

Change the game, not the girl

Understanding the role of gender-science stereotypes
in science competitions

DISSERTATION

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by
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Voor Mama & Papa,
Marieke

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Zusammenfassung

Naturwissenschaftliche Wettbewerbe scheinen für Mädchen weniger attraktiv zu sein als für Jungen. Obwohl eine Wettbewerbsteilnahme mit der Förderung naturwissenschaftlicher Interessen, selbstbezogener Überzeugungen und einer künftigen naturwissenschaftlichen Karriere einhergeht, scheinen Mädchen eher ungern teilzunehmen und sind weniger erfolgreich als Jungen. Da jedes Jahr hunderttausende Schülerinnen und Schüler in Wettbewerben teilnehmen, könnte das außerschulische Format zu Geschlechterungerechtigkeit in den Naturwissenschaften beitragen. Systematische Forschung zu den Mechanismen hinter Erfolgen und Misserfolgen in Wettbewerben sowie der Rolle, die das Geschlecht in diesen einnimmt, kann hier entscheidende Aufklärungsarbeit leisten. Zwar gibt es bereits Studien, die Geschlechterunterschiede in naturwissenschaftlichen Wettbewerben aufzeigen, die Ungleichheiten werden jedoch nicht systematisch auf erklärende Faktoren zurückgeführt.

Das erste Ziel dieser Dissertation war es daher, den Status quo der Forschung zu Geschlechterunterschieden in Wettbewerben aufzuarbeiten und theoriebasiert Faktoren zu identifizieren, die Teilnahme und Leistungen in diesem Kontext erklären können. Da Studien im Bereich des naturwissenschaftlichen Lernens bereits negative Effekte von Gender-Science-Stereotypen auf selbstbezogene Überzeugungen von Schülerinnen und Schülern nachweisen konnten, war zweites Ziel der Dissertation, die Rolle von Gender-Science-Stereotypen in Wettbewerben aufzuklären.

Mithilfe eines systematischen Literaturreviews wurden zunächst Publikationen zu Wettbewerben analysiert, um die Ausprägung von Geschlechterunterschieden zu erfassen und Faktoren und Theorien zu identifizieren, die Wettbewerbsteilnahme und -leistung in diesem Kontext erklären können. Während geschlechterabhängige Teilnahme und Leistung in Science Fairs vergleichbar waren, zeigten sich bei den Olympiaden große Geschlechterunterschiede. Es wurde suggeriert, dass Gender-Science-Stereotypen bei Mädchen das Selbstkonzept und das Interesse, und damit auch Teilnahme und Erfolg, negativ beeinflussen, insbesondere bei der Physik- und Chemieolympiade. Das Erwartungs-Wert-Modell der Leistungsmotivation von Eccles et al. (1983) wurde als bestgeeigneter theoretischer Rahmen zur Erklärung der geschlechtsspezifischen Unterschiede empfohlen.

Anschließend wurde auf der Grundlage des Erwartungs-Wert-Modells eine moderierte Mediationsanalyse durchgeführt, um Teilnahme und Erfolg an der deutschen Chemieolympiade geschlechtsspezifisch zu untersuchen. Die Ergebnisse bestätigten den negativen Einfluss von Gender-Stereotypen auf Mädchen. Während Selbstkonzept und Interesse die weitere Teilnahme positiv vorhersagten, beeinflussten Gender-Stereotypen diese negativ. Interesse stellte sich

herbei als Mediator zwischen Stereotypen und Teilnahme heraus. Weder für Mädchen noch für Jungen zeigte sich ein direkter Zusammenhang zwischen Selbstkonzept und Stereotypen, jedoch sagte das Selbstkonzept von Teilnehmenden beider Geschlechter ihre Leistungen im Wettbewerb vorher. Bei Jungen war das Interesse darüber hinaus ein positiver Prädiktor für die Bereitschaft, im Wettbewerb zu verbleiben.

Schließlich wurde die Stichprobe mithilfe einer latenten Klassenanalyse näher charakterisiert. Dabei wurden Profile basierend auf Karrieremotivation, Interesse und Identifizierung mit Naturwissenschaften gebildet. Es wurden vier Profile identifiziert, wobei die Zugehörigkeit zu den Profilen von der Ausprägung der Gender-Science-Stereotypen, der Unterstützung durch Eltern und Lehrkräfte, sowie dem Geschlecht vorhergesagt wurde. Das am wenigsten erfolgreiche Profil, in dem besonders viele Mädchen vertreten waren, zeigte den größten Zusammenhang zu Gender-Science-Stereotypen und den geringsten Zusammenhang zu Unterstützung durch Eltern und Lehrkräfte.

In der Gesamtschau sprechen die Ergebnisse dieser Dissertation für einen Bedarf, die Struktur naturwissenschaftlicher Wettbewerbe zu ändern, um negativen Effekten von Gender-Science-Stereotypen bei Mädchen entgegenzuwirken. Zukünftige Forschung kann dazu beitragen, den Zusammenhang zwischen Wettbewerben, naturwissenschaftlichen Lernen und leistungsstarken Schülerinnen und Schülern besser zu verstehen. Darüber hinaus erscheint es lohnend, die Rolle von Eltern und Lehrkräften sowie den Einfluss einer Wettbewerbsteilnahme auf Schülerinnen und Schüler stärker zu berücksichtigen. Strukturelle Änderungen und begleitende Interventionen können unter anderem an der Stärkung des Selbstkonzepts von Mädchen, beispielsweise mithilfe von Rollenvorbildern, der aktiven Einbindung von Lehrkräften, dem Zugang zu authentischen und ungegenderten Berufsinformationen, sowie der Einbindung von Eltern ansetzen, um Gender-Science-Stereotypen angemessen zu begegnen. Perspektivisch sollte dieser Forschungsansatz auf verschiedene benachteiligte Gruppen ausgeweitet werden und kann hier einen entscheidenden Beitrag dazu leisten, Bildungsungleichheiten in den Blick zu nehmen und zu verringern.

Abstract

Science competitions do not seem as appealing to girls as they do to boys. Even though participation in a science competition is linked to promoting science interest, self-beliefs, and future science careers, girls seem more reluctant to join, and are less successful than boys. As hundreds of thousands of secondary school students take part in a science competition each year, these out-of-school science activities could be a significant source for gender inequity. This is why in depth research to understand success and failure in science competitions, the mechanisms behind them, and the role of gender are of great importance. Although several studies reported about gender differences in science competitions, no systematic analysis of the gender gap is available to date.

The first aim of this dissertation was therefore to determine the status quo on gender differences in science competitions and to identify theoretical frameworks and factors explaining participation and achievement. Since prior publications in the context of both science education and science competitions have indicated gender-science stereotypes as the main negative influence on female self-beliefs, the second aim of this dissertation was understanding the role of gender-science stereotypes in mechanisms explaining participation and achievement.

By means of a systematic review, publications on science competitions were analyzed to determine the degree of the gender gap and identify factors and theories explaining participation and success. Participation and achievements in science fairs were comparable, but gender differences were found to be especially large in science Olympiads. Especially in the physics and chemistry Olympiad, gender-science stereotypes were suggested to have a negative influence on female self-concept and interest, thereby affecting participation and achievements. Eccles et al.'s (1983) expectancy-value theory of achievement motivation was recommended as most suitable theoretical framework for explaining gender differences.

Subsequently, a moderated mediation analysis was performed to examine gendered participation and success in the German chemistry Olympiad on the basis of expectancy-value theory. The results confirmed the negative impact of gender stereotypes on girls. Although female self-concept and interest positively predicted further participation, gender-science stereotypes were found to negatively predict further participation. Interest was found to mediate this relationship between stereotypes and participation. There was no link between self-concept and stereotypes, but self-concept did predict achievement for male and female participants. Interest positively predicted male participants' willingness to continue with the competition.

Finally, a latent profile analysis was executed to characterize profiles distinguished by career motivation, interest, and domain identification. Four profiles were identified and participant

membership was predicted by gender-science stereotype endorsement, support from parents and teachers, and gender. Profile membership of the least successful profile harboring the most girls, had the strongest link with gender-science stereotypes and the weakest link with support from parents.

In summary, the findings reported in this dissertation stressed the need for change in science competition structures to help diminish the negative effects of gender-science stereotypes on girls. Further research could contribute to understanding the relation between different science competitions, science education, and top performers in science education. Furthermore, future research could provide more insight into the role of parents and teachers and the influence of participation in science competitions on students. Changes and interventions improving gender equity of science competitions could be focused on strengthening female self-concept through role models, actively involving teachers, providing authentic and ungendered career information, and involving parents in the fight against gender stereotypes. In the future, this research could be extended to other minority groups and make a decisive contribution to reducing inequity in science education.

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Chapter 1

Introduction

“I believe boys are ‘naturally’ better right now, but this may change in the future”

– Female science competition participant, 2018

Girls and science competitions are not a perfect match. While they are open to all, girls seem reluctant to participate and struggle to become top performers. This raises an important question: Why do science competitions appeal differently to girls and boys?

Successful participation in science competitions has been linked to promoting science-specific interests, self-beliefs, and domain identification (Jaworski, 2013; Mitchell, Dori, & Kuldell, 2011; O’Kennedy et al., 2005; Wu, 1996), and it increases the chances of getting into a top university in several countries (Edge, 1989; Wu & Chen, 2001). On a broader level, this means science competitions help stimulate participants to continue their professional career in science (e.g., Campbell & O’Connor-Petruso, 2008; Lengfelder & Heller, 2002; Sahin, Gulacar, & Stuessy, 2015).

