ISSN: 2619-7162 (print); 2619-7189 (online)
Volume 2, Issue 1
December 2018

Journal of Education and Society

Research Article | A Refereed Journal

Principal Component Analysis: A Revalidation of the Mathematics Persistence Scale

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ABSTRACT

A reliable and valid instrument on mathematical persistence, appropriate for Filipino students, can address gaps in mathematics education especially that there is a relationship between persistence and problem solving. This paper addressed the purpose of providing additional data concerning the reliability and validity of Mathematics Persistence Scale (MPS) in the Philippine setting. An instrument used by Stoll in his study in 2015, which looked into different components relevant to mathematical persistence in education, was revalidated considering Filipino participants. The questionnaires were distributed to randomly selected 194 senior high school students. Factor structure extraction was done making use of the principal components method with varimax rotation. Four factors were extracted specifically labeled as; Effortful Math, Understanding Math Concepts, Innate Math Persistence and Math Confidence. MPS has good internal consistency with Cronbach's alpha in the range of .508 to .860. Based on the findings, the same factor structure was extracted and is consistent with what this instrument is supposed to measure. Therefore, this MPS can also be administered among Filipino students in evaluating their level of persistence and can also be a reliable basis to further establish interventions to improve mathematics learning.

Keywords: *persistence; mathematics persistence scale; reliability; validity; principal component analysis*

Introduction

Mathematics is commonly perceived to be difficult and abstract, in the sense that there could be a lot of solutions, making it vague (Stoll, 2015). This challenge is not only true internationally but also among Filipino students. There are evidences showing that students have mathematical anxieties and hard time coping with their mathematical tasks (Klados, Pandria, Micheloyannis, Margulies, & Bamidis, 2015). Yet its practical use in the day to day must not also be disregarded. The skill we learn from mathematics can be a means to find solutions for future problems (Ogena & Tan, as cited in SEI-DOST & MATHTED, 2011). In addition, a country's economic development relies heavily on its progress in science and engineering, promoting the development of mathematically empowered Filipino students (Pascua; Ogena & Tan, as cited in SEI-DOST & MATHTED, 2011).

Persistence is doing something even if it is hard (Merriam Dictionary, 2018). It is more about the acceptance to fail, learning from the experience and trying again (LieffBenderly, as cited in Stoll, 2015). The nature of true problem solving, as outlined by Schoenfeld in 1992, requires persistence in mathematics (Stoll, 2015). There is a significant relationship between persistence and mathematical problem solving (Breen, Cleary, & O'Shea, 2010; Stoll, 2015). Thus students who are persistent are more willing to seek challenges and pursue learning mathematics. There are studies regarding attitude towards mathematics and performance yet only a few have included other factors such as persistence in between (Liu, & Koirala, 2009).

Furthermore, continued strategies in education are seeking towards increased academic persistence to improve performance and college readiness (Nagaoka et al., 2013; Reason, 2009). Different materials are developed to attain this goal. But emphasis on

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Volume 2, Issue 1
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the validity and reliability must be taken into consideration. Existing instruments should still undergo revalidation, replication, and retesting as these factors may be affected contextually, as this is being influenced by culture difference in countries which also exists among islands in the Philippines (Fredricks, & McColskey, 2012; Lai, 2013). Principal component analysis (PCA) identifies the underlying structure which may exist in a particular scale. It further explains a latent variable with items belonging to the same clusters or constructs, which can be a basis for the scale's construct validity. Internal consistency or the inter-rater reliability of the scale can be gauged and compared whether it is consistent among respondents. This is a preliminary initiative for scales like mathematics persistence to be appropriate among its participants.

The New York City Transfer School Common Core Institute (2016) stated from their paper that these tools designed to identify and build student's persistence in doing challenging math tasks help them not only to be confident in their ability to learn but also having the drive to learn more. With this influence to mathematics teaching and learning, the need of testing the validity and reliability of an instrument in mathematics persistence considering high school students in the Philippines was perceived, which led to the conception of this paper. Results in this paper will contribute to strengthening the scale's purpose of measuring the mathematics persistence among Filipino students and thus aiding educators and administrators for an intervention promoting optimum mathematics learning and developing in them the skill of pursuing tasks despite difficulties.

