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Academic self-concept in science: Multidimensionality, relations to achievement measures, and gender differences☆

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ABSTRACT

Students' academic self-concept is a good predictor of academic achievement and a desirable educational outcome per se. In this study, we take a closer look at the nature of the academic self-concept in the natural sciences by examining its dimensional structure, its relation to achievement, and gender differences. We analyzed data from self-concept measures, grades and standardized achievement tests of 6036 German 10th graders across three science subjects – biology, chemistry, and physics – using structural equation modeling. Results indicate that (a) a 3-dimensional, subject-specific measurement model of the self-concept in science is preferable to a 1-dimensional model, (b) the relations between the self-concept and achievement are substantial and subject-specific when grades are used as achievement indicators, and (c) female students possess a lower self-concept in chemistry and physics even after controlling for achievement measures. Therefore, we recommend conceptualizing the self-concept in science as a multidimensional, subject-specific construct both in educational research and in science classes.

1. Introduction

Science, technology, engineering, and mathematics (STEM) education is regarded as crucial by policy makers as shown in official statements; for example, "leadership tomorrow depends on how we educate our students today, especially in math, science, technology, and engineering" (The White House, 2010, para. 6). Such spirited statements have been backed up by scientific research that shows that achievement in STEM – measured indirectly by the number of patents and Nobel Prize laureates per capita – is a good predictor of wealth on a national level (Rindermann & Thompson, 2011). Therefore, various programs intend to strengthen education in STEM, some focusing on engaging more women to bridge "a gender gap to innovation" (United States Department of Commerce, 2011, p. 1). As mathematics and science cover the largest part of school education in STEM subjects, predicting academic success in these domains has become a goal for educational research.

The academic self-concept – the self-perception of one's ability in an academic domain – shows substantial positive relations to academic effort (Trautwein, Lüdtke, Schnyder, & Niggli, 2006), the choice of academic courses (Marsh & Yeung, 1997), and academic achievement (Marsh & Martin, 2011). Meta-analyses (Huang, 2011; Valentine, DuBois, & Cooper, 2004) and longitudinal studies (Marsh & O' Mara, 2008) have shown that the relation between academic achievement and the self-concept is positive and reciprocal. The finding that students who feel more competent in a specific school subject will also achieve better results than their equally able peers makes the academic self-concept one of the most influential non-ability predictors of school achievement and, in general, a desirable educational outcome (OECD, 2003). Whereas there are many studies on the academic self-concept in math and languages, few studies have focused on the self-concept in the domain of science even though it may be an important factor in explaining both students' academic success and their aspirations to pursue a career in the sciences. In this study, we scrutinize the nature of the academic self-concept in science by examining its internal structure and its relation to student achievement. Furthermore, we investigate gender differences in the academic self-concept in science and the moderating effects of gender on the relation between the self-concept and student achievement.

1.1. The internal structure of academic self-concept

Different conceptualizations of the internal structure of the academic self-concept have been proposed. One of the first models that introduced the assumption of the academic self-concept as a multidimensional construct, later called the Shavelson model (Shavelson, Hubner, & Stanton, 1976), organizes different self-concepts hierarchically. It includes several higher order factors covering different facets of self-concept such as an emotional, a social, and an academic self-concept. Below the general academic self-concept factors are subject-specific self-concept factors. However, empirical results have shown that the self-concept in mathematics and the self-concept with regard to the language of instruction

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are almost uncorrelated, even though student abilities in the mathematical and verbal domains are strongly correlated (Marsh, 1986; Marsh, Byrne, & Shavelson, 1988)—a pattern that is contrary to the idea of a general academic self-concept factor affecting all domain-specific self-concepts. This pattern can be explained by the Internal/External frame of reference model (further referred to as the I/E model, Marsh, 1986). It postulates that students use two comparison processes that rely on two different frames of reference to evaluate their ability in a given domain. On the one hand, they compare their achievement to the achievement of their peers (usually class mates) within the same domain—a social comparison within an external frame of reference resulting in positive effects of achievement on the self-concept within each domain. On the other hand, they compare their achievement in one domain with their own achievement in other domains—a dimensional comparison within an internal frame of reference resulting in negative effects of achievement in the verbal domain on the self-concept in the mathematical domain and vice versa (Möller & Marsh, 2013). These negative across-domain effects of achievement on self-concept explain the almost nonexistent relation between mathematical and verbal self-concepts. To account for these processes and the implied distinction of the mathematical and the verbal domains, Marsh and colleagues also developed a new model of the internal structure of the academic self-concept, the Marsh/Shavelson model (Marsh, 1990; Marsh & Shavelson, 1985; Marsh et al., 1988). The Marsh/Shavelson model discards the idea of a general factor of academic self-concept in favor of two uncorrelated factors—a general mathematical and general verbal self-concept. Even though extensions have been proposed lately (Arens, Yeung, Craven, & Hasselhorn, 2011; Brunner, Lüdtke, & Trautwein, 2008; Brunner et al., 2010; Chiu, 2012), the I/E model and the Marsh/Shavelson model have been supported by a vast amount of empirical data including cross-cultural studies (Marsh & Hau, 2004), meta-analytic studies (Möller, Pohlmann, Köller, & Marsh, 2009) and longitudinal studies (Marsh & Köller, 2004; Marsh, Kong, & Hau, 2001; Möller, Retelsdorf, Köller, & Marsh, 2011), and have guided much of the research on the academic self-concept.

