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Reciprocal determinism between students' mathematics self-concept and achievement in an African context

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The study tests the theoretical and methodological models of the direct feedback loop in which mathematics self-concept and achievement are specified as both causes and effects of each other using the TIMSS–2011 cross-sectional data set. The participants were students in grades 8–9 from five African countries participating in TIMSS–2011 (N=38,806, M_{Age} =15.42, SD =1.37). Using nonrecursive structural equation models, the author examined the reciprocal-effects model indicating that achievement has an effect on self-concept (skill-development model) and that mathematics self-concept has an effect on achievement (self-enhancement model). There was support for the skill-development, self-enhancement as well as direct feedback loop models. Discussion centres on the theoretical, methodological, and practical implications of the results.

Keywords: Mathematics self-concept, achievement, reciprocal determinism, TIMSS.

INTRODUCTION

Cross-national comparative studies such as the TIMSS and PISA have recently gained considerable attention. Research on TIMSS and other large-scale surveys has consistently shown strong relationship between achievement and self-beliefs across nations (Chiu & Klassen, 2010; Huang, 2012; Marsh et al., 2013; Parker, Marsh, Ciarrochi, Marshall, & Abduljabbar, 2014). Studies reporting different levels of self-belief (e.g., self-concept) across nations normally report with strong theoretical backing, a common trend of lower self-concept among Asian countries when compared to other nations (e.g., Wilkins, 2004).

Culturally, the causal relation between affect (e.g., self-concept) and achievement has been demonstrated to be valid cross-culturally, but more typically in the Western hemisphere (e.g., Seaton, Parker, Marsh, Craven, & Yeung, 2014). Moreover, other studies have shown that self-belief (e.g., self-concept) may operate differently across cultures (Chiu & Klassen, 2010; Markus & Kitayama, 1991) due to the fact that the self is highly influenced by *the frame of reference effect*—social comparison, causal attribution, and reflected appraisals from significant others (Bong & Skaalvik, 2003).

In the present study, the nature of the relationship between students' mathematics self-concept and achievement was investigated using a non-recursive structural equation models in the five African countries that participated in TIMSS–2011. The bidirectional cause–effect between affect and achievement is of practical importance because many affective enhancement programs as well as educational policy statements throughout the world are based on the fact that an improvement in affects (e.g., self-concept) will lead to better academic achievement. The full intent is to test the reciprocal relationship between affect and achievement. The study is also based on the fact that indigenous research and theorising which integrate cross-cultural perspectives are crucial to the establishment of more useful and universal theories (e.g., van de Vijver & Leung, 2000). As Chiu and Klassen (2010) put it: "Cultural differences in self-beliefs can challenge the foundations of current theories and provide new ways of looking at the self" (p. 2). Furthermore, there is a paucity of cross-cultural studies on domain-specific self-concept and achievement in the African context. The data for the present study is from TIMSS–2011, which provides a comparable open data source for these analyses.

The causal determinism of affects and achievement

Self-belief (e.g., self-concept) theories have developed into several branches (for a review, see Wang & Lin, 2008). One such branch concerns the differing relationships between self-belief and achievement (Calsyn & Kenny, 1977; M-S. Chiu, 2012). Within this context are competing hypothesis such as the *self-enhancement model*, which posits that self-belief is a determinant of academic achievement (Chiu & Klassen, 2010; Marsh & O'Mara, 2008), and the *skill-development model*, which sees self-belief as simply a reflection of performance (Chen, Yeh, Hwang, & Lin, 2013; Chiu & Klassen, 2010; Ma & Xu, 2004; Wang & Lin, 2008). Moreover, a more realistic and logical compromise between the self-enhancement and skill-development models is the reciprocal-effects model (Guay, Marsh, & Boivin, 2003; Hannula, Bofah, Tuohilampi, & Metsämuuronen, 2014; Parker et al., 2014; Seaton et al., 2014), which posits that prior self-belief influences subsequent achievement and prior achievement influences subsequent self-belief (for an in-depth review, see Guay et al., 2003).