Literature Review

Common core state standards in mathematics recognize the significance of persistence to mathematical problem solving and even considers it a 21st century skill (Common Core Initiative, as cited in Stoll, 2015). It is one of the key factors to attain different professions or careers (Kooken, Welsh, McCoach, Johnston-Wilder, & Lee, 2016). This has even been a highlight in a study whose findings showed that students who were not able to meet their career goals are less persistent which has an impact to social concerns or being involved to harmful behaviors (Barnett, 2011). Measuring non-cognitive factors like persistence can be done through a self-report instrument, getting informant (such as a parent, or teacher), school records, and observation. However, it can also increase the indicators of persistence, which may include extraneous factors (US Department of Education, as cited in Stoll, 2015). This has also been argued by Bandura that a number of factors would affect an individual's physical and emotional state, making it more difficult to come up with an instrument for non-cognitive factors (Usher, & Pajares, 2009). Different scales contain different underlying components which is necessary to further model and explain latent variables or variables which cannot be explicitly identified. Researchers recommend that studies involving a latent variable and focused on identifying its variation base from a set of factors must conduct factor analysis on existing instruments (Fredricks, & McColskey, 2012). Analyses of data using the same instruments, contributing to the strength of measures, can be referred to as construct validity. Also, internal consistency can identify the inter-rater reliabilities of scores from the assessed materials. Some of the standard reliability measures are Cronbach's Alpha and factor analysis (Veenman, 2011). Malaysian researchers also insisted for these procedures, as it is a common mistake that standard instruments validated in the United Stated can already be used by anybody. Underlying factors are affected contextually, thus existing instruments must be validated across different groups of participants. One reason is on differences of culture among populations and countries like the Philippines (Lai 2013). Aside from the fact mathematics education is also affected by these differences (Martin, 2009).

The principal component analysis (PCA), which is one type of factor analysis, is

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commonly used to identify underlying structure, done to establish the validity of the instrument and also for cross-validations (Bro, & Smilde, 2014). In a study of Kooken et al. (2016), they have used this methodology, to identify cluster of items whose patterns of responses will belong to the factors which were included in their study. The same methodology was also part of the study which developed and validated the Bandura's items assessing self-efficacy of middle school mathematics students (Usher, & Pajares, 2009). Another replication study was also done to validate and improve their identified measurement instrument. Their study also found a comparable result with its original measures yet still with recommendations of implementing to larger participants (Fisher, Elrod, & Mehta, 2011). A similar study also conducted the reinvestigation in the construct validity of an instrument—the Phlegm pattern questionnaire—considering a new set of data and confirming the feasibility of its use to a different set of population (Kim, H., Ku, B., Kim, J.Y., Park, Y-J., & Park, Y-B, 2016). Different instruments can then be revalidated, replicated, and improved with the different circumstances that it will be used in studying a body of knowledge. Validation reporting and testing on psychometric research instruments use is already emphasized in researches. Although a study showed that it has also been evident since 2007 among the research studies included in the Journal of American Society for Information Science and Technology (Kim, 2009).

Persistence has been associated in terms of perseverance, tenacity, and grit. In a study, relationships between academic tenacity and performance were determined using a self-report grit scale (Duckworth et al, as cited in Stoll, 2015). Findings showed that students with a higher grit score obtained higher levels of education. It further implies that in terms of education those who are more persistent tend to be on course. This can also be supported by a study with findings showing that students with avoidance on goals are less persistent in doing mathematics tasks which are hard, leading to lower mathematics scores (Mohsenpour, Hejazi, & Kiamanesh, 2006). Consistent to another study which found that students who are average and above average are also the ones who persisted longer, especially when faced with more difficult problem solving items, implying that they are also the ones who get higher mathematics scores (Montague, & Applegate, 2000). But intelligence can still be compensated by hard work and determination (Moutafi et al, as cited in Stoll, 2015). Many studies have involved student's attitude towards mathematics and their achievement but only a few are investigating factors which may lie between them such as self-efficacy and persistence (Liu, & Koirala, 2009).