Yet girls are underrepresented in out-of-school school science learning activities (OECD, 2016) and science competitions seem to be no exception. Female students appear to steer clear from competitions focused on ‘hard’ sciences (e.g., Adamson, Foster, Roark, & Reed, 1998; Lawton & Bordens, 1995) and generally become increasingly scarce the higher the competition level (Nick, 2017; Petersen & Wulff, 2017). As successful participation is positively linked to subsequent study and career, science competitions may thus unintentionally stimulate gender inequity.

As hundreds of thousands of secondary school students from around the world take part in local, national and international science competitions each year (Institute of Competition Sciences, 2017; Microsoft, 2020), a thorough understanding of the mechanisms explaining success and failure—and the way in which these mechanisms are gendered—is essential. Eccles et al.’s (1983) expectancy-value theory of achievement motivation has been widely used to explain gender differences in the science domain, and points to gender role stereotypes as primary instigators of girls’ negative self-beliefs (Eccles, 2005; Eccles & Wang, 2016). That is why gender-science stereotypes, cultural beliefs implying men are naturally better at science, have been extensively investigated in the context of science education where they were found to be negatively

connected to female representation and achievement (Miller, Eagly, & Linn, 2015; Nosek et al., 2009). Even though several studies specifically focused on gender differences in science competitions (e.g., Feng, Campbell, & Verna, 2002; Greenfield, 1995; Jones, 1991), only few tried to find underlying mechanisms and acknowledged the influence of gender stereotypes or social gender roles in these activities. Urhahne, Ho, Parchmann, and Nick (2012), however, noticed that male participants outperformed female participants in a national Chemistry Olympiad, and found that female participants received less support from parents, had weaker ability self-beliefs, and a stronger fear of failure. Following Eccles et al.'s (1983) expectancy-value theory, the authors mentioned social role stereotypes as a potential negative influence on female participants' competitiveness and science motivation. A few other studies attempted to explain success and failure in science competitions in general, but these studies all focused on different types of competitions, based their work on different theoretical frameworks (or did not use a theoretical framework at all), and used different methodologies (e.g., Dionne et al., 2012; Lengfelder & Heller, 2002). Thus, an overarching systematic overview is still missing.

The current dissertation aims to bridge this gap and improve the fit between girls and science competitions in two steps. During the first step a systematic analysis and categorization of publications on the gender gap in science competitions is carried out to uncover the exact extent of the problem. This analysis will determine the extent to which science competitions in their current form stimulate gender inequity, which is then followed by the question: In what way can science competitions be adapted to promote gender equity? To help answer this question, the second step of this study entails gaining a better understanding of the role of gender-science stereotypes in mechanisms explaining participants' success and failure. This step investigates the gendered influence of gender-science stereotypes on individual expectancy and value constructs, as well as on groups of similar participants in the German chemistry Olympiad. Out of biology, chemistry, and physics, the three most common secondary school science subjects, chemistry is typically considered to be positioned between biology and physics in terms of altruistic and feminine-masculine associations (Bruun, Willoughby, & Smith, 2018; Kessels, Rau, & Hannover, 2006; Yang & Barth, 2015). This dissertation focuses on gendered aspects of participation and achievement but the extent to which the topic of a competition is gendered likely influences participants' stereotyped behavior. From this perspective, findings in the chemistry Olympiad are potentially the most average among the three disciplines and therefore best transferable to the biology and physics Olympiad.

The theoretical framework of this research in Chapter 2 elaborates on science competitions, gender differences in science, expectancy-value theory, and gender-science stereotypes. A brief overview of the overall study design is explained in Chapter 3. Chapter 4 contains a systematic review analyzing gender differences in science competitions as well as variables and theoretical

frameworks explaining participation and achievement. Chapter 5 and 6 focus on the investigation of gender-science stereotypes in the German Chemistry Olympiad. Effects of gender-science stereotypes on participation and achievement, and in what way these effects are mediated by self-concept and topic interest, is explained by means of a moderated mediation analysis in Chapter 5. In Chapter 6, motivational profiles of participants are characterized, linked to achievement in the Olympiad, and profile membership is predicted by gender-science stereotypes, gender, and support from parents and teachers. Chapter 7 contains an overarching discussion of this dissertation's findings and implications for future research and practice.

Chapter 2

Setting & Theoretical background

2.1 Science competitions

Science competitions are informal learning activities targeting interested, talented, or gifted students. They take place at school, or on a regional, national, and international level and are usually focused around school science subjects such as biology, chemistry, physics, mathematics, or geography, or extracurricular topics such as engineering, computer science, neuroscience, design, or robotics (Institute of Competition Sciences, 2017).

Science competitions are a collection of individually structured competitive activities with a different scientific focus, sharing a common goal of motivating, inspiring, and engaging motivated students. They do so by reinforcing interest, providing a real-world network, and easing entry into top universities (Miller, Sonnert, & Sadler, 2018; Smith, Jaeger, & Thomas, 2019). Worldwide hundreds of thousands of primary, secondary, and occasionally tertiary school students annually take part in countless science competitions. The *Imagine Cup* for example, a global technology competition initiated in 2003, has thus far reached over two million participants from over 100 countries (Microsoft, 2020).

The following two sections will discuss science fairs and Olympiads in more detail, as they are the main focus of this current research.

2.1.1 Science fairs

Science fairs are project-based competitive events challenging students to test and present their research hypotheses (Institute of Competition Sciences, 2017). They have a strong tradition in the US and Canada, which over the last decades resulted in several competitions attracting big corporate sponsors such as Intel, Google, and Microsoft (Google Science Fair, 2019; Microsoft, 2020; Society for Science & the Public, 2018; Youth Science Canada, 2020). Many science fairs also receive government funding and the Obama administration in the US even organized the *White House Science Fair* (European Commission, 2018b; Wellcome Trust, 2018; White House Science Fair, 2016).

Science fairs are characterized by their project-based design and use of the scientific method to solve research problems (Jaworski, 2013). Students, individually or in groups, choose a research

topic and develop a hypothesis. Project results are then presented in the form of a display board, model, presentation, or report. Following the science fairs, which are often organized at schools, the winners are invited to participate in regional, national and eventually international competitions. Oftentimes, participants are paired with experts from local companies or universities, providing them with knowledge, instruction, equipment, and networking opportunities (Institute of Competition Sciences, 2017).

Every year numerous science fairs are organized for students of different grade levels all over the world (e.g., European Commission, 2018b; SSEF, 2018; Youth Science Canada, 2020). In Germany, the two most renowned project-based science competitions are *Jugend forscht* (literal translation "Youth researches"; Jugend Forscht, 2020) and the *BundesUmweltWettbewerb* (literal translation "Federal environmental competition"; BUW, 2020). *Jugend forscht* is Germany's best-known project-based student science competition. It aims to excite and promote talented students between the ages of 9 and 21. Participants are challenged to use creative strategies and research-based learning to find answers to their own research questions in one of the 120 nationwide competitions. To date, approximately 300,000 students have participated in a *Jugend forscht* competition and of all the successful participants, about 90% pursued a STEM university major (Jugend Forscht, 2020).

The *BundesUmweltWettbewerb* is an annual, nationwide project-based competition, promoting interested and talented students aged 10 to 20 in the areas of environment, sustainability and society. It challenges students to implement scientific and technological solutions in order to solve complex environmental issues. Selected students or groups are invited to present a project poster to a jury of experts (BUW, 2020).

2.1.2 Science Olympiads

International science Olympiads are a collection of test-based competitions attracting high-achievers from all over the world. Four- to six-member teams represent their country and compete against each other in theoretical and practical tests. Winners receive a medal or trophy but no monetary prizes, and in many, especially Asian countries, entrance to top universities is strongly facilitated (Edge, 1989; Wu, 1996). Each year, about 75 to 125 countries participate in the International Biology, Chemistry, Physics, and Mathematical Olympiads (51st IChO, 2019a; International Biology Olympiad, 2018a; International Mathematical Olympiad, 2018; International Physics Olympiad, 2018). Countries generally select their team by means of a national qualification competition, consisting of one or more theoretical and practical selection rounds organized by governmental institutions or universities (Petersen & Wulff, 2017; Wu, 1996). Most qualification competitions attempt to attract as many students as possible from all over the country after which the best performing participants are selected for the national team

through a system of elimination (Petersen & Wulff, 2017; Verna & Feng, 2002).

German science competitions

Thousands of students participate in one of the German science Olympiads each year (Arbeitsgemeinschaft bundesweiter Schülerwettbewerbe, 2020). National qualification competitions for the International Biology, Chemistry, Physics, Junior Science, and European Union Science Olympiads, as well as the *BundesUmweltWettbewerb* are organized by the Leibniz Institute for Science and Mathematics Education (IPN). They are largely funded by the Federal Ministry for Education and Research (Petersen & Wulff, 2017). All German students between ages 15 and 20 are invited to participate in the first of four selection rounds of the biology, chemistry, and physics Olympiads (IBO Deutschland, 2017; IChO Deutschland, 2017; IPhO Deutschland, 2017). The first and second selection rounds consist of homework assignments, after which the fifty best performing students continue to the third selection round. The best fifteen participants of the third round qualify for the fourth and final team selection. For the final two selection rounds students are invited to a one-week camp filled with theoretical tasks, experiments, and lectures. The best four or five students (depending on the Olympiad) eventually qualify for the team that participates in the international competition (IBO Deutschland, 2017; IChO Deutschland, 2017; Petersen, Blankenburg, & Höffler, 2017; Petersen & Wulff, 2017).

The IPN not only selects the national team during national qualifications, but also tries to develop a long-term science motivation among the remaining participants (Petersen & Wulff, 2017). Even though the overall number of participants has increased in recent years, efforts are being made to engage a larger group of more diverse students (Petersen et al., 2017; Petersen & Wulff, 2017).

