Interdisciplinary Learning: Development of Mathematical Confidence, Value, and the Interconnectedness of Mathematics Scales

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This paper describes the process of developing a survey instrument aimed at measuring aspects of mathematical confidence, value, and the interconnectedness of mathematics as part of a larger study investigating the thinking processes and attitudes towards mathematics of Singaporean secondary school students (aged 12-14) during interdisciplinary learning. Results from exploratory and confirmatory factor analyses on scale items tested revealed six scales with sound validity and reliability properties. The scales are intended for measuring attitudes towards mathematics particularly during interdisciplinary education.

Background

Interdisciplinary and integrated curricula are present in education systems in the United States (Berlin & Lee, 2005) and Australia (VCAA, 2006; Norton, 2006). Interdisciplinary projects were introduced in Singapore schools in 2000 to provide opportunities for students to engage in holistic learning (Curriculum Planning and Development Division, 2001). This paper describes the process of developing a survey instrument aimed at measuring aspects of mathematical confidence, value of mathematics, and the interconnectedness of mathematics for Singaporean secondary students before and after participation in an interdisciplinary project undertaken over approximately 15 weeks.

It is assumed that mathematical confidence, value of mathematics, and the interconnectedness of mathematics are three affective domains directly associated with interdisciplinary learning involving mathematics. Such interdisciplinary tasks require integrating relevant mathematical knowledge with other school subject knowledge for decision making and problem solving within real-world contexts.

A review of literature revealed that different aspects were considered in the definitions of mathematical confidence and the perception of the value of mathematics. Hence, the decision was made to develop the scales for these domains in the study instead of adopting established ones so as to explore aspects of the constructs proposed by others, especially within the Singaporean context. The perception of the interconnectedness of mathematics, nonetheless, is a new contribution to literature by the first author. Though empirical studies on the impact of integrated learning on mathematical confidence and perception of the value of mathematics exist (e.g., Austin, Hirstein, & Walen, 1997), none was found measuring the effect of interdisciplinary learning on perceptions of the interconnectedness of mathematics. Empirical investigations into students' perceptions of the interconnectedness of mathematics pave the way for statistical generalisations on the impact of mathematically-based interdisciplinary work for secondary schools in Singapore that, on the average, conduct one interdisciplinary task per year level annually. Moreover, these scales could be useful for future research involving interdisciplinary learning in different education contexts.

Proceedings of the 30th annual conference of the Mathematics Education Research Group of Australasia
J. Watson & K. Beswick (Eds),

Literature Review on Theoretical Components of Domains

For this study, mathematical confidence consists of three components: students' perceptions of their (a) abilities to carry out mathematical tasks (Barnes, 2003), (b) confidence in learning and succeeding in mathematics with and without making comparisons with their peers (Fennema & Sherman, 1986; Lester, Garofalo, & Kroll, 1989), and (c) determination and effort in mathematics (Schunk, 1984). Items measuring mathematical confidence were adapted from confidence in mathematics scales of Fennema and Sherman (1986), Tapia and Marsh II (2002), and Mittelberg and Lev-Ari (1999), together with Sandman's (1979) self-concept in mathematics scale and Barnes' (2003) items measuring self-efficacy as part of mathematical confidence. Some items were also created by the first author according to the definition presented.

Perception of the value of mathematics is considered from three aspects: (a) current relevance or usefulness of mathematics (Meece, Parsons, Kaczala, Goff, & Futterman, 1982), (b) importance of mathematics for further education and career choice (Barnes, 2003), and (c) value of mathematics in society (Bishop, 2001). Initial items measuring the perception of the value of mathematics were adapted from Barnes' (2003) and Sandman's (1979) value of mathematics scales.

Interconnectedness of mathematics involves students' perceptions about (a) the possible links between mathematics with other subject areas (Jacobs, 1989), (b) usefulness of mathematics in understanding and learning other subjects (Boix Mansilla, Miller, & Gardner, 2000), and (c) complementary relationships between mathematics and other subjects in problem solving (Boix Mansilla et al., 2000). Items measuring this domain were created by the first author from a synthesis of literature about interdisciplinary education. The three components espoused in the definition can be represented on a continuum, ranging from awareness of interconnectedness knowledge through consideration of possible action upon this awareness to concrete use of relevant interconnectedness understanding.

