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## ► To cite this version:

Pia Tscholl. Gender differences in optimistic, realistic, and pessimistic mathematical self-concepts among first-year STEM students. Proceedings of the Fourteenth Congress of the European Society for Research in Mathematics Education (CERME14), Free University of Bozen-Bolzano; ERME, Feb 2025, Bozen-Bolzano, Italy. <hal-05228207>

**HAL Id: hal-05228207**

**<https://hal.science/hal-05228207v1>**

Submitted on 28 Aug 2025

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# Gender differences in optimistic, realistic, and pessimistic mathematical self-concepts among first-year STEM students

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*This contribution examines (1) whether a gender gap in mathematical self-concept can be found among first-year STEM students at the University of Innsbruck and (2) if the accuracy of mathematical self-perception relative to performance differs by gender. The study analyses samples of 302 and 260 participants using linear mixed-effects models and chi-squared tests. The results show that female STEM freshmen have a higher mathematical self-concept than their male counterparts. Further, women show a larger proportion of optimistic self-concepts – i.e. higher self-concepts than expected based on their mathematical performance – compared to men. Based on theoretical considerations, it is assumed that this is the result of social and criterial comparisons. Overall, gender-specific filter mechanisms appear to persist when entering STEM degree programs, which different stakeholders should consider in the future.*

*Keywords: Women, self-concept, mathematics, STEM, higher education.*

## Relevance

As one of the 17 UN Sustainable Development Goals, goal 5 calls for gender equality and the empowerment of all women and girls. This includes ensuring equal opportunities across social, economic, and political domains and ending discrimination against women. Increasing female representation in STEM (Science, Technology, Engineering, and Mathematics) fields is vital to these efforts, as women remain underrepresented (Binder et al., 2021; Goldman & Penner, 2016; Sax et al., 2015). Moreover, with many countries facing a shortage of skilled STEM workers, encouraging women to enter these fields is increasingly important (Bünning et al., 2020).

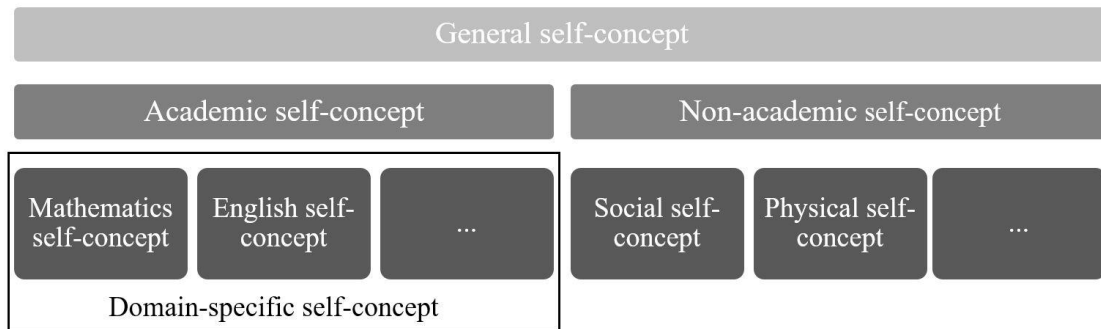
To determine the causes of female underrepresentation in STEM fields, Kanny et al. (2014) conducted a meta-narrative systematic review of 324 academic publications from the 1970s to the early 2000s. The psychological factor of *self-confidence* emerged as the most commonly cited reason for women not pursuing STEM studies. More precisely, choosing a STEM major is frequently associated with having a strong mathematical self-concept (Goldman & Penner, 2016; Musu-Gillette et al., 2015; Sax et al., 2015).

Austria presents an intriguing case for examining the complex relationship between gender, mathematical self-concept, and STEM enrolment, as this paper will demonstrate. Furthermore, this study introduces a novel perspective by assessing the accuracy of mathematical self-perception relative to actual performance by gender. This approach yields new insights into marginalisation processes at the intersection of mathematics, higher education, and gender.

## Theoretical background

### Self-concept

Most of the early research on this phenomenon focused on the broad idea of self-concept and frequently lacked a sound theoretical framework. Consequently, Shavelson et al. (1976) developed a well-defined self-concept model that is organised, multifaceted, hierarchical (see Figure 1), stable, developmental, evaluative, and differentiable. They describe self-concept as “a person's perception of himself” (Shavelson et al., 1976, p. 411), shaped by environmental and social influences.