2.1.3 Girls in science competitions

It appears girls are underrepresented in science competitions, an issue addressed in several prior studies on science competitions (Cho & Lee, 2001; Feng et al., 2002; Jones, 1991). Even though two US studies mentioned that the gender gap is diminishing (Campbell & O'Connor-Petruso, 2008; Greenfield, 1995), most underlined the problem and searched for possible explanations. Parental support, socialization, cultural gender roles, motivational factors, and the biased structure of science competitions itself were pointed out as possible reasons for gendered participation patterns.

A number of studies specifically focusing on science fairs, reported clearly gendered topic preferences and experimental approaches: girls traditionally preferred biology-related topics, whereas boys were more likely to select a physics or computer science project (Adamson et al.,

1998; Bunderson & Bunderson, 1996; Greenfield, 1995; Jones, 1991; Lawton & Bordens, 1995; Sonnert, Sadler, & Michaels, 2013). Moreover, girls more often used a literature search to answer their research questions, while boys favored experimental research (Greenfield, 1995).

Most competitions appear to successfully attract girls in their first qualification round, but then gradually lose them in the course of the qualification competition. During each qualification round female drop-out rates are disproportionately high, resembling a 'leaky pipeline' pattern (Nick, 2017; Urhahne et al., 2012). Since participants qualify for a follow-up round based on their achievements, competitions may not only have a problem with girls' participation but also with performance.

2.1.4 Gender differences in science achievement

Participants of science competitions are usually secondary school students, and competitions are mainly based around assessment situations focusing on secondary school subjects. Therefore, students' performance in science competitions and their achievements in school may be comparable (Jones, 1991). General science achievement among students could, therefore, provide some insight into possible mechanisms behind the gender differences in science competitions.

Two programs monitoring worldwide science achievement among 13 to 15 year-old students are the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). PISA results across 79 participating countries showed that on average, girls performed slightly better in science than boys. More specifically, girls performed significantly better than boys in 34 countries, whereas boys performed better than girls in six countries (OECD, 2018). The 2015 TIMSS showed a comparable result with girls outperforming boys in 14 countries, and boys outperforming girls in five countries (Martin et al., 2016).

Thus, instead of gender patterns in science performance mirroring those in science competitions, they seem rather the opposite. This discrepancy may possibly be traced back to the specific student population participating in science competitions. During national selection competitions, a group of increasingly better-performing students is selected for each subsequent selection round (Campbell & O'Connor-Petruso, 2008; Lengfelder & Heller, 2002). That is why data on the average student population may not provide sufficient explanation for the underperformance of female participants in science competitions, yet data on science top performers may.

Baye and Monseur (2016) analyzed data from the TIMSS, PISA, and Progress in International Reading Literacy Study (PIRLS) between 1995 and 2015 for gender differences in extreme scores. Their meta-analysis data showed that, even though gender differences in mean science

scores were practically non-existent, among top performers boys consistently scored better. The authors therefore recommend against the reporting of only gender differences in mean scores because of their large contrasts with gender differences in the extreme tails of the distribution (Baye & Monseur, 2016). Likewise, in the most recent PISA study, which was not included in Baye and Monseur's (2016) analysis, girls generally performed better than boys, but among top performing students, boys were significantly better than girls (OECD, 2018). Two studies on science performance of gifted students found gender differences in a group of top performing students to be larger than in average-ability students, similar to the above study (Preckel, Götz, Pekrun, & Kleine, 2008; Reis & Park, 2001). Moreover, in an attempt to explain their findings, both studies also tested gender differences in self-concept, interest, and achievement goals. Male top performers were found to have an advantage in all three motivational variables. Preckel et al.'s (2008) study also reported that gender differences among top performers were larger compared to average-ability students. A more detailed look at this finding revealed that average-ability boys had lower interest and self-concept than top performing boys, but remarkably enough, average-ability as well as top performing girls had comparable interest and self-concept. As becomes clear from these findings, data on comparisons between groups, whether boys versus girls or average-ability versus top performing students, can only provide insight on the status quo of the current situation, but do not offer enough information to fully explain the mechanisms behind success and failure in science competitions. In order to get a more integrated and detailed picture of participants' behavior, the use of interaction models is therefore indispensable.

2.2 Expectancy-value theory

Motivational factors ostensibly play a role in explaining gender differences among average-ability science students, and even more so among science top performers. In what way motivation is connected to (1) the choice whether or not to participate in a science competition, (2) persistence in the competition, and (3) performance in the competition, is explained by Eccles' expectancy-value theory of achievement motivation (see Figure 1; Eccles et al., 1983; Wigfield & Eccles, 2000). This framework was initially designed to explain gender differences in the fields of mathematics, physical science, and engineering and was then widely used in the context of science education and careers (Eccles, 2005; Eccles & Wang, 2016).

Expectancy-value theory argues that the choice to participate, perseverance, and eventual performance in an upcoming activity depend on personal beliefs about the expectation of success and the amount of value placed on the activity. Expectations and values, in turn, are presumed to be influenced by activity-specific beliefs such as self-schemas, goal orientations, ability beliefs,

and the perceived difficulty of the activity.

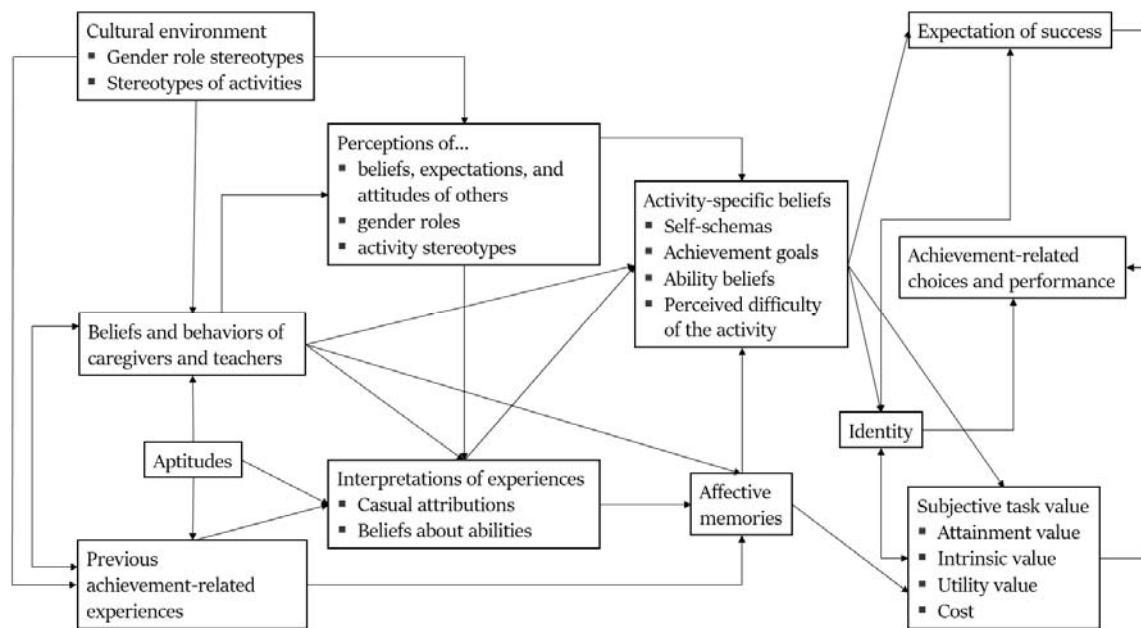


Figure 1. Adaptation of Eccles et al. expectancy value model of achievement-related choices (Eccles, 2005). Note. The arrows in the figure show which indicators influence each other and the direction of influence. The double-headed arrows signify that the indicators influence each other.

Self-beliefs, such as achievement goals and ability beliefs, are highly context-specific. They vary within an individual depending on the domain and specific activity (Wigfield & Eccles, 2000). Since this dissertation concentrates on science competitions, self-beliefs are focused around activity-specific beliefs emphasizing both the activity as a whole and the domain in which the competition takes place.

Science competitions are defined by their competitive and voluntary nature, the following sections therefore specifically focus on activity-specific beliefs and subjective task value.

2.2.1 Activity-specific beliefs

Self-schemas

Garcia and Pintrich (1994) described self-schemas in the context of education as the self-perceptions students have in different subjects and classroom situations. Self-schema theory is based on the idea that self-perceptions are dynamic, based on previous experiences in a similar domain, and are mediated by the current context (Alexander, 1997). This type of individual knowledge is supposed to be so extensive it encompasses every aspect of a students' sociocultural, physical, and academic existence.

Achievement goals

When considering academic activities, students are guided by motivation and achievement-

related goals (Ames, 1992). Achievement goal orientations describe an interaction between beliefs, attributions, and intentions that explains how a student approaches, participates in, and reacts to specific achievement activities (Grant & Dweck, 2003). Original achievement goal theory proposed two types of goals: performance goals and learning goals (Ames, 1992). Performance goals (also known as ego-involved goals or ability goals) revolve around students' abilities and their connected sense of self-worth. In situations driven by performance goals, ability is demonstrated and verified in a normative way, by outperforming classmates, having above average scores, or by putting in little effort in relation to success (Covington & Omelich, 1984). Students adopting performance goals regard learning processes as a means to achieve success, and as a result enhance their self-worth. This strategy only works for students with strong ability-perceptions, as they can demonstrate their abilities compared to others. Students with weak ability-perceptions adopting performance goals may risk damaging their self-concept. This may happen when they are unsuccessful, even after putting in a lot of effort (Covington & Omelich, 1979). Grant and Dweck (2003) subdivided performance goals into 1) ability-linked goals emphasizing the conformation of intelligence; 2) normative goals focusing on comparing intelligence with others, and 3) outcome goals affirming intelligence by getting good grades. Learning goals (also known as mastery goals or task goals) focus on overcoming learning obstacles and gaining as much knowledge and competence as possible. They emphasize persistent growth and the development of new skills, also for students who have a low assessment of their own abilities (Ames & Archer, 1988). Learning goals are especially interesting in the context of science competitions. Students with a desire to gain a true understanding of subject matters, as opposed to just passing tests, enjoy challenging activities, are persistent when facing set-backs, and have positive learning attitudes (Elliot & Harackiewicz, 1996). As to be expected, learning goals were found positively linked to achievement and perseverance (Ames, 1992; Ames & Archer, 1988). Furthermore, girls were more likely to emphasize learning goals, whereas boys had a stronger focus on performance goals (Freudenthaler, Spinath, & Neubauer, 2008; Patrick, Ryan, & Pintrich, 1999).