1.2. The structure of the academic self-concept in science

In the above-mentioned theoretical models, the academic self-concept is considered subject-specific. Which science subjects are taught in a given learning environment varies, however: in contrast to some other countries in which the natural sciences are taught interdisciplinarily, science education in Germany is traditionally taught in three separate subjects in secondary school (physics, chemistry, and biology) even though interdisciplinary science classes are sometimes taught in lower grades or offered in addition to subject-specific teaching. Accordingly, different conceptualizations of the self-concept in science have been proposed: In the original Shavelson model, the self-concept in science was represented by a single first-order factor (Shavelson et al., 1976). This conceptualization also underlies a prominent and widely used measure of academic self-concept—the *Academic Self-Description Questionnaire* (ASDQ; Marsh, 1990). However, in the Marsh/Shavelson model (Marsh, 1990), the physical and biological sciences are theoretically distinguished and strong assumptions concerning their relations to higher order factors are made; in detail, the physical science factor is explained solely by a higher order mathematics-and-science factor, whereas the biological science factor is explained by both a higher order verbal factor and the higher order mathematics-and-science-factor. In their description of the Marsh/Shavelson model, Möller and Köller (2004) differentiated between three science subjects: biology, physics, and chemistry, in accordance with the curriculum in Germany. In their model, the self-concepts in physics and chemistry are explained by a higher order mathematics factor, whereas the self-concept in biology is explained by a higher order verbal factor.

Reviewing the literature on the self-concept, curiously, self-concepts in the natural sciences play a minor role. Whether one or more science self-concept factors are assumed depends largely on the country in which the study was conducted and the curriculum. The allocation of the science self-concepts to the higher order factors of the Marsh/Shavelson model seems to have been founded on the implicit assumption that the self-concepts in different science subjects can be ordered along a continuum ranging from a verbal to a mathematical pole. In this assignment, the self-concept in biology is located near the verbal pole and the self-concept in physics is located near the mathematical pole, whereas chemistry takes an intermediate role. Despite the plausibility of these assumptions at first glance (e.g., more mathematical formalization is used in school physics than in school biology), empirical data that capture the internal structure of self-concepts in science covering all three subjects are missing.

1.3. The self-concept and achievement in science

Most studies on the structure of the academic self-concept are not conducted in the domain of science. Similarly, the relation between academic self-concept and achievement is often reduced to mathematics and languages. In the few studies that consider science achievement, the self-concept in science is either regarded as a one-dimensional construct, or the analyses focus on one domain of science: Only weak relations between the science self-concept and science achievement – as measured by standardized achievement tests – were found in a student sample from Hong Kong (Wang, Oliver, & Starver, 2008), whereas others found substantial positive relations (e.g., Chiu, 2008, 2012). Other studies focused on specific science domains only and consistently found positive effects. For example, the self-concept in chemistry was found to be a valid predictor of course grades in chemistry (Bauer, 2005), performance on an examination of the American Chemical Society (Lewis, Shaw, & Heitz, 2009), and the understanding of chemical concepts (Nieswandt, 2007). Substantial correlations have also been found between the self-concept in biology and a test on genetics (Thomas et al., 1993), between the self-concept in life science and course grades (Britner, 2008) and between the self-concept and course grades in physics (Möller, Streblow, Pohlmann, & Köller, 2006). Overall, these studies suggest a positive relation between the academic self-concept and achievement, especially when the operationalization of achievement and self-concept is domain-specific and when grades are used as achievement indicators. However, a substantial drawback of these studies is that the extent to which the relation between the self-concept and achievement is actually subject-specific remains unclear because different science subjects are not considered simultaneously.

The lack of studies that have considered multiple science subjects also constitutes a desideratum for further research considering the impact of dimensional comparisons on self-concept formation that is formulated in the I/E model (Marsh, 1986; Möller & Marsh, 2013). Whereas numerous studies have shown contrast effect of dimensional comparisons (i.e., negative relations between achievement and self-concept across subjects) when mathematics and the language of instruction are examined (Möller et al., 2009), the evidence is mixed when more similar subjects (e.g., mathematics and science) are considered. In this case, both contrast and assimilation effects have been found. For example, Möller et al. (2006) tested the I/E model across two verbal (German, English) and two mathematical subjects (math, physics). Self-reported grades in both mathematical subjects were negatively related to the self-concepts in both verbal subjects, and grades in both verbal subjects were negatively related to the self-concepts in both mathematical subjects, thus, showing contrast effects between domains. However, within both domains, assimilation effects were found—that is, achievement in one subject (e.g., math) was positively related to the self-concept in the other subject from the same domain (e.g., physics). Chiu (2008, 2012) tested the I/E model within the mathematical domain by examining the self-concept and test scores in math and science. Contrary to Möller's study, no assimilation effects across subjects were found. Achievement in one subject (e.g., math) and the self-concept in another subject (e.g., science) were negatively related