Every item included in the initial item pool was examined carefully to determine if it needed rephrasing to suit Singaporean students between the ages of 12 and 14 who are non-native speakers of English. It was expected that subsequent piloting phases would reduce the number of items to critical representations of the three domains.

Scale Development, Analysis, and Results

Ten experts from mathematics education in Australia and Singapore, and 292 students (aged 12-14) with varying English competencies from seven Singaporean government co-educational secondary schools were involved in the pilot. Participating students had yet to encounter interdisciplinary projects at secondary level. An initial pool of 45 items was piloted in four phases consisting of student interviews, a large scale trial with exploratory factor analysis, confirmatory factor analysis, and test-retest reliability checks. The items were ordered differently without any section headings in the various versions of the scales used during the first two pilot phases to avoid presentation bias. A five-point Likert scale was used to elicit students' responses to the items.

Validity of Scales

The first author employed three approaches to address the content validity of the scales. Firstly, the theoretical components of the three affective constructs established or discussed in existing research were investigated. Some of these theoretical components were validated by extensive empirical research. Secondly, items measuring mathematical confidence and perception of the value of mathematics were chosen from item pools of established scales. The first author used professional experience as a secondary Mathematics and English teacher at a Singapore school to rephrase selected items to suit non-native speakers of English. For the scale measuring perception of the interconnectedness of mathematics, however, literature pertaining to interdisciplinary education was relied upon for creating the initial items. Lastly, two expert panels of mathematics educators from Singapore and Australia vetted the phrasing of each item and checked item appropriateness of the scales. The experts also commented on whether the scale items were grouped appropriately according to the identified theoretical components. Construct validity of the scales was further established through factor analysis techniques.

Phase I: Individual Student Interviews

The first pilot phase was conducted in stages. In the first stage, items from the three scales were reviewed by nine students (aged 12-14) of varying English language abilities from three educational streams in six schools. During face-to-face individual interviews, students selected their responses from the options and explained their choice to the researcher. Particular attention was paid to the selection of the neutral option in order to confirm if the option was chosen because of ambiguity in phasing or an informed reflection on the statement. Occasionally, students were asked to rephrase problematic items in their own words to check if they had interpreted them as intended. Rephrased versions of difficult items were re-tested immediately on subsequent interviewees for clarity.

In the second interview stage, all 45 items (reworded or otherwise) were administered to another group of 36 students (aged 13-14) from an average-ability stream in one school to attempt on two separate occasions one week apart. Their responses to each item both times were compared qualitatively to identify items of high response inconsistency. The first author then selected 13 students who had inconsistent responses to the majority of the tested items for individual face-to-face interviews to explain their response differences. Special attention was paid to the phrasing of items with general high response inconsistency in order to identify any confusing statements for deletion.

The scales were reduced to 41 items here. One example of deletion was an item from the mathematical confidence scale, "I can usually come up with good approaches for solving problems". This item was highly ambiguous for the students because the phrase "good approaches" was misleading. Even mathematically confident students may "disagree" with the statement if they were not sure if they came up with "good" approaches most of the time during problem solving.

Tables 1 and 2 present the list of items measuring the three affective domains retained for large scale trial after reduction based on student interview feedback and item sources. Negatively phrased items are marked with "#" and scored in reverse during analysis. Items that were subsequently deleted after the large scale trial and confirmatory factor analysis are in italics. The items are arranged according to the theoretical components identified in the definitions of the three domains. For the component, "Perceiving Links between Mathematics and Other Subjects" under the interconnectedness of mathematics domain, a high score on "Math may share some common topics and skills with other subjects" indicated high personal sensitivity to the interconnectedness of mathematics.