Ability beliefs

Students' ability beliefs reflect current perceived abilities concerning a specific subject or topic in achievement situations. According to the expectancy-value theory, they directly affect expectations of success, on the one hand, and subjective task value, on the other. The two most established and widely used positive ability self-beliefs are self-efficacy and self-concept (Bong & Clark, 1999; Marsh et al., 2019; Nagy et al., 2010). Both constructs are closely related to outcome expectations and have strong similarities but their components differ in terms of prospective (what am I capable of?) versus retrospective (how have I done so far?) and descriptive (based

on learning criteria) versus evaluative (based on social comparison information). Self-efficacy is a self-belief about future capabilities based on learning criteria, whereas self-concept focusses on a combination of past and future accomplishments in social comparison (Bong & Clark, 1999; Jansen, Scherer, & Schroeders, 2015; Marsh et al., 2019).

Self-efficacy

Bandura (1977) originally defined self-efficacy as beliefs people have about their capabilities when encountering activities affecting their personal situation. These beliefs influence peoples' thoughts, motivations and choices. In the context of science competitions, self-efficacy defines participants' beliefs about how well they will be able to perform in various test situations based on the competition's criteria. In a study among Chemistry Olympiad participants in a national penultimate selection round, Urhahne et al. (2012) found significant gender differences in self-efficacy in favor of male participants. Even though male participants also achieved significantly higher scores than female participants, the authors found no direct link between self-efficacy and achievement. In comparison, findings in line with the expectancy-value theory, confirming a positive link between self-efficacy and achievement, were reported in mathematics and science education (e.g., Britner & Pajares, 2006; Schöber, Schütte, Köller, McElvany, & Gebauer, 2018; Uçar & Sungur, 2017).

Although gender differences in science-related self-efficacy are not consistent (Pajares & Britner, 2001; Pajares & Miller, 1994; Tzu-Ling, 2019), female secondary school students' self-efficacy beliefs were found to be negatively linked to male-dominated STEM majors (Schuster & Martiny, 2017). Furthermore, Cheryan, Ziegler, Montoya, and Jiang (2017) explored the gender gap in STEM in a systematic review and proposed self-efficacy as one of three major factors (besides differences in domain identification and early experiences with all STEM fields) explaining gendered participation.

Self-concept

Self-concept is a subject-specific self-belief based on past accomplishments alongside comparisons with peers and between subject areas (Marsh, 1990; Marsh et al., 2019). Students' comparisons between subject areas can be explained on the basis of the internal/external frame of reference model (Marsh, 1986). The model explains how students with the same grades in a science-subject may have different science self-concept based on comparisons with their grades in a language-subject. Important in the context of science competitions is the big-fish-little-pond effect (Marsh, 1987, 2005). It predicts how students base their self-concept on comparisons with peers. In science competitions this may result in students from average ability schools with relatively high self-concepts, competing against students from high ability schools with relatively low self-concepts. Therefore, self-concepts of students with little to no previous experience in

science competitions, and therefore no substantial competition-specific past accomplishments to draw from, may be truncated. They are most likely based on previous educational achievements and comparisons with classmates. Part of this assumption was first made by Höffler, Bonin, and Parchmann (2017) in a study among junior science Olympiad participants. All participants made it to the third selection round, but boys had significantly higher self-concepts than girls. Höffler et al. (2017) noted that, even though all participants were equal in terms of success (as they all made it to the third selection round), girls still underestimated their abilities relative to boys. Accordingly, Blankenburg, Höffler, Peters, and Parchmann (2016) found competition-specific self-concept positively related to intended participation in a science competition.

Another finding in Höffler et al.'s (2017) study was that participants' self-concept correlated with achievement. Chang and Lin (2017) found the same in the international Earth Science Olympiad. Similar relationships were found in secondary school science education with several studies linking achievement and participation to self-concept (e.g., Jansen et al., 2015; Liu, Hu, Jiannong, & Adey, 2010). Also in a science education context, girls with the same grades as boys, were still found to have lower self-concepts (Jansen, Schroeders, & Lüdtke, 2014; Makwinya & Hofman, 2015)

2.2.2 Subjective task value

Students' ability beliefs directly influence the value-portion of the expectancy-value theory. Whether and how a specific task meets the needs of a person is subjective. Different people therefore value each task differently (Wigfield & Eccles, 1992). Eccles et al. (1983) defined four subjective task value components. Attainment value is the personal importance of succeeding at a certain task. Intrinsic value is the enjoyment connected to engaging in an activity. Utility value refers to a task's usefulness for the future. Cost reflects effort, and how engaging in one activity limits time for other activities. Combined, these components mirror the relative attractiveness of a future activity or task. Students associating science competitions with positive subjective task value may feel motivated to participate, while students with negative value may not.

Attainment value

Attainment value measures the degree to which personal values and identities are confirmed by participating in an activity (Eccles, 2009). It was found predictive of pursuing a science career among high achieving secondary school students (Andersen & Ward, 2014). Because of its identity-congruent nature (Oyserman & Destin, 2010), attainment value could potentially be important in explaining the lack of girls in science competitions. Girls may be having a harder time than boys identifying as 'a science talent' and 'a competitive person'.

Intrinsic value

In developing the expectancy-value theory, Eccles et al. (1983) primarily derived intrinsic value from Deci and Ryan's (1985) construct of intrinsic motivation. Based on affective theories, Deci and Ryan (1985), and later Wigfield and Eccles (2000) placed the interest construct as described by Krapp, Schiefele, and Winteler (1992), at the core of intrinsic value. Krapp and Prenzel (2011), in turn, elaborated on the essential intrinsic nature of interest. Consequently, interest became the core intrinsic value construct in achievement motivation research (e.g., Hulleman, Durik, Schweigert, & Harackiewicz, 2008; Köller, Baumert, & Schnabel, 2001; Krapp et al., 1992).

Current interest theories conceptualize interest as an intrinsically motivated focus, with an affective and a cognitive component, directed towards particular subject areas and related activities (Krapp & Prenzel, 2011; Renninger & Hidi, 2011). Interest development models (Hidi & Renninger, 2006; Krapp, 2002) distinguish situational and individual interest. Situational interest describes a temporary emotional state, triggered by specific aspects of an activity with subjective ability, goal, and behavioral components (Renninger, 2000; Wigfield & Cambria, 2010). Individual interest is considered a stable and long-lasting inclination towards particular activities, subjects, or domains (Hidi & Renninger, 2006).

In science competitions, a well-developed individual interest would be characterized by positive feelings, knowledge, and value about the activity and in particular the main topic of the competition. Thus far one study on science competitions could link participation to interest (Blankenburg, Höffler, Peters et al., 2016). Generally among secondary school students, several studies positively linked interest to academic achievements in STEM domains (e.g., Denissen, Zarrett, & Eccles, 2007; Köller et al., 2001; Pekrun, Lichtenfeld, Marsh, Murayama, & Goetz, 2017) as well as science-related activities and career choices (Aeschlimann, Herzog, & Makarova, 2016; OECD, 2016; Sadler, Sonnert, Hazari, & Tai, 2012). Girls, however, were on average less interested in science than boys (Denissen et al., 2007; Krapp et al., 1992; Leibham, Alexander, & Johnson, 2013; OECD, 2016). Correspondingly, a lack of female participants in U.S. science Olympiads was found to be linked to lower levels of interest among girls (Feng et al., 2002).

Utility value & cost

The estimated utility and cost of an activity describe the perceived cost-benefit. Utility value defines the usefulness of an activity in terms of future plans (Wigfield & Eccles, 1992). Even if a certain activity in itself may not seem particularly attractive, it may still be worth participating in for the sake of, for example, pursuing a career, pleasing caretakers, or being with friends.

The cost of participating in an activity refers to limitations in other areas. Participating in a science competition, for instance, may take a lot of effort, limit time for friends and hobbies, and have high emotional costs (e.g., anxiety, insecurity, fear of failure).

Utility value was found positively linked to science achievement on the basis of TIMSS data from 8th grade students in 26 countries (Liou, 2017). Furthermore, in their study among high achievers, Andersen and Ward (2014) identified utility value as a positive predictor for STEM persistence, whereas cost was unrelated.

Perez, Cromley, and Kaplan (2014) investigated undergraduate chemistry students and found that their perception of cost, especially the effort needed to be successful, was negatively linked to motivation. Moreover, they found that activities stimulating identity formation, such as finding information and reflecting, were negatively related to cost, but positively related to ability beliefs and value.

