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The Math and Science Engagement Scales: Scale development, validation, and psychometric properties

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ABSTRACT

There is an urgent need to develop appropriate instruments to measure student engagement in math and science for the fields of research and practice. The present study developed and validated student- and teacher-report survey measures of student engagement in math and science. The measures are built around a multidimensional perspective of engagement by using a bifactor modeling approach. The sample was recruited from an ethnically and socioeconomically diverse middle and high school student population in the United States. The findings confirmed that student engagement is comprised of multiple related yet distinct dimensions, with evidence to support a bifactor structural model. There was also empirical evidence supporting measurement invariance and predictive validity. The results demonstrate the soundness of the psychometric properties of the Math and Science Engagement Scales.

Active engagement in math and science classes is a key contributing factor to adolescents' academic success and selection of college majors and careers in science, technology, engineering, and mathematics (STEM) (Maltese & Tai, 2010; Wang & Degol, 2014b). Research shows a decline in math and science engagement during the secondary school years, especially among low-income and minority youths (Martin, Way, Bobis, & Anderson, 2015). In order to increase student engagement in math and science and identify students who have the highest risk for opting out of the STEM pipeline, we need to conceptualize and measure *"student engagement"* appropriately. Unfortunately, research in this area has been hindered by inconsistencies in both the definition and measurement of the student engagement construct (Greene, 2015; Sinatra, Heddy, & Lombardi, 2015). Despite these variations, there is growing consensus that engagement is a multidimensional construct that includes behavioral, emotional, and cognitive components (Fredricks, Blumenfeld, & Paris, 2004; Wang, Willett, & Eccles, 2011). However, current self-report measures do not capitalize on what a multidimensional conceptualization of engagement can offer. In particular, there are only a handful of self-report student engagement measures that include multidimensional indicators, especially in math and science domains (see Kong, Wong, & Lam, 2003, for one exception). Moreover, the extent of psychometric support for these measures is very limited (Appleton, Christenson, & Furlong, 2008; Fredricks & McColskey, 2012; Greene, 2015).

Developing appropriate instruments to measure math and science engagement is urgently needed for both research and practice. The limited number of validated self-report measures that take a multidimensional perspective has made it difficult to examine predictors and consequences of each type of engagement, and investigate how these dimensions develop and interact over time. This impedes our ability to identify those students most at risk for disengaging from math and science classes and to design more targeted and nuanced interventions for enhancing student engagement in math and science learning. The present study addresses these gaps in the literature by using a bifactor modeling approach to test the psychometric properties of two newly developed student- and teacher-report survey measures focusing on math and science domains. The measures were initially developed through a mixed methods research design using an ethnically and socioeconomically diverse middle and high school student sample (see Fredricks et al., 2016; this issue for more information).

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1. Multifaceted nature of student engagement

This study builds upon self-system motivation theory, which assumes that engagement results from an interaction of the individual with the context and is responsive to variations in contextual characteristics (Connell, 1990). The experiential quality of the learning activity provides adolescents with information about themselves as being competent to succeed, as being related to others in these settings, and as being autonomous learners (Eccles, Wigfield, & Scheifele, 1997). This information cumulates to influence adolescents' engagement across various educational activities, as well as future educational and career aspirations. Over time, these reciprocal, cyclical processes shape the educational achievement and choices linked to these aspirations.

Drawing on the self-system motivation theoretical framework, engagement refers to the observable and unobservable qualities of student interactions with learning activities (Deci & Ryan, 2000). In this study, we included four dimensions of engagement: behavioral, emotional, cognitive, and social engagement. These four components of student engagement are dynamically embedded within the individual and operate at multiple levels—the school level, the subject area/specific classroom setting level, and the moment-to-moment activity level (Wang & Degol, 2014b). Given our interest in understanding the relationship between student engagement and STEM outcomes, we focused on engagement in math and science classroom settings.