Table 1
Mathematical Confidence: Items for Large Scale Trial and Sources

Item Code	Item	Item Source
Mathematical Confidence 1: Confidence in Learning and Succeeding in Mathematics		
CS1	I feel good when I am doing math.	FS[a]
CS2#	Math is my weakest subject.	FS[a]
CS5#	I am not good in math.	FS[t]
CS10	I am sure I can learn math.	FS[t]
CS11#	I will always find math difficult no matter how I hard I study.	FS[a]
CS12	I want to learn higher-level math.	FS[a]
CS13	I usually understand what is going on in my math class.	SM[a]
CS16#	I'm not the type to do well in math.	FS[t]
CA1#	Studying math makes me feel nervous.	TM[a]
CA2#	I am scared of math.	TM[a]
Mathematical Confidence 2: Confidence in Ability to Carry Out Mathematical Tasks		
CS3#	I am afraid to use math because I am not good at it.	R
CS4	I have a lot of self-confidence when it comes to doing math.	FS[a]
CS6	I am good at working with math problems.	SM[a]
CS9	I am ready to try more difficult math problems.	FS[a]
CS14	I'm confident I can understand even the most difficult material in my math class if it is explained clearly.	BN[a]
Mathematical Confidence 3: Determination and Effort in Mathematics		
CS8	I like to think how to solve the difficult math problem first before asking for help.	ML[a]
CS17#	*If I don't get an idea how to solve a math problem right away, I will never solve it.*	SM[t]
CS18#	*I often think, "I can't do it," when a math problem seems hard.*	SM[t]
CS19	When I meet a difficult math problem, I do not give up until I solve it.	ML[t]
Mathematical Confidence 4: Confidence in Mathematical Performance in Relation to Peers		
CR1	*Overall, I feel I am better than some of my friends in math.*	R

Note. FS = Fennema & Sherman (1986), SM = Sandman (1979), BN = Barnes (2003), ML = Mittelberg & Lev-Ari (1999), TM = Tapia & Marsh II (2002), a = adapted, t = taken, R = researcher-created, # = negatively phrased item.

Phase II: Large Scale Trial and Exploratory Factor Analysis

The second phase consisted of a large-scale trial (n = 204) using 41 scale items with students (aged 12-14) from two schools. Statistical analysis was conducted using SPSS (Noonan, 2001). The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.833, implying that exploratory factor analysis was necessary to ascertain the minimum number of hypothetical factors. Initial solution to exploratory factor analysis using principal component extraction with eigen values more than one and varimax rotation revealed 12 orthogonal components accounting for 66.6% of variance. However, inspection of the scree plot (Figure 1) derived indicated the possibility of fewer components as the graph levelled off to form a straight line with an almost horizontal slope beginning at the fifth component.

Table 2
Value and Interconnectedness of Mathematics: Items for Large Scale Trial and Sources

Item Code	Item	Item Source
Value of Mathematics 1: Current Relevance/Usefulness of Mathematics		
VA1#	The math I am studying is useless to me now.	BN[a]
VA2#	The math I am learning won't be useful to me later in my life.	BN[a]
Value of Mathematics 2: Importance of Mathematics for Further Education and Career		
VE1#	The math I am learning won't be important in my future studies.	BN[a]
VE2	I expect to be able to use the math I am studying in my future job.	BN[a]
VE3	Being good in math will help me get a job more easily.	BN[a]
VC1	*I will choose to do math after secondary school because I will need it to get a job next time.*	BN[a]
VC2	*Getting high marks for math will get me more respect from family and friends.*	BN[a]
Value of Mathematics 3: Value of Mathematics to Society		
VS1#	*Math cannot help me understand my surrounding world.*	SM[a]
VS2	Math is of great importance to a country's development.	SM[a]
Interconnectedness of Mathematics 1: Perceiving Links Between Mathematics and Other Subjects		
IR1	Math may share some common topics and skills with other subjects.	R
IR2	I can see links between some math topics and other subjects.	R
IR3	I find learning more meaningful when math and other subjects have common topics.	R
IR4#	I don't try to make connections between math and other subjects when I learn.	R
IR5#	Math has no connections with the other subjects I am studying.	R
IR6	It is important to relate math to other subjects when learning.	R
Interconnectedness of Mathematics 2: Perceiving the Usefulness of Mathematics in the Learning of Other Subjects		
IU1	I can use math to help me learn another subject better.	R
IU2#	*We can't use another subject to help understand some math topics better.*	R
IU3	Sometimes I use math to help me understand another subject.	R
IU4	I use another subject to help me learn math sometimes.	R
IU6	I have used math while working in another subject before.	R
Interconnectedness of Mathematics 3: Perceiving the Complementary Relationship of Mathematics and Other Subjects in Problem Solving		
IC2	Sometimes, I combine what I know from math and other subjects to solve problems.	R