2.2.3 Identity

A person's or group's identity is made up of beliefs, abilities, personality, and appearance. Identity research addresses the influence of people's identities on their behavioral choices under the assumption that most choices are made in agreement with own self-meanings (Hogg, 2016). Adolescence is a period generally focused on identity formation in which students explore educational and occupational opportunities and ambitions (Wigfield & Wagner, 2005). Within academic achievement frameworks, identity can be summarized as developing relative ability beliefs, exploring and understanding values, and developing self-confidence from positive achievements in valued domains (Eccles et al., 1989). In their conceptualization of adolescents' academic identity formation, Roeser and Lau (2002) make a distinction between positive and negative student identities. Positive student identities are characterized by positive past experiences with classmates and achievements, ability beliefs, goals, and overall self-image as a student. Negative identities are the opposite: they entail experiences with failure, problems with school environment, and negative ability beliefs, goals, and self-student conception.

Domain identification

According to theory of domain identification (Steele, 1997) a students' identification with a certain domain is shaped by subjective perceptions about abilities, interests, and possibilities to succeed. Domain identification is often operationalized by feelings of belonging, which are in constant interaction with relative domain-specific beliefs, subjective task value, and present identity (Eccles, 2009). Domain identification in STEM fields was found to be positively linked to achievement (Dasgupta & Stout, 2014; Howard, 2015) and intended career goals (Good, Rattan, & Dweck, 2012; Wilson et al., 2015). As STEM domain identification is often colored by masculine cultures, female students have a harder time feeling connected (Cheryan et al., 2017; Good et al., 2012). In the same way, a study by Petersen and Wulff (2017) suggested female science Olympiad participants experience a discrepancy between their own identity and

masculine science Olympiad environments.

Gender identity

Gender and gender differences are a noticeable common thread in narratives trying to explain academic choices and achievements. As gender is an essential factor influencing ability beliefs, values, goals, and expectancies, gender identity should be accounted for in any educational research study.

Egan and Perry (2001) described gender identity as knowledge about which gender group one belongs to, feelings of compatibility and contentment with one's gender group, perceived pressure to behave in a gender-conform way, and personal stance towards gender groups. Students placing importance on gender conformity will pursue activities fitting their gender role because these activities have high attainment value for them (Eccles, 1994; Wigfield & Wagner, 2005).

Balanced identity theory

In most cultures science is perceived as a masculine domain (Hill, Corbett, & St. Rose, 2010; Miller et al., 2015). Students identifying with a female gender group may therefore place little attainment value on science-related activities from a gender perspective. They may, however, nevertheless be interested or talented in science and therefore have strong science-ability beliefs. These students likely feel there is a mismatch between their identities, goals, and values. Greenwald et al. (2002) explained this mechanism by means of the balanced identity theory (see Figure 2; Cvencek, Greenwald, & Meltzoff, 2012).

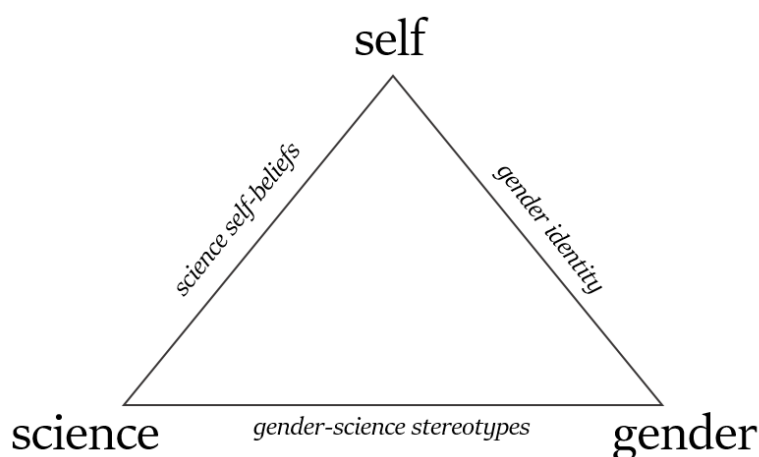


Figure 2. Adaptation of the balanced identity theory by Greenwald et al. (2002)

Balanced identity theory can be used to explain numerous interrelationships, but in a science educational context it defines associations between the self, a gender group, and the science domain. Associations between the self and gender are characterized by a student's gender

identity. The science domain and the self are described by science-related self-beliefs. As mentioned before, most cultures associate the science domain with men, causing many people to have “science is male” stereotypes. The association between gender and science is therefore represented by gender-science stereotypes (see section 2.3 for more detailed information).

According to the balance–congruity principle (Heider, 1958) students naturally avoid imbalance between the three main constructs. This explains why stereotypes connecting science to men make it difficult for students with a female gender identity to develop strong science self-beliefs and why girls may feel particularly demotivated when considering participation in a science competition. Studies in science education underline these patterns: Strong identification with the female gender combined with gender-science stereotype endorsement were found to predict negative science attitudes, weaker performance, and less ambition to pursue a career in mathematics or science (Kiefer & Sekaquaptewa, 2007; Lane, Goh, & Driver-Linn, 2012; Nosek, Banaji, & Greenwald, 2002). A strategy for women in science could therefore be the adaptation of a slightly more male gender identity. A study by Kao (2015) among mathematically gifted students indeed indicated the girls in this group used exactly this approach. They refuted the importance of beauty and gravitated towards masculine characteristics and interests.

A second and perhaps more sustainable approach for women in science could be to adjust the strength or even the direction (“female is science”) of their stereotypes, to balance them with their science self-beliefs. In line with this strategy, girls majoring in engineering held significantly weaker gender-mathematics stereotypical beliefs compared to male engineering students and students majoring in humanities (Smeding, 2012). Moreover, women working in areas that were perceived as scientific, endorsed gender-science stereotypes substantially less than men working in the same disciplines (Smyth & Nosek, 2015). A decrease in stereotype endorsement on the cultural or individual level would therefore potentially encourage students in taking on activities that currently seem incompatible with their gender group.

2.2.4 Gender role stereotypes

Activity-specific beliefs and subjective task value are affected by students’ interpretations of previous experiences on the one hand, and by perceptions based on gender role stereotypes and stereotypes stemming from the cultural environment on the other (Eccles et al. (1983) call this the “cultural milieu”). Stereotypes are widely kept images of defined groups representing specific characteristics of the individuals belonging to this group (McGarty, Yzerbyt, & Spears, 2002). Even though in everyday life, stereotypes can be helpful when making sense of a new situation in a short amount of time, they often promote biased perceptions of the world because of their oversimplified nature (Bordalo, Coffman, Gennaioli, & Shleifer, 2016). Stereotypes cover

different types of groups, such as populations (e.g., “The Dutch are tall”), demographic groups (e.g., “Overweight people are lazy”), occupations (e.g., “Physicists are nerds”) and genders (e.g., “Women are emotional”).

Social role theory argues that gender role stereotypes are formed and influenced by cultural perceptions of social roles (Eagly, 1987; Eagly & Wood, 2012). Perceptions of social roles are, in turn, shaped by cultural gender-congruent behaviors, which are directly conveyed through social interactions with family, teachers, and peers and indirectly through media such as social media, series, films, and games (Koenig & Eagly, 2014).

Gender and competition

Competitiveness and science are generally perceived as a male activity and a male domain (Kessels, 2005; Lever, 1987) causing science competitions inherently prone to disadvantage girls. In a study about gender differences in a number of U.S. science competitions, Jones (1991) mentioned how the competitive nature of science competitions may have negatively affected female participants. Jones (1991) also connects gender differences in competitiveness to differences in achievement goals (as explained in section 2.2.1). Boys have a stronger preference for performance goals than girls, indicating they are generally more comfortable with measuring themselves against others (Freudenthaler et al., 2008; Patrick et al., 1999). These findings were confirmed in the most recent PISA study which found that girls in most countries were less in favor of competition than boys. In general, girls also expressed less joy about competitive working situations, fewer girls than boys reported to try harder in competitive situations, and girls carrying out competitive activities put less importance on outperforming others than boys (OECD, 2020).

In a study comparing learning preferences in English and mathematics, Owens and Barnes (1982) found boys to have a competitive learning preference in mathematics, whereas girls preferred competing in English. These findings indicate that, girls not only feel less eager and comfortable participating in competitive situations than boys (Gupta, Poulsen, & Villeval, 2013), the competitions’ topic may also amplify gender differences in competitive behavior.

2.3 Gender-science stereotypes

Eccles and colleagues have executed numerous studies using expectancy-value theory to explore STEM-related gender differences in educational settings (e.g., Eccles, 1994; Eccles, 2005; Eccles & Wang, 2016). Many of these studies mentioned the fundamental role of gender-science stereotypes (e.g., Eccles, 1994; Eccles, 2011; Eccles & Wang, 2016; Jacobs & Eccles, 1992). Gender-science stereotypes are cultural beliefs about men being more talented and interested in science than women (e.g., Nosek et al., 2009; Smyth & Nosek, 2015). Not only do gender-science

stereotypes imply that men are more talented in science, they also suggest that the science domain as a whole is considered masculine (Kelly, 1985). The basis of this belief partly lies in the perceived lack of communal goals in mathematics and science, which are more strongly endorsed by women than men (Diekman, Brown, Johnston, & Clark, 2010). Gender role socialization guides girls towards activities and occupations related to people, social interaction, and helping (in line with family role plans), whereas boys are stimulated to pursue occupations that are more abstract, object-focused, and well-paid (to provide for their family; Eccles, 2005). However, there seem to be distinctions in perceived communal goals between mathematics, physics, chemistry, and biology. These distinctions could explain why physics is perceived as more masculine than biology (Cheryan et al., 2017; Lerdpornkulrat, Koul, & Sujivorakul, 2012), and why girls rather choose biology-related topics in science competitions, compared to boys, who prefer physics (see section 2.1.3; Diekman, Steinberg, Brown, Belanger, & Clark, 2017).