Cross-culturally, reciprocal effect models have been found to exist. For instance, evidence has been found in Germany (Marsh & Köller, 2004), Finland (Hannula et al., 2014), Canada (Guay et al., 2003), Australia (G. Marks, McMillan, & Hillman, 2001), United States (Marsh & O'Mara, 2008), and many OECD countries (Williams & Williams, 2010) but not in the African context. However, on the relationship between affect and achievement, some studies have indicated affect as the strongest predictor of achievement (Marsh & O'Mara, 2008; Morony, Kleitman, Lee, & Stankov, 2013), whereas others have indicated achievement to be the strongest predictor of affect (e.g., Hannula et al., 2014; Ma & Xu, 2004). Other studies have found no causal relationships (e.g., Williams & Williams, 2010). Taken together, no firm conclusions can be drawn about the causal ordering of affect and academic achievement cross-culturally.

Assumptions in cross-sectional models in causal determinism

Modeling reciprocal effects with cross-sectional data sets is uncommon in mathematics-related affect studies; rather the normal approach uses a longitudinal data set. The arguments lie in the methodological challenges, assumptions and theoretical considerations associated with cross-sectional data to examine the causal ordering (Kline, 2011; Ma & Jiangming, 2004; Wong & Law, 1999). Structural equation models that are used to estimate the reciprocal relationships involving cross-sectional data are known as non-recursive models. Kaplan, Harik, and Hotchkiss (2001) indicated that data from cross-sectional designs only give a "snapshot" of an ongoing dynamic process; as such estimations of reciprocal causal effects with cross-sectional data sets require the assumption of *equilibrium*. Kline (2011 p. 108) summarized that: "any changes in the system underlying a presumed feedback relation have already manifested their effects and that the system is in a steady state. That is, the values of the estimates of the direct effects that make up the feedback loop do not depend on the particular time point of data collection". For an in-depth discussion, see Heise (1975) and Kaplan and colleagues (2001). With respect to the present study, the argument is that during the eight or nine years that these students have been in school and engaged in mathematics learning, their mathematics mastery levels and self-concept have reached a point of equilibrium where each student has formed a realistic view of their perception with regards to performing a given task (See Williams & Williams, 2010, for similar arguments).

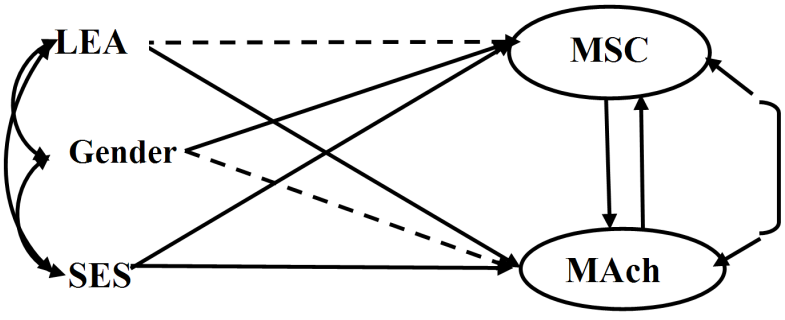

Figure 1: Reciprocal causal effects between maths self-concept (MSC) and achievement (MAch) with a direct feedback loop based on a cross-sectional design. The assumptions are shown with dotted lines. These indicate effects that were fixed to zero a priori. SES = socioeconomic status, LEA = Students' long-term educational aspirations. To avoid cluttering, only paths are shown

METHODS

The hypothesized model for the study is depicted in Figure 1. Each model was analyzed separately for each country. The result of a confirmatory factor analysis (CFA) verified a clear factor structure after incorporating the *method effect* associated with combining both negative and positive items in a survey (for similar argument see M-S. Chiu, 2012; Marsh et al., 2013). Moreover, in a multigroup CFA, measurement invariance (e.g., factorial invariance) of the MSC construct across the five educational/cultural groups was supported. Due to restrictions of space, these results are not presented here.