Note. SM = Sandman (1979), BN = Barnes (2003), a = adapted, t = taken, R = researcher-created, # = negatively phrased item.

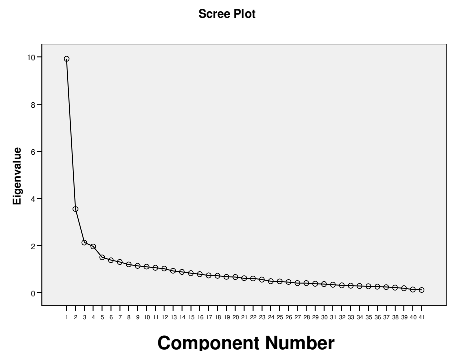

Figure 1. Scree plot showing initial 12-factor solution.

Having 12 factors for 41 items meant that small scales were formed with possibly low validity and reliability. Although there were ten theoretical components to start with, some were made up of single items which could either be deleted or grouped in stronger components. Factor models consisting of fewer components were then investigated to see if these could fit the data set. More solutions were thus generated using principal component analysis, in particular two to ten factor models, judging from the marked changes in the slope of the scree plot. Item factor loadings of less than 0.3 were suppressed. The results of selected models generated by exploratory factor analysis were analysed with the theoretical components defined for the three affective domains in mind. For each model, items purported to belong statistically to the same component were checked if they also fitted in meaningfully as part of a coherent construct. Allocation of items with similar factor loadings to two or more components was based on theoretical decisions.

Initial scale reliability checks and decisions about item deletions were based on an eight factor model. This was because the components of this model were closest in alignment with the theoretical components first envisioned. In this model, items from the mathematical confidence domain were grouped into four scales whereas those from value and the interconnectedness of mathematics domains were categorised into two scales each. The model explained 56% of total variance in the sample data, with the first two components accounting for the highest percentage of variance. Five relatively small scales were derived from the model. Four of the scales had Cronbach's alpha values of less than 0.6.

The process of scale reduction was cyclical, consisting of reiterated tests. Firstly, items with low communalities and low factor loadings within the component were marked for possible deletions. Secondly, student interview records of the marked items were examined for whether the item had appeared ambiguous to some students at times. Thirdly, the frequencies of neutral responses to the marked items were examined because items with high frequencies of such responses would not be helpful in future analyses. Fourthly, the internal consistency reliabilities of the scales generated in the eight factor model were assessed. Some items increased alpha values of the scales when deleted. Fifthly, items with low corrected item-total correlation values were considered for deletion. For scales with more than one item considered for deletion, repeated scale reliability checks with various combinations of items or single items deleted were carried out to choose the best option. Lastly, exploratory factor analysis was conducted again on the remaining items to check if they remained intact within the eight components generated earlier.

Five out of 41 items were deleted in the process of scale reduction. A deletion from the value of mathematics domain was, "Math cannot help me understand my surrounding world". Compared to others, this item had the lowest communality value of 0.317. It did not have any factor loadings greater than 0.3 to any of the eight components. Some student interviewees were puzzled about what the item meant. A high 42.6% of respondents chose the neutral response to this item. Its corrected item-total correlation in the scale was 0.269. Deleting this item raised the alpha value of the scale to 0.735. In addition, some items had similar factor loadings to more than one scale. For example, the item, "I feel good when I am doing math", had factor loadings of 0.469 and 0.508 to two scales. A model involving fewer components could be more best-fitting to the data. Confirmatory factor analysis was conducted next on a different sample to test this hypothesis.