2.3.1. Parents' stereotypical beliefs

Parents' gender-science stereotypes have been suggested to play a significant role in the development of their children's gendered perceptions (Eccles, 1994; Eccles, 2011; Eccles & Wang, 2016; Jacobs & Eccles, 1992). Parents' gender-science beliefs were found to be a significant influence on their child's abilities perceptions (Frome & Eccles, 1998) and intended career choice (Muenks, Peterson, Green, Kolvoord, & Uttal, 2020). Several studies on science competitions mentioned the positive influence of support from parents on their child's success (Campbell & O'Connor-Petruso, 2008; McDonough, 1995; Verna & Feng, 2002; Wu & Chen, 2001). Furthermore, a combined Korean study among mathematical and science Olympiad participants as well as the parents of over 300 gifted children found that parents encouraged their children in choosing gender-specific careers (Cho & Lee, 2001). The authors identified the parents' gender stereotypes as main explanation for the small amount of female participants. In addition, Feng et al. (2002) found that the influence of gender stereotypes on the socialization of children was one of the main reasons for female underrepresentation in American science Olympiads.

2.3.2 The influence of gender-science stereotypes on girls

The direct influence of gender-science stereotypes on participants of science Olympiads has not been studied abundantly yet. Just one paper describes how gender stereotypes were mentioned by former participants of science Olympiads as a reason for low female participation rates (Lengfelder & Heller, 2002).

In the context of science education, several studies have linked gender-science stereotypes to female underrepresentation and underachievement. Two large-scale international studies by Miller et al. (2015) and Nosek et al. (2009) linked gender-science stereotype endorsement to

national gender differences in science and mathematics performance and university enrolment. These studies, as well as several others (Cundiff, Vescio, Loken, & Lo, 2013; Deemer, Thoman, Chase, & Smith, 2014; Lane et al., 2012; Steffens, Jelenec, & Noack, 2010), showed that science achievement and career choices reflect gender roles within the socio-cultural context, with stronger national endorsement of gender-science stereotypes connecting to larger gender differences in achievement and fewer women choosing a major or a career in mathematics or science.

As proposed in expectancy-value theory, gender role stereotypes influence ability-specific beliefs and subjective task value. These relationships have been confirmed in various studies in the context of STEM education. Female students that held stronger gender-science or gender-mathematics stereotypes were found to have weaker subject-specific self-concept (Bonnot & Croizet, 2007; Cvencek, Kapur, & Meltzoff, 2015; Cvencek, Meltzoff, & Greenwald, 2011; Ertl, Luttenberger, & Paechter, 2017; Steffens et al., 2010), self-efficacy (Garriott, Hultgren, & Frazier, 2016; Lerdpornkulrat et al., 2012; Master, Cheryan, Moscatelli, & Meltzoff, 2017), and interest (Master et al., 2017; Plante, O'Keefe, Aronson, Fr chet te-Simard, & Goulet, 2019).

2.4 Research aims

As clearly depicted in this chapter, science competitions are having problems attracting and promoting girls. Similar to science education in schools, girls seem less drawn to physics or mathematics, and boys have greater chances of reaching top performer levels. Since participation in a science competition has been positively linked to science motivation and science career intentions, science competitions might therefore, in their current form, increase the gender gap in science.

Even though some studies have addressed the differences between boys and girls in science competitions, so far none tried to systematically identify the full extent of the problem. The first aim of this study was therefore to summarize the status quo of knowledge about science competitions. The publication in Chapter 4 describes a systematic literature review that (1) categorizes gendered participation and achievement patterns in different types of science fairs and Olympiads, (2) identifies existing theoretical frameworks and variables explaining participation and achievement, and (3) discusses gender as a possible moderator in these frameworks.

Studies in science education and science competitions often point to cultural gender roles and stereotypes as the basis for gender differences. Chapter 5 and 6 therefore specifically aim to understand the mechanisms behind the influence of gender-science stereotypes on gendered participation and achievement in the German Chemistry Olympiad. The publication in Chapter

5 uses variable-centered moderated mediation analysis to (1) investigate the influence of gender-science stereotypes on participants' performance and continued participation, and (2) measure the extent to which self-concept and interest mediated the influence of gender-science stereotypes. Finally, the manuscript in Chapter 6 describes how a person-centered approach was used to (1) characterize motivational profiles of participants, (2) determine in what way gender, gender-science stereotypes, teacher support, and parental support predicted profile membership, and (3) establish how competition score was linked to the different profiles.

In conclusion, the present dissertation aims to provide an overview of existing gender differences in science competitions and help understand mechanisms explaining the impact of gender-science stereotypes, with the goal of supporting potential strategies towards gender equity in science.

Chapter 3

Project design

3.1 The WinnerS-project

This study was conducted as part of the IPN project titled ‘Effects of academic science competitions’ (WinnerS) – a collaboration of all six scientific departments of the IPN (Biology Education, Chemistry Education, Mathematics Education, Physics Education, Educational Research and Educational Psychology, and Educational Measurement). First preparations for the project started in January 2016, after receiving the confirmation for project funding from the German Leibniz Association (grant number K194/2015).

The WinnerS-project aimed to (1) identify determinants predicting participation and achievement in science competitions, and (2) investigate the effects of success and failure on participants’ cognitive and affective characteristics. In total, four dissertations have been written as part of the WinnerS-project. Two focused on the German Physics Olympiad: One specifically concentrated on mathematics and the attribution of success and failure (Treiber, 2020), and the other investigated female students’ physics engagement (Wulff, 2019). The third dissertation addressed socioscientific decision-making in the context of the *BundesUmweltWettbewerb* (Garrecht, 2020). Lastly, the present dissertation zooms in on gendered participation in all science competitions, after which it focuses on the German Chemistry Olympiad to address the first aim of the WinnerS-project from the female participants’ perspective.

3.2 Method

3.2.1 WinnerS-project

The WinnerS-project was designed as a comparative longitudinal study of the *BundesUmweltWettbewerb* and German selection rounds for the International Biology, Chemistry, Physics, and Junior Science Olympiad. For each of the individual competitions a questionnaire was administered after each of the four selection rounds. Each questionnaire took approximately 30 to 50 minutes to fill out. Participants who qualified for the upcoming selection round, as well as participants that were eliminated in the previous round, were included in each of the measurement rounds. A couple of months after completion of the competition, one final

follow-up questionnaire of all participants was administered. In sum, the complete study consisted of minimally three and maximally five 30 to 50 minute questionnaires for each of the participants.

Administering of the questionnaires took place from 2017 to 2019. Participation was voluntarily and online. A total of 6726 students participated in one of the science competitions, of which 1429 (21%) took part in the first round of the study. In the fourth round of the study 70 students were left (56% stopped participating in the WinnerS-study and the rest were eliminated at an earlier stage of the competition).

Besides information on goals, self-beliefs, interests, achievement-related expectations and values, which was collected during each measurement, the first questionnaire contained additional instruments measuring stable person characteristics, parental influences, implicit stereotype endorsement, and previous achievement-related experiences. Furthermore, the second questionnaire (filled out by all participants, independent of their success in the first selection round) contained cognitive ability and problem-solving tests. Competition managements provided achievement scores for each of the selection rounds.

3.2.2 Current dissertation

The publication and manuscript in Chapter 5 and 6 of the current dissertation are based on data from the first questionnaire among participants of the German chemistry Olympiad. In total, $N = 445$ participants completed the survey (mean age = 16.50 years, $SD = 0.92$, 51% female) after completing the first selection round, but before receiving feedback about their performance. The questionnaire consisted of 262 items and one implicit association test, and the estimated response time was 45 minutes. All items of the instruments used in this dissertation can be found in Appendix F.

Chapter 4

Gender Differences in Mathematics and Science Competitions: A Systematic Review

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4.1 Introduction

Since 1901, Nobel Prizes in Physics, Chemistry and Medicine have been awarded to 604 outstanding researchers. Only 19 of these researchers were women (The Nobel Foundation, 2018). Certainly, the small number of female Nobel Laureates can be considered a logical consequence from the pre-existing low female rates in science, but these rates cannot completely explain the discrepancy (Lunnemann, Jensen, & Jauffred, 2018). Rather, the mechanisms leading to gender differences among Nobel Laureates are believed to start at the early stages of the young Laureates' careers. This is in accordance with gender differences in science education that generally reveal themselves in secondary education when students are allowed to choose their specialization (UNESCO, 2017). Adolescents become aware of their strengths and interests and specialize accordingly by choosing, for instance, major and minor subjects (Nagy, Trautwein, Baumert, Köller, & Garrett, 2006; Wang & Degol, 2013; Wigfield, Tonks, & Klauda, 2009). It is during this crucial time that they are increasingly given the opportunity to participate in informal and out-of-school learning programs. One such program, the academic mathematics and science competitions, feature prominently as well-established national and international events, usually financed with large sums by countries' research and education budgets, and aiming to promote participants' mathematics and science interest (Abernathy & Vineyard, 2001; Petersen & Wulff, 2017). Yet, the question arises whether these competitions contribute to gender equity by promoting females' and males' interests alike, or whether they in fact mirror the gender participation rates of secondary mathematics and science education and thus potentially exacerbate gender inequity by promoting the interests of males more strongly than those of females. Although a large body of research on gender and mathematics and science education is available (i.e., Blickenstaff, 2005; Brotman & Moore, 2008; Hill et al., 2010), little is currently known about gender and academic mathematics and science competitions. Therefore, we aim to provide a systematic review about gender differences and the mechanisms explaining success and failure in mathematics and science competitions.