**Figure 1: Hierarchical structure of the *self-concept* model according to Shavelson et al. (1976), figure based on Filiz et al. (2020, p. 2)**

As Figure 1 shows, the *general self-concept* is divided into an *academic* and *non-academic self-concept*. The academic self-concept is

generally defined as one’s perceived competence in a specific domain (often an academic subject) in a normative way (in comparison to peers or the average person) that includes both cognitive and affective evaluations of the self. (Sax et al., 2015, p. 815)

The perception of one's cognitive and affective competencies in a *specific* academic area, i.e. English, is known as the domain-specific self-concept (Filiz et al., 2020; Sax et al., 2015). The domain-specific self-concept in mathematics is known as the *mathematics* or *mathematical self-concept*.

### Mathematical self-concept development

Marsh's (1986) *internal/external frame of reference model* (I/E model) posits that the domain-specific self-concept is shaped by *internal* and *external* comparisons. Internal (*dimensional*) comparisons contrast one’s mathematical abilities with those in other domains, often verbal skills, while external (*social*) comparisons involve measuring against peers (Dickhäuser et al., 2005; Marsh, 1986). Recent research expands the model by adding *temporal* and *criterial* dimensions (Dickhäuser et al., 2005; Geisler et al., 2023). The temporal dimension reflects comparisons between past and current performance (Wolff et al., 2019), while criterial comparisons involve self-selected or externally set benchmarks (Geisler et al., 2023). So:

- The better my skills in another domain, the worse I will rate my math skills and vice versa (*dimensional*, formerly *internal*).
- The worse the math skills of my peers, the better I will rate my math skills and vice versa (*social*, formerly *external*).

- The better my past performance in math, the more cautious I will be in assessing my current performance and vice versa (*temporal*).
- The better my performance is assessed by external criteria such as school grades, the better I will assess my performance and vice versa (*criterial*).

## **Empirical findings on mathematical self-concept and gender**

The positive relationship between mathematical self-concept and performance has been repeatedly highlighted by extensive research (Heyder et al., 2019). Further, Goldman and Penner (2016) discovered that STEM career aspirations are more strongly correlated with one's mathematical self-concept than with academic success. Other researchers, such as Musu-Gillette et al. (2015) and Sax et al. (2015), concur with this conclusion.

Unfortunately, there is evidence that girls – even at the same performance level – exhibit a lower mathematical self-concept than boys since elementary school (Fiedler, 2024; Heyder et al., 2019; OECD, 2015). This trend extends into the tertiary education sector: it is typical for female STEM students to have a lower academic self-concept than their male peers (Fiedler, 2024). This applies to both STEM and non-STEM fields, where women exhibit a lower mathematical self-concept according to data from about 1.5 million first-year students from American baccalaureate-granting institutions between 1971 and 2011 (Sax et al., 2015).

Paasch and colleagues' (2017) study provides an Austrian example of such gender differences at secondary school level: The analysis of roughly 76,000 fourth-graders reveals that among students with similar mathematical proficiency, 7% of boys and 13% of girls had a pessimistic mathematics self-concept – a lower self-concept than expected based on performance outcomes (Paasch et al., 2017). Data from 83,000 Austrian eighth-graders show that 16% of the girls but 9% of the boys hold a pessimistic mathematical self-concept, while 21% of the girls but 27% of the boys exhibit an optimistic mathematical self-concept – one that exceeds performance-based expectations (Paasch et al., 2017).

## **Data and methods**

### **Research questions and hypotheses**

While numerous international studies have explored the relationship between gender, mathematical self-concept, and its influence on performance and career aspirations, research on this topic within the Austrian tertiary education sector remains scarce. Austria is intriguing in this context, as it exhibits significant gender disparities in mathematics education. According to the 2022 PISA study, which focused on mathematics, Austria – alongside Italy – recorded the largest performance gap between boys and girls. Moreover, girls in Austria receive on average 46 minutes less mathematics instruction per week than their male peers (Toferer et al., 2023). These distinctive circumstances underscore the need for a focused, country-specific examination of mathematical self-concept and STEM career aspirations as a function of gender in Austria. Additionally, it is still unclear whether the gender-specific patterns of *optimistic* and *pessimistic* mathematics self-concepts can be found in the tertiary education sector. Thus, the research questions are: (1) Is there a gender gap in mathematical self-concept among first-year STEM students at an Austrian university? (2) Is the mathematical self-

concept of STEM freshmen realistic, optimistic, or pessimistic, and are there gender differences in this regard?