Phase III: Confirmatory Factor Analysis

Data collection with the remaining 36 items was conducted from another three schools. The items were grouped under three headings during data collection, namely, (a) your feelings when doing mathematics, (b) mathematics in relation to other subjects, and (c) your feelings about school mathematics. It was not necessary to divide further the three sections consisting of items from the three domains into eight components.

Confirmatory factor analysis was conducted on a total of 398 questionnaire responses using AMOS (Noonan, 2001). The best-fitting model resulting from confirmatory factor analysis using data here could further establish scale validity because by then, the scales would be exposed to at least two implementations involving separate student samples. Results revealed that a six factor model consisting of 34 items and six correlated scales was best-fitting to the data. Two items (i.e., CS17# and CS18#) were deleted in this process. The six factor model (Tables 3 and 4) classified items from the three affective domains into two scales for each domain. There were still items having dual factor loadings to components under their theoretical scales. In such cases, item allocation was based on the standardised regression weights of these items to their scales.

This model explained about 50% of variance in the sample and had internal consistency reliability values of more than 0.7 in at least four of the scales. The AMOS run yielded a goodness of fit index (GFI) of 0.876. The adjusted goodness of fit value was close to this (0.855). Tabachnick and Fidell (2001) postulate that the GFI should be close to 100% for the model to be a good fit. In this case, the six factor model was a comparatively better fit compared to other models according to GFI values. The choice of the six factor model was further substantiated by its root mean square error of approximation value of 0.048, which indicated a good fit using standards proposed by Hu and Bentler (1999). Moreover, the root-mean square residual value was 0.044, an ideal fit according to Tabachnick and Fidell. Taken together, these statistics indicated the six factor model was a good fit to the data.

Phase IV: Test-Retest Reliability

The last piloting phase checked the test-retest reliability of scales from the six-factor model consisting of 34 items. The scale items were administered on two occasions one month apart to 34 students (aged 12-13) from a non-related sample who had not undergone interdisciplinary projects at secondary level. Correlations between the mean scores to the six scales from both administrations were calculated. Except for the smaller scales of usefulness of mathematics and prospects with mathematics, the test-retest reliabilities of the remaining scales were relatively high, ranging from 0.596 (Beliefs and Efforts at Making Connections) to 0.854 (Self-Concept in Mathematics) (Tables 3 and 4).

Table 3
From Six Factor Model: Mathematical Confidence

Item	Subscale/ Item Statement	Corrected Item-Total Correlation	F1	F2
Scale 1: Self-Concept in Mathematics (SCM)				
Cronbach's $\alpha = 0.880$; Test-retest correlation $r = 0.854$**				
CS5#	I am not good in math.	0.820	*0.728*	
CS2#	Math is my weakest subject.	0.695	*0.798*	
CS3#	I am afraid to use math because I am not good at it.	0.645	*0.792*	
CA2#	I am scared of math.	0.668	*0.752*	
CS11#	I will always find math difficult no matter how I hard I study.	0.625	*0.767*	
CA1#	Studying math makes me feel nervous.	0.565	*0.728*	
CS16#	I'm not the type to do well in math.	0.639	*0.740*	
Scale 2: Confidence in Ability and Motivation in Mathematics (CMM)				
Cronbach's $\alpha = 0.850$; Test-retest correlation $r = 0.772$**				
CS6	I am good at working with math problems.	0.544	0.542	*0.531*
CS12	I want to learn higher-level math.	0.567	0.397	*0.603*
CS9	I am ready to try more difficult math problems.	0.709	0.343	*0.701*
CS1	I feel good when I am doing math.	0.658	0.449	*0.514*
CS4	I have a lot of self-confidence when it comes to doing math.	0.628	0.420	*0.648*
CS10	I am sure I can learn math.	0.599		*0.638*
CS13	I usually understand what is going on in my math class.	0.517	0.366	*0.553*
CS14	I'm confident I can understand even the most difficult material in my math class if it is explained clearly.	0.391		*0.611*
CS8	I like to think how to solve the difficult math problem first before asking for help.	0.476		*0.562*
CS19	When I meet a difficult math problem, I do not give up until I solve it.	0.458		*0.590*

Note. # represents item in reverse coding. Factor loadings for stated scale in italics. *$p < 0.05$. **$p < 0.01$.