On the other hand, underlying factors which promote persistence are academic mindsets, effortful control, and learning strategies. Academic mindset is defined as the student's background and self-image as learners. It includes their beliefs and attitudes towards what they are learning. These insights about self can serve as guide for teachers and researchers to determine a student's ability to persist. It also suggested promoting growth mindset in terms of learning, rather than being fixed (US Department of Education, as cited in Stoll, 2015, p.6). Students must be seen as lifelong learners where their success is determined by their work ethic rather than intelligence. The effortful control is referred to as motivation which can be intrinsic or extrinsic in nature. These extrinsic influences may come from social and cultural factors, like families, school, and communities (Ellington, & Frederick, 2010). Thus completing tasks depends on the student's motivation on accomplishing it (Thom & Pirie; Schwartz, as cited in Stoll, 2015). To demonstrate persistence, effortful control is also combined with the willpower, ability to avoid disturbances and manage emotional stress, keeping the task going despite hardships and less entertaining (Leon, Medina-Garrido, & Núñez, 2017). Also, this factor on effortful math is considered to be the first factor in the persistence scale of Stoll (2015). Another study on the development and validation of a motivational persistence scale identified

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ISSN: 2619-7162 (print); 2619-7189 (online)
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underlying factors which are also rooted from a student's goals or purposes. The researchers termed these purposes as long-term, current and recurrence of unattained purposes (Constantin, Holman, & Hojbotă, 2011).

Issues on low persistence and academic completion rates have driven different proponents to reconsider the delivery in math courses (Burdman, Rutschow & Schneider as cited in Ngo, & Kosiewicz, 2017). This is not only evident internationally but there are also evidences showing these academic issues in the Philippines (Andaya, 2014). There are institutions which included additional courses, termed as developmental mathematics education, with the belief that it will improve the persistence of students. Yet there are still limited studies to have an in-depth explanation about this (Wolfle, 2012). Although some academic issues can be explained by student's academic preparation, the idea of having a clear understanding of their non-cognitive skills and strengthening it, cannot be eliminated. Practitioners and policy-makers are also exploring alternative models of delivery that accelerate student progress, contextualize curriculum and instruction, or provide additional support to students (Rutschow & Schneider, as cited in Stoll, 2015). Consistent with this, the Department of Education in the Philippines also had paradigm shift, adding two years in high school, referred as senior high school and implemented the K to 12 curriculum, catering the needs of students and quality education (RA 10533, 2013). But it should also be noted that educators must be aware of the student's mathematics achievement and engagement, which is related to his/her persistence, as these factors decline in secondary education (Leon et al., 2017).

These studies emphasizing the importance of persistence, ways of measuring it and initiatives of including it to support student's performance, establishes strong basis of revalidating a mathematics persistence scale, strengthening its validity and reliability, considering it to be context specific to Filipino participants. These have highlighted the essence the topic investigated. Thus, making the conduct of this study relevant.

Theoretical Framework

Different theories will support the importance of mathematics persistence and establishing a valid and reliable scale. One of these theories is the expectancy theory, which pertains to the beliefs of an individual in accomplishing and doing a task (Zerpa, Hachey, van Barneveld, & Simon, 2011). A student has a personal perspective on how well he/she can do a task, perceive its importance, enjoyment and benefits, and being reflected in his/her output. These tasks can also be drawn from a students' goals where Asian students like Filipinos are known for adopting multiple goals contributing to increase in achievement and motivation (Dela Rosa, & Bernardo, 2013). Another framework also on student's mathematics identity development or an individual's perception on how he/she does mathematics showed the roles of interest and external recognition and not merely contributed by competence and performance (Cribbs, Hazari, Sonnert, & Sadler, 2015). This still goes back to the personal beliefs of the student.