Given the research findings of the previous section, it is hypothesised that (1) women exhibit a lower mathematics self-concept and (2) women own a pessimistic mathematics self-concept more often and an optimistic self-concept less often compared to men.

### Sample and statistical methods

Given the limited availability of local data in Austria on the relationship between gender, mathematical self-concept, and STEM studies, a quantitative study serves as a valuable first approach to identifying trends in this area. In a subsequent phase, qualitative research methods will be essential to gain deeper insights.

A sample of 100 science- ( $n_f = 39$ ;  $n_m = 61$ ), 102 technology- ( $n_f = 26$ ;  $n_m = 76$ ), and 100 mathematics-freshmen<sup>1</sup> ( $n_f = 65$ ;  $n_m = 35$ ) at the University of Innsbruck is used to answer the research questions. The sampled first-year STEM students completed an extensive mathematical performance test with about 130 closed-end exercises from the areas of *numbers and functions, equations and inequalities, vectors and coordinate systems, geometry and trigonometry, integral and differential calculus, stochastics*, and *general mathematical thinking*, an assessment of mathematical self-concept created and validated by the Austrian Federal Ministry of Education<sup>2</sup>, and a demographic questionnaire to obtain the necessary data. Mathematical performance data and self-concept scores were further categorised as *high* and *low* based on median splitting. According to Paasch and colleagues (2017), people with an *optimistic* mathematics self-concept fall into the low-performance group but are in the *high* self-concept category. Conversely, a *pessimistic* self-concept applies vice versa. People who fall into the *high* or *low* group for both maths performance and self-concept have a *realistically high* or *realistically low* self-concept respectively.

To answer the first research question, a linear mixed-effects regression model was fitted with *gender*<sup>3</sup> as the main independent input variable. The *standardised self-concept score* is used as the dependent output variable, while the obtained maths performance score (0-100), the last school grade in mathematics (1 – very good – to 4 – sufficient), age categories (15 - <20, 20 - <25, 25 - <30, or >= 30), the degree program (S, T, M), and the nationality (Austria, Germany, Italy, other) serve as control variables.

To address the second research question, nearest-neighbour matching was employed to pair the 130 women from the original sample with the available men, ensuring (mathematical performance) comparability. A chi-squared test was applied to determine whether the proportions of optimistic, pessimistic, and realistic mathematics self-concepts differ significantly between males and females.

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<sup>1</sup> These students voluntarily participated in a mathematics bridging course at the named university. The *engineering* branch was excluded due to the small sample size. Nevertheless, the term *STEM* is still used throughout the manuscript.

<sup>2</sup> Excerpts of the questionnaire used can be accessed in German at <https://p-gw.github.io/oegp-2018/>.

<sup>3</sup> The available options for gender identification were *female*, *male*, and *non-binary*. However, the *non-binary* group was excluded from the analysis due to insufficient sample size for a meaningful quantitative study.

## Results

### Findings for the first research question

The fitted linear mixed-effects model yields an R-squared value of 0.56 for the fixed input variables. The fixed factors that were statistically significant in at least one category are reported alongside their  $\beta$ -coefficients, standard errors, and p-values in Table 1.

**Table 1:  $\beta$ -coefficients, standard errors, and p-values of the fixed factors of the fitted linear mixed-effects model**

Variable	Estimated $\beta$ -coefficient	Standard error	p-value
Intercept	-0.976	0.253	< 0.001
<b>Gender = Female</b>	0.196	0.09	0.03
Math. performance test score	0.017	0.004	< 0.001
Last school grade = 2	-0.391	0.102	< 0.001
Last school grade = 3	-1.045	0.131	< 0.001
Last school grade = 4	-1.665	0.193	< 0.001
STEM = M	0.549	0.11	< 0.001
STEM = S	0.375	0.107	< 0.001
Age = 20 - <25	0.189	0.09	0.037
Age = 25 - <30	0.409	0.273	0.136
Age $\geq$ 30	-0.028	0.286	0.921

As Table 1 shows, the primary input variable *gender* is significant ( $p = 0.03$ ): Ceteris paribus, the standardised self-concept score increases by roughly one-fifth of a standard deviation ( $\beta = 0.196$ ) when *gender* is changed to female. Furthermore, the self-concept score is significantly influenced by age category, STEM degree program, last school grade in mathematics, and performance on the mathematical assessment. In contrast, nationality does not have a significant effect on mathematical self-concept and is therefore omitted from Table 1.