Discussion and Conclusion

Scale development requires a delicate balance between theory and statistical evaluation. Although the theoretical components conceptualised were assessed during factor analyses, the selection of factor models generated for further testing also depended on theoretical considerations. A limitation in this study is that the scales were only tested at high school level. To further validate the scales, the scale instrument could be administered to students from other levels of schooling in various educational settings where interdisciplinary learning takes place. The two small scales consisting of three to four items generated by both factor analyses had comparatively lower internal consistency values. An extension to this study would be to reassess the item composition of these scales, possibly adding parallel items for testing.

Table 4

From Six Factor Model: Value and Interconnectedness of Mathematics

Item	Subscale/ Item Statement	Corrected Item-Total Correlation	F3	F4	F5	F6
Scale 3: Usefulness of Mathematics (UOM)						
Cronbach's α = 0.735; Test-retest correlation r = 0.540**						
VA2#	The math I am learning won't be useful to me later in my life.	0.629	*0.844*			
VE1#	The math I am learning won't be important in my future studies.	0.575	*0.836*			
VA1#	The math I am studying is useless to me now.	0.484	*0.787*			
Scale 4: Prospects with Mathematics (PWM)						
Cronbach's α = 0.584; Test-retest correlation r = 0.445**						
VE3	Being good in math will help me get a job more easily.	0.436		*0.805*		
VS2	Math is of great importance to a country's development.	0.364		*0.752*		
VE2	I expect to be able to use the math I am studying in my future job.	0.381	0.379	*0.487*		
Scale 5: Inter-subject Learning (ISL)						
Cronbach's α = 0.735; Test-retest correlation r = 0.608**						
IU3	Sometimes I use math to help me understand another subject.	0.551			*0.687*	
IU1	I can use math to help me learn another subject better	0.560			*0.750*	
IU4	I use another subject to help me learn math sometimes.	0.503			*0.667*	
IC2	Sometimes, I combine what I know from math and other subjects to solve problems.	0.396			*0.615*	0.326
IR4#	I don't try to make connections between math and other subjects when I learn.	0.367			*0.554*	
IR3	I find learning more meaningful when math and other subjects have common topics.	0.351			*0.478*	
IR6	It is important to relate math to other subjects when learning.	0.408			*0.547*	
Scale 6: Beliefs and Efforts in making Connections (BEC)						
Cronbach's α = 0.622; Test-retest correlation r = 0.596**						
IU6	I have used math while working in another subject before.	0.442				*0.638*
IR2	I can see links between some math topics and other subjects.	0.382				*0.725*
IR1	Math may share some common topics and skills with other subjects.	0.424			0.472	*0.536*
IR5#	Math has no connections with the other subjects I am studying.	0.374			0.388	*0.528*

Note. # represents item in reverse coding, factor loadings for stated scale in italics. *$p < 0.05$. **$p < 0.01$.

In summary, items from the three affective domains, mathematical confidence, value of mathematics, and the interconnectedness of mathematics were classified into six scales, with two scales representing each domain during scale development. All items and their scales have been tested rigorously and the scales were found to have sound validity and reliability properties. Nevertheless, this study recognises that the scales especially purporting to measure perceptions of the interconnectedness of mathematics are new contributions to research on interdisciplinary learning, and that there were limitations to interpretations using the scales. However, information generated through the scales is useful in facilitating interdisciplinary learning. Hence, the scales are recommended for use in future research involving interdisciplinary education.

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