4.2 Promoting Mathematics and Science: Informal Learning and Mathematics and Science Competitions

Efforts to promote mathematics and science among students typically target schools and focus on curricula, teacher training and strengthening the mathematics and science pipeline. Yet, even though school is a key context for mathematics and science engagement, learning opportunities outside of school make a significant contribution to mathematics and science education as well. Furthermore, they offer adolescents the opportunity to specialize according to their emerging

interests during a crucial phase of their development. Informal mathematics and science learning experiences, such as family conversations, visiting museums, meeting scientists, watching videos, playing games, and participating in clubs and competitions (Bell, 2009; Rennie, 2014; Wellcome Trust, 2018), create opportunities for enhancing mathematics and science interest in a manner fitting a student's personal preferences (Dabney et al., 2012; Rennie, 2014; Sahin et al., 2015; Venville, Rennie, Hanbury, & Longnecker, 2013). The importance of informal mathematics and science learning projects is underlined by the extent to which governments provide support for them. Initiatives such as Science Learning+ and the CoM'n'Play-Science project, for example, are government-funded projects that support informal mathematics and science learning experiences and investigate the impact of these experiences in Europe and worldwide (European Commission, 2018a; Wellcome Trust, 2018).

4.2.1 Targeting talented students: Mathematics and science competitions

Some informal mathematics and science learning activities specifically target interested, talented, or gifted students. Since it is practically impossible to cover all subjects in depth, schools often fail to meet talented students' needs (Reis & Renzulli, 2010). For this group of students special enrichment activities such as academic competitions can be stimulating challenges that offer additional support and foster interests. Examples of mathematics and science competitions are a vast variety of fairs and Olympiads at different grade levels and for specific subjects, in which students can win medals, trophies, and scholarships. Generally, they aim to identify and encourage interested and talented students, provide networking opportunities, and promote mathematics and science at large (e.g., European Commission, 2018b; International Biology Olympiad, 2017; International Mathematical Olympiad, 2017; Youth Science Canada, 2020). Mathematics and science fairs are competitions in which contestants present a science, technology, engineering or math project of their own choosing. Annually, numerous regional, national and international mathematics and science fairs are organized around the world for students of different grade levels (e.g., BT, 2018; Eskom, 2018; European Commission, 2018b; SSEF, 2018; Youth Science Canada, 2020). For instance, each year during the Intel International Science and Engineering Fair, the world's largest international science fair, about 1,800 students from over 75 countries present a project in one of 22 different categories. Contestants of this fair are selected from millions of students worldwide through qualification in an affiliated local or regional science fair (Society for Science & the Public, 2018).

Mathematics and Science Olympiads are annual national or international competitions in which students compete against each other in one or more domains. In international settings, each of the participating countries is represented by a four- to six-member team which competes in

theoretical and, in most competitions also, practical tasks. For the selection of the national team, many countries organize a national qualification competition. In this competition, interested students from all over the country take part in one or more theoretical tests, from which the best performing participants are selected for the national team (Petersen & Wulff, 2017; Verna & Feng, 2002).

4.2.2 Career advancement through participation in mathematics and science competitions?

By generally promoting mathematics and science whilst at the same time targeting talented students, fairs and competitions are organized to take place at possibly career-defining moments in the lives of the participating students. During adolescence, students take inventory of their strengths and interests and specialize accordingly. Thereby, evidence points towards career decisions forming starting from the age of nine (Auger, Blackhurst, & Wahl, 2005) and continuing during secondary school and course selection (Bandura, Barbaranelli, Caprara, & Pastorelli, 2001). Consequently, junior science Olympiads target junior high school students still in the process of advanced course selection, whereas senior science Olympiads generally target senior high school students. Thus, the vast majority of adolescents participating in mathematics and science fairs or Olympiads still have numerous important career choices ahead of them, which are potentially influenced by their participation in mathematics and science competitions. In accordance with this, numerous studies showed that participation in a mathematics or science competition resulted in participants' higher probability of pursuing a successful mathematics or science career (Campbell & O'Connor-Petruso, 2008; Campbell & Walberg, 2011; Eremin & Gladilin, 2013; Gordeeva, Osin, Kuz'menko, Leont'ev, & Ryzhova, 2013; Marsa, 1993; Sahin, 2013; Sahin et al., 2015; Schmidt, 2014; Wirt, 2011; Wu & Chen, 2001). Furthermore, participation in mathematics and science competitions has been found to have a positive influence on students' mathematics and science interests, self-beliefs, and identification (Jaworski, 2013; Mitchell et al., 2011; O'Kennedy et al., 2005; Wu, 1996). The potential of mathematics and science competitions has been acknowledged by governments from around the world that are providing financial and political support (Australian Science Innovations, 2018; European Commission, 2018b; Petersen & Wulff, 2017; SSEF, 2018; Youth Science Canada, 2020).

4.3 Gender Differences in Participation and Achievement in Mathematics and Science

Gender differences in mathematics and science interest emerge in early childhood (Cvencek et

al., 2011; Leibham et al., 2013). Around early adolescence gendered patterns arise, concurrent with the development of gender identity and adult gender roles (Bandura et al., 2001; Calabrese Barton et al., 2013; Eccles & Roeser, 2011; Kurtz-Costes, Rowley, Harris-Britt, & Woods, 2008). It is around this time that educational and occupational interests begin to take shape, resulting in a differential participation in, and enthusiasm for in-school and out-of-school mathematics and science learning. Subsequently, during advanced course selection in secondary education, gender differences in participation in mathematics and science education become clear (UNESCO, 2017). Thereby, two patterns are of particular importance: (a) Gender participation varies across subjects. Biology courses generally tend to attract more females, whereas males seem to have a stronger propensity towards physics. Gender participation also varies (b) across educational levels, i.e., from secondary to tertiary education and more advanced levels such as doctorate studies. For example, in tertiary physics education, females earn only 18% of all U.S., and 27% of all European bachelor degrees (Eurostat, 2018a, Eurostat, 2018b; National Science Board, 2018). Since participation in the different mathematics and science subjects varies by gender, gender also seems to be an influential factor in adolescents' career decision making. Cultural beliefs, but also differences in competitiveness, have been found to influence the early career decisions of men and women differently (Buser, Niederle, & Oosterbeek, 2012; Correll, 2001), making it evident that gender plays a role in career decision making. Mathematics and science competitions are one means of promoting mathematics and science careers, and are offered during a critical phase of adolescent development. Therefore, questions arise whether participation and achievement in these competitions is also gendered, and whether they contribute to gender equity or rather to inequity.

4.4 The Current Study

As evident in the previous sections, participation and excellence in mathematics and science is highly gendered, with women underrepresented in science (e.g., chemistry, physics) and increasingly underrepresented the higher the educational level. At the same time, we saw that mathematics and science competitions have a positive effect on students' mathematics-related and science-related interests and attitudes, and that they are offered during the critical life phase in which adolescents make course and, ultimately, career decisions.

While the role of gender in science has been approached based on different and highly elaborate paradigms (for instance in sociological or gender equity research, often with a focus on gendered access to science learning opportunities and individual narratives in female adolescents' construction of identity, or in psychological and educational research, which is often quantitative and variable-centered, with an emphasis on identifying parameters manipulable for solving the

problem; see also Brotman and Moore, 2008), we chose none of these paradigms as a basis for our review of studies on gender and science competitions. The reason for doing so is that we needed to account for the fact that—theoretically and empirically—the study of science competitions is underdeveloped; hence, choosing a theoretical approach prior to our literature search runs the risk of seriously biasing our findings. Thus, we selected studies and summarized their findings on gender disparities in science competitions independently from the respective theoretical approaches in these studies. In a final step, we review which theoretical frameworks guided the publications in our selection, as well as their implications on the general study of the role of gender in science competitions and their potential to promote gender equity in mathematics and science.

In sum, the following research questions are addressed in this review:

1. To what extent is participation in mathematics and science competitions gendered?
2. To what extent is achievement in mathematics and science competitions gendered?
3. What variables explain participation and achievement in mathematics and science competitions? Do these variables influence males and females differently?
4. Which theoretical approaches are used to explain participation and achievement, and the role of gender in mathematics and science competitions?

In answering these questions the current study joins two issues thus far addressed separately, namely (1) the gender gap in mathematics and science as a consequence of gender's influential role in adolescents' career decisions, and (2) mathematics and science competitions as preeminent informal learning opportunities aiming to actively promote mathematics and science and foster adolescents' career decisions. The present study contributes in furthering our understanding of the extent to which gender plays a role in adolescents' career decision making by analyzing the literature related to mathematics and science competitions. By reviewing previous studies (research questions 1 and 2), and addressing underlying mechanisms and research approaches in the study of gender and mathematics and science competitions (research questions 3 and 4), the current study advances the field in not only summarizing the status quo of knowledge, but also points out potential and fruitful avenues for future studies.

4.5 Identification and Analysis of Publications

Mathematics and science competitions have not been extensively investigated, yet we aimed to include a wide range of publications on the topic (see previous section). We initially searched the

Web of Science¹ database for all types of publications with the words “competition”, “Olympiad” or “science fair”, combined with “math”, “science”, “biology”, “chemistry”, or “physics” in the title. This search generated 560 publications. A search on the ERIC database² with the same search criteria generated an additional 247 publications. During an initial screening of all selected publications, we excluded 139 publications using the word “competition” in the context of biological systems, chemical reactions, or social situations, instead of academic competitions. We also excluded 100 publications on competitions that were not specifically on mathematics or science, such as engineering, political sciences, social sciences and sports competitions, as well as art or photography competitions in mathematics or science. We then continued examining all publications describing the general course of a competition (e.g., number of participating countries, winning countries, social program and excursions, future prospects, and sponsors), competition guidelines, and instructions for teachers, participants, caregivers, and judges on participation in a mathematics or science competition. Many of these publications also reported (parts of) test papers used in past Olympiads or descriptions of Mathematics and Science Fair projects. Here we searched for information on gender differences and potential variables and theories explaining success that would contribute to answering our research questions. We excluded another 297 publications based on these criteria.