### Findings for the second research question

Despite an equivalent mathematical performance, the proportion of optimistic, realistic, and pessimistic mathematical self-concepts (see Table 2) differs substantially by gender according to a chi-squared test ( $p = 0.021$ ). Subsequent chi-squared tests for each category reveal a significantly ( $p$

= 0.014) higher proportion of females who own an optimistic mathematical self-concept. The odds of having an optimistic mathematical self-concept are 2.292 (95% confidence interval: 1.121 – 4.864) times higher for women than for men.

**Table 2: Number of participants by gender (male, female) and degree program who fall within the categories of optimistic, realistically high, realistically low, and pessimistic mathematical self-concept.**

	Science		Technology		Mathematics		Total	
	Female	Male	Female	Male	Female	Male	∑ Female	∑ Male
<b>Optimistic</b>	7	4	3	4	20	7	30	15
<b>Realistically high</b>	18	19	2	6	25	14	45	39
<b>Realistically low</b>	8	14	19	31	15	7	42	52
<b>Pessimistic</b>	6	13	2	4	5	7	13	24
∑	39	50	26	45	65	35	130	130

## Discussion and outlook

The outcomes of the first and second research questions contradict the stated hypotheses: Women exhibit a higher mathematical self-concept when entering a STEM degree program at the University of Innsbruck, but they overestimate their mathematical abilities more often. This leads to a higher proportion of optimistic self-concepts among females.

Theoretical explanations for these unexpected results are rooted in the *social* and *criterial* comparative frameworks. First, the *social* comparison was found to be highly relevant, especially for females in Austria (OECD, 2013). Second, the *criterial* comparison emerged as the most important frame of reference according to Geisler et al. (2023). Based on these two reference dimensions, it is reasonable to assume that women who choose a STEM degree program come from secondary school classes with a low mathematical performance level. As a result, they had the opportunity to develop a strong mathematical self-concept in *social* comparison, despite their relatively moderate mathematical abilities – also called the *big-fish-little-pond effect* (Geisler et al., 2023). Due to their relative superiority compared to the rest of the class, they probably achieved good grades, which in turn enables a good mathematical self-concept based on the *criterial* dimension. This explanation, which accounts for the results of both the first and second research questions, is underpinned by the results of PISA 2022 (Toferer et al., 2023): Girls in Austria systematically receive less mathematics instruction than boys because they are more likely to attend schools that are less mathematics-intensive and, consequently, classes with a relatively lower level of mathematics performance.

This suggests, however, that women from mathematically strong secondary school classes may be less likely to pursue STEM careers, despite having adequate mathematical ability. This argument

aligns with the research findings of Goldman and Penner (2016), which show that self-concept has a bigger influence on career decisions than performance.

In addition to these psychological explanations, constructs from sociology or social psychology, such as power relations or *brilliance beliefs*, play a significant role when analysing these results. Due to page limitations, these are omitted in this contribution but should be considered in broader discussions.

Apart from the explanation, the key finding of this research is that men and women in Austria still undergo different comparison and filtering mechanisms when it comes to STEM career aspirations. Particularly, women need to have a higher-than-average self-concept in mathematics to choose a STEM degree program. This results in several suggestions for (1) scholars, (2) policymakers, and (3) universities:

- (1) It needs to be investigated whether these results can be replicated at other universities and, if so, to identify the filtering mechanisms causing them. Furthermore, research that not only focuses on gaps but also highlights potential is necessary.
- (2) The discovered inequities must be taken seriously by policymakers: Laws and other initiatives should address gender inequality and increase societal awareness. To address the lack of STEM workers in Austria, it is crucial to guarantee equitable access to these fields.
- (3) Universities need to account for the found gender gaps while recruiting new students and providing remedial instruction for STEM degree programs. Furthermore, it is crucial to support and enhance the accurate self-perceptions of men and women in mathematics.

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