The students' long-term educational aspirations (LEA), gender, and socioeconomic status (SES)—measures of their home educational resources—are the exogenous variables—variables that no explanation is offered by the model; that is, no directional path point to them. In order for a non-recursive model to be identified, some parameters need to be specified a priori as such gender and LEA were assumed to have no direct influence on MAch and MSC respectively. The theoretical basis for fixing the effect of gender on achievement to zero is based on Deaux and Major's (1987) interactive approach model of gender differences which recognizes the importance of cognitive and cultural influences on gender roles, suggesting that more immediate factors, such as social and cultural patterns of discrimination, shape gender-related belief (see also gender stereotype threat: Spencer, Steele, & Quinn, 1999).

Arguing similarly as in Williams and Williams (2010), for all things being equal, the notion of males reporting higher mathematics achievement reflects a similar notion in mathematics self-concept (e.g., Nagy, Trautwein, Baumert, Köller, & Garrett, 2006). The assumption about SES is based on numerous studies that have established a firm relation between SES and achievement, and self-belief (Chiu & Klassen, 2010; Howie, 2013; Williams & Williams, 2010). The level of educational resources at home has been found to relate to students' achievement even after controlling for parental education and other factors (e.g., Teachman, 1987). However, in developing countries where large numbers of students have no access to basic educational resources, home educational resources are likely to be a more important component of socioeconomic disparity in education (Marks, Cresswell, & Ainley, 2006).

Concerning LEA, documented evidence (e.g., Gil-Flores, Padilla-Carmona, & Suárez-Ortega, 2011) suggests higher educational aspirations to be associated with higher achievement, and vice versa. With no documented evidence on the relationship between LEA and MSC, our argument is that students' mathematics self-concept mediates the relationship between LEA and MAch. Moreover, the error terms associated with the unexplained variance in mathematics self-concept and achievement were allowed to covary since they influence each other (Wong & Law, 1999; Kline, 2011).

Model evaluation and estimation criteria

The models tested in the present study were assessed by Mplus 7.2. The estimator used was the Mplus Robust Maximum Likelihood Estimates (MLR) with standard errors and tests-of-fit that are robust to non-normality and non-independence of observations (Muthén & Muthén, 1998–2012). The Mplus feature of full information maximum likelihood (FIML) was used to impute missing data. To ascertain the model fit, emphasis was placed on the comparative fit index (CFI), the root-mean-square error of approximation (RMSEA) as well as the chi-square test statistic (for informative purposes only because of it sensitivity to large sample size). The CFI is normed along a 0-to-1 continuum with values greater than .95 reflecting excellent fits to the data, and for the RMSEA, values less than .05 are indicative of a "close fit"(West, Taylor, & Wu, 2012). Due to the complex design of the TIMSS survey, the Mplus complex survey design option to account for the clustered design and to adjust standard errors was used. Students' class was used as the clustering variable, and students' sampling weights were also taken into account (*weighting variable supplied with the data*). The fit indices shown in Table 1 indicate the model fits well in all countries.

Data Source

Data were obtained from 38,806 (M_{Age} = 15.42, SD = 1.37) students who participated in TIMSS–2011 in five African countries (see Table 1). For detailed TIMSS sampling and method procedures, see Martin and Mullis (2012).

The maths self-concept scale

Maths self-concept (MSC) was measured through five items on a scale with a 4-point Likert response for-

mat: Agree a lot (1), Agree a little (2), Disagree a little (3), Disagree a lot (4). Item scales were reverse-coded to indicate higher values represent a more positive self-concept and vice versa. The items on the MSC are the following: 1) I usually do well in mathematics, 2) I learn things quickly in mathematics, 3) I am good at working out difficult mathematics problems, 4) Mathematics is more difficult for me than for many of my classmates [reverse coded], and 5) Mathematics is not one of my strengths [reverse coded]. The reliability (composite reliability) (Raykov, 2012) of the MSC ranged from acceptable in Botswana (.645) and Tunisia (.624), to low in South Africa (.557), Morocco (.526), and Ghana (.513). The maths self-concept scale was treated as a latent variable to account for measurement error. The reliability of the MSC was incorporated into the measurement model by fixing the variance of the error term to [(1- reliability)*variance]. This approach is discussed in (Heise, 1975), and a similar procedure was used in (Williams & Williams, 2010).