Research Questions

This study aimed to provide additional data on the reliability and validity of the Mathematics persistence scale (MPS) with Filipino participants. It sought to answer the following:

1. What are the different factor structures underlying MPS?
2. What is the difference in the identified factor structure compared to a previous study of Stoll?
3. What is the level of reliability of the MPS?
4. What is the difference in the level of reliability compared to a previous study of Stoll?

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Methodology

Research Design

This study is quantitative in nature making use of a correlational research design, which factor analysis in general underlies. It used quantitative data collection and analysis with the goal of exploring relationships among variables in the study. Items on the scale are considered to be individual variables, drawing relationships among them and clustering them into components.

Data Collection and Instruments

Public senior high schools from Valenzuela City and Bataan were considered in this study, taking into account that these schools are some of the high schools which offers the different academic strands implemented in the Philippines. From the targeted schools, a random selection was made to which sections from Grades 11 and 12 were given the scale. Approval from respective principals and school heads was sought for the conduct of the study. Two sections were selected among the schools for each grade level. There was a total of 194 students who participated in the survey, 75 of which were grade 11 and 119 were grade 12. The final sample size with a ratio of over 13 cases per variable satisfied the condition that the number of observations must be at least five times the variables or items to be analyzed (Hair, Black, Babin, & Anderson, 2009). The administration of the scale took a maximum of 10 minutes for the 15-item questionnaire, using a 5-point Likert scale (with 1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, and 5 – Strongly Agree), which was adopted from the Mathematics persistence questionnaire of Stoll (2015).

Data Analysis

Responses were tallied and consolidated for data analysis. Principal component analysis was performed to extract the underlying structure in the gathered dataset. This method was used to verify the construct validity of the new set of participants with different culture compared with that included by Stoll (2015). Extracted factors were rotated by varimax rotation. The resulting factors were also compared with the previous study and comparisons regarding the similarities and differences were also analyzed. Finally, the reliability of items in each factor was examined by Cronbach's α and the likelihood of items for deletion were also considered.

Ethical Considerations

Ethical considerations for conducting research were highly regarded. Standard protocols and procedures were followed in the data gathering and its implementation. A letter of consent for their participation, was given to the schools and the students. Participation was voluntary and the participants had the option to refrain or exclude themselves from participating in this study. Confidentiality and anonymity were ensured in the responses of the participants and results were collated with no individual response used against the participating student nor the school.

Results and Discussion

Initially, the factorability of the 15 items in the Mathematics persistence scale was examined. First, it was observed that all the items correlated at least .3 with at least one other item, suggesting reasonable factorability. Second, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .795, above the commonly recommended value of .6, and Bartlett's test of sphericity was significant $\left(\chi^2(105) = 918.33, p < .05\right)$. Lastly, the communalities were all above .3 (see Table 1), further confirming that each item shared some common variance with other items. These overall indicators implied that factor analysis was deemed suitable with all items, leading no item deleted with possibilities of being grouped in particular components.

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Table 1
Factor loading results of the Principal Component Analysis

Item No.	Component 1 Effortful Math	2 Understanding Math Concepts	3 Math Persistence	4 Math Confidence	Communalities
15	.822				.751
12	.804				.677
4	.762				.612
2	.735				.552
8	.701			.334	.607
11	.689				.554
13		.878			.777
3		.786			.640
14		.705	.377		.651
5			.724		.599
6			.663		.576
1			.661		.460
7				.719	.585
10		-.318		.680	.618
9				.623	.483

