items on the adapted questionnaire, based on a science identity survey developed by [30], loaded on the proposed sub-constructs through instrument validation using exploratory factor analysis (EFA) and reliability analysis.

3. Methodology

In this study, 19 items were selected from existing literature to measure the mathematics identity construct. These items were adjusted to align with the objectives of the study and translated into the Malay language to suit the target population. The pilot testing phase was conducted specifically to evaluate and enhance the questionnaire's content and discriminant validity. To accomplish this, the Malay version of the questionnaire was distributed to a panel of five experts for their review. The expert panel consisted of three academicians specializing in mathematics education, one academician with expertise in education and psychology, and a secondary school mathematics teacher. After incorporating the necessary revisions based on the experts' feedback, the questionnaires were further pilot tested with potential respondents.

The pilot test conducted with potential respondents focused on identifying potential issues with the questionnaires, specifically regarding the clarity of the questions and any difficulties encountered while answering them. This pilot test involved participants who shared similar characteristics with the actual respondents. The data collected from this pilot test was utilized to initially assess the validity and reliability of the measurement items.

When determining the sample size for a pilot study, a general guideline suggests obtaining 10% of the sample size used in the main study [31]. Considering a main study sample size of 400, this pilot study would require a sample of 40 respondents. However, for refining the measurement using empirical assessment, particularly the EFA, a larger sample size is necessary. According to the absolute sample rule proposed by [31], a minimum sample size of 50 observations is recommended for conducting EFA, although a sample size of 100 or larger is preferred. Consequently, 213 participants are deemed appropriate for this pilot study. To select these representative participants, the cluster sampling method is employed [32].

In order to conduct the EFA, a principal component analysis with varimax rotation was utilized. Before analyzing the EFA output, the data underwent a preliminary assessment to determine its suitability for conducting EFA. This assessment involved examining the results of the Kaiser-Meyer-Olkin (KMO) test and Bartlett's Test of Sphericity. A KMO value of 0.6 or higher indicated the appropriateness of the data for EFA, while a significant Bartlett's test (with a p-value lower than alpha value) was also necessary [33]–[35].

After establishing the suitability of conducting EFA, the communalities of the variables were assessed, and variables with low values below 0.3 were identified as potential candidates for removal [34]. Subsequently, the factor loadings and cross-loadings of each item were examined to assess convergent and discriminant validity, respectively. Any item that exhibited weak correlation with the factor, indicated by factor loadings below 0.40 for a sample of 200 [36] or demonstrated significant loadings on other constructs, was excluded from the analysis [33], [35], [36].

Additionally, the reliability of both the construct and its items was examined, with a focus on internal consistency. Cronbach's alpha was employed as a reliable measure for various types of research [37]. According to [36], a Cronbach's coefficient value of 0.7 or higher is typically regarded as acceptable for establishing internal consistency of scales. Therefore, a threshold of 0.7 was adopted in this study as the minimum criterion to determine the reliability of the scales. Consequently, any construct with a Cronbach's alpha value equal to or above 0.7 was considered for further investigation [33], [36], [38].

4. Results and Discussions

A total of 213 responses were successfully collected from a sample of form four science stream students, which consisting of 38.5% (82) male and 61.5% (131) female. The majority of respondents in this study were Malay students, comprising 76.1% (162). Other races, including Indians and Chinese, accounted for 8.5% (18) and 8.0% (17) respectively, while the remaining 7.5% (16) represented other ethnicities. Details of respondent's background are shown in Table 1.

Table 1. Respondents' Background

Background	Item	Frequency	Percentage (%)
Gender	Male	82	38.5
	Female	131	61.5
Ethnic	Malay	162	76.1
	Chinese	18	8.5
	Indian	17	8.0
	Other ethnics	16	7.5

Before conducting the exploratory factor analysis (EFA), preliminary tests were conducted to assess the sample size and normality. The sample size of 213 respondents met the required criteria. The analysis of skewness and kurtosis statistics indicated that all values fell within the range of ±2 [39]. This suggests that the items were reasonably normally distributed (Table 2). As no significant violations were found, the data was deemed suitable for further analysis.