Mathematics achievement

TIMSS–2011 reported students' MAch in terms of five plausible values—random numbers drawn from the distribution of scores that could be reasonably assigned to each individual (Martin & Mullis, 2012).The use of plausible values has been discussed at length in the TIMSS–2011 methods and procedures (Martin, & Mullis, 2012). The composite reliability of the MAch score ranged from .969 in Botswana, .966 in South Africa and Tunisia, and .957 in Morocco, to .946 in Ghana. Mathematics achievement was treated as a latent variable and was given the same format and procedure (i.e. on the variance and reliability) as that described earlier for MSC.

Instrumental variables

Socioeconomic Status (SES). The SES scale was derived from students' reported home educational resources based on their responses concerning three home resources: Number of books in the home, Highest level of education of either parent, Number of home study supports: Own room, Internet connection. (See Foy, Arora, & Stanco, 2013 supplementary 3 for more details on the process of determining SES.)

Long-term educational aspirations (LEA). The LEA scale was a self-report asking participants to indicate the highest level of education they expected to attain on a scale ranging from (1) "Lower secondary education" to (6) "University program - Master/Doctorate." (See Foy et al., 2013 supplementary 2 for specific nationally define classifications).

Gender. The gender measure was based on students' responses to the questionnaire coded as 1 = *girl* and 2 = *boy*.

RESULTS

Overall, the results shown in Tables 1 and 2 are congruent with similar models estimated by other researchers (e.g., Williams & Williams, 2010). This lends credence to the validity of the results and supports the hypotheses. As indicated in Table 2, the causal relationship between MAch and MSC is supported in Tunisia. Furthermore, in the remaining four countries one or both of the bidirectional relationships failed. In Ghana and Botswana, only the effect of MSC on MAch was statistically significant, validating the self-enhancement model. In Morocco, the effect of MAch on MSC was statistically significant supporting the skill-development model. In South Africa, neither the self-enhancement nor skill-development model was supported. These findings indicate that the countries vary in their causal relationships between MSC and MAch.

The effect of SES on MAch was statistically significant and positive in all but two nations (Ghana and Botswana). Similarly, the relationship between SES and MSC was less consistent across the countries. A statistically significant relation between SES and MSC was found in all but two of the countries (South

Country	χ^2	*df*	S	CFI	RMSEA	Sch	Stu	Grade
Ghana	537.451	57	1.580	.991	.034	161	7,323	8
Botswana	654.534	57	1.105	.989	.044	150	5,400	9
South Africa	931.099	57	1.764	.990	.036	285	11,969	9
Morocco	642.498	57	1.359	.990	.034	279	8,986	8
Tunisia	430.827	57	1.181	.994	.036	207	5,128	8

Table 1: Measures of model fit and sample size by country. χ^2 = chi-square; *df* = degrees of freedom ratio; s = Mplus scaling correction Factor; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; Sch= Schools; Stu = students (unweighted sample)

	Achievement estimates			Self-concept estimates		
Country	MSC	SES	LEA	MAch	Gender	SES
Ghana	38.519***	-2.158	2.744***	0.003	0.089***	0.071***
Botswana	-13.009***	-0.359	3.474***	0.000	0.096***	0.036*
South Africa	11.045	4.458***	3.847***	0.000	0.069***	0.012
Morocco	0.898	6.842***	1.726***	0.016***	0.098***	-0.057**
Tunisia	41.140***	2.757***	0.685***	0.015***	0.035**	-0.022

Table 2: Path Estimates by country. The absolute size of these metric estimates varies considerably because of the differences in the scales of Maths self-concept (MSC) and Maths Achievement (MAch). The effect of MSC, SES, and LEA on MAch is shown under the heading Achievement estimates. The effects of MAch, gender, and SES are shown under the heading Self-concept estimates. Socioeconomic Status (SES); Long-term educational aspirations (LEA). ***p <.001, **p <.01, *p <.05.