Note: Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Factors were extracted by the principal components method and rotated by varimax rotation. Initial eigen values indicated that the first four factors explained 24%, 14%, 12% and 10% of the variance respectively, explaining more than half of its cumulative variation. Factor structures of the PCA results and the previous model from the study of Stoll (2015) are compared in Table 2. Underlying items in each factor were similar to the study of Stoll (2015) and so their factor labels were retained. The least factor loading was on Mathematics confidence which may be because students seem to have false impression of their own levels of persistence and confidence compared to what they actually have (Breen et al., 2010). All items had factor loadings of greater than .4, which indicates that these are significant loadings. Items 8, 14 and 10 can be considered to have cross loadings since a loading of .3 is a marginal significant loading. But the higher loading is significantly high and these items are also consistent with the study of Stoll, belonging to the same factor, and so the items were retained. Only items 9 and 1 were placed on a different construct but the transfer made the innate Math persistence factor to be valid since originally it only has two items which violated the guidelines of factor analysis in considering factors (Hair et. al., 2009).

Table 2
Comparison of factor structure between this study and a previous study

Factor structure of this study		Factor structure of the previous study	
Factor 1	15, 12, 4, 2, 8, 11	2, 12, 8, 11, 4, 5, 9	Factor 1 (Effortful Math)
Factor 3	5, 6, 1	5, 6	Factor 2 (Innate Math Persistence)
Factor 4	7, 10, 9	7, 10, 1	Factor 3 (Math Confidence)
Factor 2	13, 3, 14	13, 14, 3	Factor 4 (Understanding Math Concepts

Internal Consistency

The overall internal consistency of the Mathematics Persistence scale is .750 which means that the entire questionnaire has a good internal consistency in the items. Factor Cronbach's of each item are presented in Table 3. All the extracted factors have moderately good internal consistency ranging from .508 to .860 and thus reliable. The derived reliability from this dataset is also consistent with the original version with Cronbach's alpha that ranges from .54 to .84. (Schommer-Aikins et al., as cited in Stoll, 2015, p. 10). Although the resulting Cronbach's alpha has a lower range of .508 in the Math Confidence factor, this indicates that this factor must still be tested to a wider range of respondents and review the items in this factor to verify its reliability and validity, considering that this factor has also the lowest loadings in the PCA. It can be noted that the reliability of Factor 3 increases when item #1 is deleted. But both factor reliability and the item when deleted yields a .6 Cronbach's alpha when rounded to 1 significant figure. It is consistent with the item's high factor loading which was .661, and so the item was still retained. Yet further investigations can be done to verify whether the item really belongs to that particular factor or if it can be deleted from the scale.

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Table 3
Internal consistency of factors

Cronbach's α	Item	Cronbach's α if item is deleted
Factor 1 .860	15	.822
	12	.824
	4	.841
	2	.848
	8	.839
	11	.843
Factor 2 .774	13	.600
	3	.754
	14	.722
Factor 3 .568	5	.336
	6	.408
	1	.614
Factor 4 .508	7	.339
	10	.387
	9	.486

Conclusion

Based on the findings, items and constructs of this scale does not deviate with what this instrument is supposed to measure. Consistent results from the previous study were obtained extracting four factors labeled as effortful Math, understanding Math concepts, innate Math persistence and Math confidence. In general, the Mathematics persistence scale has been validated and tested among Filipino participants with good construct validity and internal consistency for evaluating the level of persistence in an individual.

Identifying students' level of persistence can give educator's better ideas in assisting better opportunities for students to portray persistence especially in solving mathematics problems and succeed in their educational undertaking (Stoll, 2015). In spite of the confirmation of the similar factor structure model of the previous study, this is still an exploratory study based on the survey research method and data-driven aspects. Further testing can still be done to a wider scope of schools and larger number of participants as well as considering confirmatory factor analysis.

Acknowledgement

The researchers would like to express their utmost gratitude to their participants, mentors, families, relatives and peers especially to the Almighty God for making this paper possible. Special credit is also due to Dr. Antriman Orleans of De La Salle University – Manila, requiring this study for a coursework and so is the conception to this paper. Extended thanks is also given to everybody, who in one way or another have contributed to the success of this academic endeavor.

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