Table 2. Descriptive Statistic

Items	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
IM1	213	3.80	0.987	-0.805	0.167	0.508	0.332
IM2	213	3.40	0.969	-0.339	0.167	-0.220	0.332
IM3	213	3.58	0.986	-0.472	0.167	-0.266	0.332
IM4	213	2.92	1.109	-0.018	0.167	-0.620	0.332
IM5	213	3.31	1.090	-0.255	0.167	-0.429	0.332
IM6	213	3.67	1.007	-0.590	0.167	0.137	0.332
IM7	213	3.61	0.983	-0.554	0.167	0.071	0.332
IM8	213	3.78	0.995	-0.482	0.167	-0.421	0.332
IM9	213	2.73	1.158	0.198	0.167	-0.671	0.332
IM10	213	2.37	1.265	0.537	0.167	-0.802	0.332
IM11	213	2.31	1.215	0.605	0.167	-0.593	0.332
IM12	213	2.39	1.253	0.537	0.167	-0.773	0.332
IM13	213	3.39	1.070	-0.165	0.167	-0.636	0.332
IM14	213	2.84	1.212	0.111	0.167	-0.896	0.332
IM15	213	3.62	1.006	-0.403	0.167	-0.245	0.332
IM16	213	3.35	1.043	-0.243	0.167	-0.403	0.332
IM17	213	3.12	1.170	-0.088	0.167	-0.755	0.332

IM18	213	3.11	1.220	-0.155	0.167	-0.866	0.332
IM19	213	3.39	1.142	-0.406	0.167	-0.518	0.332

4.1 EFA for Mathematics Identity

The EFA procedure conducted for the 19 items of mathematics identity had resulted in the Kaiser-Meyer-Olkin (KMO) value of 0.942, with significant Bartlett's Test of Sphericity value. Thus, the result suggested the adequacy of the data to proceed with factor analysis. Furthermore, all the items measuring mathematics identity exhibited a communality value above 0.3, indicating that they were strongly represented by the factor solution and thus should be included in the analysis. Further, the EFA procedure had yielded in the three factors, each with eigenvalues greater than 1, and explaining 68.19 percent of the total variance. All items have a factor loading score higher than 0.40 (with the lowest being 0.437) on their respective factor. However, items IM14 and IM16 were found to cross-load on factors 1 and 3, items IM2 and IM5 were cross-load on factors 1 and 2, while items IM13 and IM15 were cross-load on factors 2 and 3. Thus the items were deleted and re-specification of the factor structure was performed.

Table 3. Exploratory Factor Analysis for Mathematics Identity

KMO (Bartlett's test)	**Cumulative % of Variance**	**Item**	**Loadings**			**Communalities**
			Factor 1	**Factor 2**	**Factor 3**	
0.942 (significant at $p<0.05$)	68.19	IM4	0.679			0.704
		IM9	0.706			0.738
		IM10	0.885			0.862
		IM11	0.880			0.860
		IM12	0.870			0.873
		IM14	**0.614**		**0.541**	0.734
		IM1		0.649		0.458
		IM2	**0.448**	**0.628**		0.619
		IM3		0.754		0.645
		IM5	**0.463**	**0.523**		0.567
		IM6		0.743		0.665
		IM7		0.680		0.619
		IM8		0.654		0.548
		IM13		**0.437**	**0.536**	0.599
		IM15		**0.510**	**0.537**	0.537
		IM16	**0.442**		**0.593**	0.677
		IM17			0.719	0.799
		IM18			0.771	0.748
		IM19			0.754	0.677

A further EFA was conducted on the remaining 13 measurement items of mathematics identity results in the KMO value of 0.914 and significant Bartlett's Test value, suggesting the appropriateness of EFA (Table 4). All items demonstrated a communality surpassing 0.3, signifying their clear definition by the factor solution and warranting their retention. The exploratory factor analysis (EFA) outcomes revealed three factors of mathematics identity, which collectively accounted for 73.35 percent of the total variance. With minimum loadings of 0.4, Factor 1 was characterized by five items (IM4, IM9, IM10, IM11, IM12), Factor 2 by five items (IM1, IM3, IM6, IM7, IM8) and Factor 3 by three items (IM17, IM18, IM19).