Africa and Tunisia). This indicates that the relationship between SES, MSC and MAch is dependent on the national context (William & William, 2010).

With regard to the effect of gender, all parameter estimates were positive and statistically significant. This indicates that males reported higher levels of MSC in all five countries. The effects of LEA on MAch were statistically significant for all the countries as well. The coefficients indicate that higher LEA predicts higher MAch in all countries.

DISCUSSION

The reciprocal determinism of MSC and MAch was validated in one of the five countries. This supports the cross-cultural dimension of the reciprocal models (Guay et al., 2003; Marsh & O'Mara, 2008; Seaton et al., 2014). Nevertheless, the analysis indicated that reciprocal determinism is dependent on the national context specific, thus supporting Williams and colleagues (2010). In South Africa, neither the reciprocal relation nor the self-enhancement model or the skill-development models were supported. Ghana and Botswana supported the self-enhancement model (Calsyn & Kenny, 1977; Chiu & Klassen, 2010; Marsh & O'Mara, 2008), whereas Morocco supported the skill-development model (Hannula et al., 2014; Ma & Xu, 2004). Moreover, the effect of students' long-term educational aspirations and gender on their MAch and MSC, respectively, also shows evidence of cross-cultural generalization, since they are all positive and statistically significant. The findings are also consistent with higher reported MSC for males (e.g., Nagy et al., 2006) and higher MAch for students' with higher long-term educational aspirations (e.g., Marsh et al., 2013). It also supports our assumptions behind the use of gender and LEA as *instrumental variables*.

The effects of SES on MAch and MSC were less consistent, but were evident in more than half of the countries. The relationships between SES, MSC, and MAch are consistent with other studies (Chiu & Klassen, 2010; Howie, 2013; Marks et al., 2006; Teachman, 1987; Williams & Williams, 2010). In countries where a relation was found between SES and MAch, governments can institute financial support schemes for low-income families in the light of our results. Moreover, upgrading schools and increasing funding for schools in low-income areas could help bridge the gap between low and high achievers (Marks et al., 2006).

The present research is one of the few cross-cultural studies on causal relationships between the MSC and MAch in an African context, and provides important new evidence regarding the generalizability of the uni- and bidirectional relationship between MSC and MAch.

A limitation of the study is the assumption behind using cross-sectional data when modeling a reciprocal analysis. For instance, the required assumption of *equilibrium*. The problem is that there is no statistical measure to evaluate the equilibrium assumption with a cross-sectional data set; *it must be argued substantively* (Kline, 2011, p. 108). Moreover, others have argued that the equilibrium assumption does not justify using cross-sectional models for bidirectional determinism, because cross-sectional models are miss-specified due to the fact that they do not take time lags into account (Gollob & Reichardt, 1987; Wong & Law, 1999). However, others have argued for the importance of cross-sectional data to test reciprocal models because in most situations cross-lagged effects are virtually impossible to obtain (Wong & Law, 1999). As we have seen, "causal attribution is not an automatic process; useful causal conclusions are the product

of careful thought, high-quality data, and sound data analysis" (Rogosa, 1979, p. 301).

The findings of this study clearly challenge some of the foundations of current theories on self-belief, and provide new ways of looking at the self (Chiu & Klassen, 2010). Reciprocal determinism was found in some countries and was non-existence in others. The data shows the degree of cross-cultural variations on the reciprocal determinism between affect and achievement. The author could not provide sound cultural theory to explain these phenomena. Moreover, it is important to bear in mind that the analysis may not represent the dynamics of the feedback loop between math self-concept and achievement because the findings represent a static view of an ongoing dynamic system and may vary based on when the system is observed as it moves toward equilibrium (Kaplan et al., 2001).

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