The most prevalent conceptualization in the literature suggests that engagement consists of three distinct, yet interrelated components: behavioral, emotional, and cognitive engagement (Fredricks et al., 2004). *Behavioral engagement* is defined in terms of involvement in academic and class-based activities, presence of positive conduct, and absence of disruptive behavior (Fredricks et al., 2004). Previous survey studies have measured behavioral engagement with items about attention, participation, concentration, homework completion, and adherence to classroom rules (Fredricks & McColskey, 2012). *Emotional engagement* is conceptualized as the presence of positive emotional reactions to teachers, peers, and classroom activities, as well as valuing learning and having interest in the learning content (Finn, 1989; Voelkl, 1997). Emotional engagement has been measured with items about students' emotional reactions such as interest, enjoyment, and the perceived value of learning (Fredricks & McColskey, 2012). *Cognitive engagement* is defined in terms of self-regulated learning, using deep learning strategies, and exerting the necessary cognitive strategies for the comprehension of complex ideas (Zimmerman, 1990). Cognitive engagement has been measured with items about the use of shallow and deep learning strategies to learn and understand material, self-regulation, and persistence (Greene, 2015).

In addition to the three components of engagement most often included in prior studies, we added a social engagement dimension to reflect findings from our qualitative interviews with students about the meaning of engagement (see Fredricks et al., 2016; this issue). In these interviews, adolescents viewed engagement in social domains as an integral part of their learning in math and science classrooms. *Social engagement* includes the quality of social interactions with peers and adults, as well as the willingness to invest in the formation and maintenance of relationships while learning.

Previous research has shown that student engagement is a strong predictor of academic performance and choice (Hughes, Luo, Kwok, & Loyd, 2008). Students with higher behavioral and emotional engagement tend to attain higher grades and aspire for higher education (Wang & Holcombe, 2010). The use of self-regulatory and metacognitive strategies is associated with academic achievement (Pintrich & DeGroot, 1990). Students who enjoy, value, and feel competent in their social interactions are more likely to enlist the support of others for academic tasks. Students who want to form positive relationships with their peers are also more likely to have high academic achievement (Kiefer & Ryan, 2011; Wang & Eccles, 2013). Moreover, youths' interests in and beliefs about the importance of math and science are associated with intentions to enroll in elective STEM courses and career aspirations within STEM-related fields (Wang, 2012; Watt et al., 2012).

2. Measurement of student engagement

In a recent review of survey measures of engagement, Fredricks and McColskey (2012) identified only 3 out of 14 self-report survey measures that had scales assessing multiple dimensions of engagement. Items used to measure different dimensions of engagement were used inconsistently across behavioral, emotional, and cognitive dimensions, and the choice of items often did not match the theoretical conceptualizations of these constructs. For example, some measures included effort as an indicator of behavioral engagement to reflect compliance with required work in school, while others included effort as an indicator of cognitive engagement to describe the degree of psychological investment in learning. The wide variation in both the measurement and operationalization of engagement has made it challenging to compare findings across studies and draw conclusions about both the precursors and outcomes of engagement (Fredricks et al., 2004).

The majority of the survey measures (9 out of 14) focused on general engagement in school rather than engagement in specific subject areas. They excluded self-report measures of engagement in math or science that incorporate the multidimensional concept identified in the review. An extensive body of research suggests that motivational constructs can be domain specific, especially constructs that are situation- and subject-relevant (Guthrie & Wigfield, 2000). Some preliminary research also supports the domain specificity of student engagement, though more research is necessary to determine how this construct differs across subject areas (Martin, 2008). For example, Sinatra et al. (2015) contends that epistemic cognition, involvement in math and science practices, topical emotions, and attitudes are domain-specific aspects of science engagement that are important to consider.

Although researchers have conceptualized student engagement as a multidimensional construct, many studies have failed to examine the unique contributions of each dimension of engagement, as well as the general construct of engagement. Therefore, it is unclear if we can separate the unique contributions of the individual dimensions from the effects of the general construct. The uncertainty of distinguishing between the general construct and the individual dimensions makes it difficult to test both simultaneously (Chen, Jing, Hayes, & Lee, 2013). The bifactor model approach has recently been proposed to test the psychometric properties of the psychological constructs that are comprised of multiple related yet distinct dimensions (Chen et al., 2013). A bifactor model will allow us to examine if there is a global engagement factor that accounts for the commonality shared by the four dimensions. Additionally, it allows the investigation of whether there are multiple distinct factors that account for the unique contribution of the specific engagement dimension above and beyond the global engagement factor (Aguado et al., 2015). The bifactor model also enables us to test the association of an outcome variable with the global factor, and the unique contributions of the specific factors that are distinct from the global factor (Chen et al., 2013).

Furthermore, few valid teacher report measures were identified

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