Table 4. Exploratory Factor Analysis for Mathematics Identity (1st Re-specification)

KMO (Bartlett's test)	Cumulative % of Variance	Item	Loadings			Communalities
			Factor 1	Factor 2	Factor 3	
0.914 (significant at *p*<0.05)	73.35	IM4	0.683			0.683
		IM9	0.726			0.759
		IM10	0.896			0.878
		IM11	0.901			0.889
		IM12	0.882			0.878
		IM1		0.617		0.417
		IM3		0.787		0.693
		IM6		0.757		0.677
		IM7		0.712		0.663
		IM8		0.728		0.622
		IM17			0.684	0.791
		IM18			0.828	0.842
		IM19			0.782	0.744

4.2 Reliability Test

Next, the construct and its item for each construct were checked on their reliability using Cronbach's alpha values. Table 7 shows the Cronbach's alpha values for Factor 1, Factor 2 and Factor 3 scales were 0.935, 0.834 and 0.863 respectively. Thus, the Cronbach's alpha values satisfied the recommended value for reliability coefficient of 0.7 for all scales. Therefore, it was concluded that all the items were reliable measurements of their respective constructs.

Table 7. Result of Reliability Analysis

Item	Cronbach's Alpha	Number of Items
Mathematics recognition	0.935	5
IM4		
IM9		
IM10		
IM11		
IM12		
Mathematics learning performance and competence	0.834	5
IM1		
IM3		
IM6		
IM7		
IM8		
Mathematics career interest	0.863	3
IM17 IM18 IM19		

5. Conclusion

In total, the EFA and reliability analysis led to the removal of six items, specifically IM2, IM5, IM13, IM14, IM15, and IM16. Consequently, 13 out of the original 19 items were retained. Among these, items IM4, IM9, IM10, IM11, and IM12 were identified as belonging to factor 1, which represents the recognition scale. Notably, item IM4 pertains to students' self-recognition. Therefore, factor 1 was named "mathematics recognition." On the other hand, items IM1, IM3, IM6, IM7, and IM8 from the performance and competence scales were found to be part of factor 2. Upon reviewing the wording of these items, it became apparent that they shared a common theme concerning students' beliefs about their ability to understand and perform mathematics. These results indicated that competence and performance constitute a single construct for students, aligning with the findings of a previous study on the structure of the mathematics identity framework [28]. Consequently, factor 2 was renamed "mathematics learning performance and competence." Moving on, items IM17, IM18, and IM19 were classified as belonging to factor 3, all relating to students' interest in mathematics-related careers. Thus, factor 3 was labeled "mathematics career interest." The final questionnaire included 13 items distributed across three scales. The reliability of data obtained from all three scales was confirmed, as their internal consistency reliability values exceeded 0.80.

In future research, it is recommended to subject the identified factors to confirmatory factor analysis (CFA) in order to enhance the validity and reliability of the developed instrument. The factors identified in this study can serve as a valuable framework for constructing a model of mathematics identity among secondary school students. By providing mathematics teachers with a valid and useful instrument for measuring students' mathematics identity, this study can contribute to the improvement of classroom teaching practices. Additionally, the instrument can be utilized as a valuable tool for evaluating the effectiveness of informal mathematics programs and outreach activities.

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Conflict of Interest

The authors declare no conflict of interest in the subject matter or materials discussed in this manuscript.

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