We then read all publications describing research on mathematics and science competitions excluding publications with a focus on, for example, animal testing and teacher training. Publications on competitions that took place within the school curriculum were also excluded. In the end, 36 publications fit within the scope of our paper. Through cross-referencing within the selected publications, we found 10 further publications, making for a total final selection of 46 publications. Table 1 contains all selected publications, including sample, study design and the research question(s) to which they provide answers.

To answer the first two research questions on gender differences in participation and achievement we gathered data on gender compositions and accomplishments of national and international Olympiad teams through online competition databases and personal communication with Olympiad country coordinators.

¹ The actual search syntax for the Web of Science search was [TITLE: (competition OR olympiad OR “science fair”) AND TITLE: (math* OR scienc* OR biology OR chemistry OR physics)]

² The actual search syntax for the ERIC search was [title:((competition OR Olympiad OR fair) AND (mathematics OR science OR biology OR chemistry OR physics))]

Table 1. Selected publications on mathematical and science competitions

Publication	Peer review	Sample	Study design	RQ
Abernathy & Vineyard (2001)	Yes	460 Grade 7-12 science fair participants; 453 Grade 7-12 Science Olympiad participants	Cross-sectional quantitative	1
Adamson, Foster, Roark, & Reed (1998)	Yes	321 Grade 1-6 science fair participants; 168 Grade 1-6 non-science fair participants; 45 science fair judges; 125 parents of science fair participants	Cross-sectional quantitative	1,2
Baird et al. (1989)	No	462 Grade 7-12 Science Olympiad participants	Cross-sectional quantitative	3
Bellipanni (1994)	No	360 Grade 9-12 Science and Engineering Fair participants	Cross-sectional quantitative	3
Bencze & Bowen (2009)	Yes	233 Grade 7-12 Science Fair projects	Cross-sectional qualitative	3
Blankenburg, Höffler, Peters et al. (2016)	Yes	474 Grade 6 students: 199 intervention and science competition, 161 intervention and science tasks, 114 control group	Quasi-experimental intervention quantitative	3
Bunderson & Bunderson (1996)	Yes	2149 Grade 1-6 Science Fair projects; >18 teachers	Cross-sectional quantitative	1
Campbell & Feng (2010)	Yes	190 Mathematics, Physics, Chemistry Olympiad participants	Cross-sectional quantitative	3,4
Campbell & O'Connor-Petruso (2008)	No	190 Mathematics, Physics, Chemistry Olympiad participants; Parents of participants	Cross-sectional quantitative and qualitative	3
Chang & Lin (2017)	Yes	32 International Earth Science Olympiad participants (average age 16)	Cross-sectional quantitative	3,4
Cho & Lee (2001)	No	27 former Mathematical and Science Olympiad participants (age 17-31) and their parents; 321 gifted children (age 3-11)	Cross-sectional quantitative and qualitative	1,3
Czerniak (1996)	Yes	142 Grade 7-12 Science Fair participants	Cross-sectional quantitative	3
Czerniak & Lumpe (1996)	Yes	303 Grade 7-12 Science Fair participants	Cross-sectional quantitative	1,3,4
Dagani (1990)	No	4 International Chemistry Olympiad participants	Cross-sectional qualitative	3
Dionne, Reis, Trudel, Guillet, Kleine, & Hancianu (2012)	Yes	36 Science Fair participants, age 16-18	Cross-sectional quantitative	3
Edge (1989)	Yes	Physics Olympiad participants	Descriptive	3
Ellison & Swanson (2010)	Yes	~125,000 Grade 11-12 mathematics competition participants	Cross-sectional quantitative	2

Publication	Peer review	Sample	Study design	RQ
Ellison & Swanson (2012)	Yes	3,105 schools of mathematics competition participants	Cross-sectional quantitative	3
Ellison & Swanson (2016)	Yes	3,105 schools of mathematics competition participants	Cross-sectional quantitative	3
Feng, Campbell, & Verna (2002)	Yes	15 former Math, Chemistry, Physics Olympiad participants, age 22-42	Cross-sectional qualitative	3
Finnerty (2013)	No	48 Grade 5-9 Science Fair participants; 12 science teachers	Quasi-experimental intervention qualitative and quantitative	1,3
Fisanick (2010)	No	60 Grade 6-10 teachers that sponsored students in a Science Fair	Cross-sectional quantitative	3,4
Greenfield (1995)	Yes	30 years of Grade 7-12 students and school Science Fair data	Cross-sectional quantitative	1
Grinnell, Dalley, Shepherd, & Reisch (2018)	Yes	64 Grade 9-12 Science Fair participants; 267 undergraduate and 1st year graduate science students	Cross-sectional quantitative and qualitative	3
Harpole & Gifford (1985)	No	435 university physics competition participants	Cross-sectional quantitative	2,3
Höffler et al. (2017)	Yes	574 Grade 7-10 students: 133 Science Olympiad participants, 137 Olympic training participants, 304 control group	Cross-sectional quantitative	1,3
Jackson (1995)	No	104 Science Fair winners; 170 Science Fair non-winners	Cross-sectional quantitative	3
Jones (1991)	Yes	759 Grade 6-8 Science Fair and Olympiad participants; 1,243 grade 9-12 Science Fair and Olympiad participants	Cross-sectional quantitative	1,3
Lawton & Bordens (1995)	No	1319 Grade 1-12 Science and Engineering Fair participants; 338 grade 12 Science and Engineering Fair participants	Cross-sectional quantitative and qualitative	1
Leder, Pederson, & Pollard (2003)	No	2,520 Mathematical Olympiad items (questions) answered by Grade 7-12 students	Cross-sectional quantitative	2
Leder & Taylor (1995)	Yes	389,400 Mathematical Olympiad participants	Cross-sectional quantitative	1,2
Lengfelder & Heller (2002)	Yes	235 former Mathematical, Physics, Chemistry Olympiad participants, age 19-42	Cross-sectional quantitative and qualitative	1,2,3
Longo (2012)	No	113 Grade 7-8 students receiving Science Fair and inquiry program; 116 grade 7-8 students receiving direct science instruction	Quasi-experimental intervention quantitative	3

Publication	Peer review	Sample	Study design	RQ
McDonough (1995)	No	50 Science Fair participants, age 11-12	Cross-sectional quantitative	3
Nick (2017)	No	Chemistry Olympiad participants	Descriptive	1
Oliver & Venville (2011)	Yes	69 Science Olympiad participants, age 15-17	Cross-sectional quantitative	1
Petersen & Wulff (2017)	Yes	Physics Olympiad participants	Descriptive	1,3
Pyle (1996)	Yes	22 Science and Engineering Fair participants	Cross-sectional qualitative	3
Sahin, Gulacar, & Stuessy (2015)	Yes	172 International Sustainable World Energy, Engineering, and Environment Project Olympiad participants, age 14-20	Cross-sectional quantitative	1
Sonnert, Sadler, & Michaels (2013)	Yes	321 Grade 9-12 Science and Engineering Fair participants	Cross-sectional quantitative	1,2,3
Stang, Urhahne, Nick, and Parchmann (2014)	Yes	87 Grade 10-13 Biology and Chemistry Olympiad participants	Cross-sectional quantitative	2,3,4
Urhahne et al. (2012)	Yes	52 Grade 10-13 Chemistry Olympiad participants	Cross-sectional quantitative	2,3,4
Verna & Feng (2002)	Yes	83 former Chemistry Olympiad participants, age 16-34; 102 parents	Cross-sectional quantitative and qualitative	1,3
Wu (1996)	Yes	36 former Mathematical Olympiad participants and their parents	Cross-sectional quantitative and qualitative	3
Wu & Chen (2001)	Yes	31 former Chemistry and Physics Olympiad participants, age 18 to 24; 29 parents	Cross-sectional quantitative and qualitative	3
Wulff, Hazari, Petersen, and Neumann (2018)	Yes	30 Physics Olympiad participants	Quasi-experimental intervention quantitative	3

Note. RQ = research question; 1 = gender differences in participation; 2 = gender differences in achievement; 3 = variables explaining participation and achievement; 4 = theories explaining participation and achievement.

4.6 Results

4.6.1 Gender Differences in Mathematics and Science Competition Participation

According to the publications in our selection, on a national level no large gender differences

exist in overall participation rates of Mathematics and Science Fairs and Mathematical and Science Olympiads. However, when subdividing according to subjects, females clearly preferred biology topics whereas males preferred physics related topics. On an international level, on the other hand, females were found grossly underrepresented in all Mathematical and Science Olympiads with the exception of the Biology Olympiad.

Mathematics and Science Fair participation rates

Male and female participation rates in Mathematics and Science Fairs were about equal, but males mostly chose physics projects whereas females generally preferred biology. Seven studies mentioned overall male and female participation rates in Mathematics and Science Fairs. Six publications, all describing U.S. fairs (two first- to sixth-grade, two fifth- to ninth-grade, and two for seventh- to twelfth-grade competitions), reported an equal share of male and female participants (Abernathy & Vineyard, 2001; Adamson et al., 1998; Bunderson & Bunderson, 1996; Czerniak & Lumpe, 1996; Finnerty, 2013; Jones, 1991). Only one publication on a U.S. Science and Engineering Fair for students from Grade 6 to 12 mentioned more female than male participants (Abernathy & Vineyard, 2001; Sonnert et al., 2013).

Not all publications subdivided participation rates into subject areas; the six that did (spanning Grades 1 to 12) all reported that females mostly preferred projects about biology or life science (Adamson et al., 1998; Bunderson & Bunderson, 1996; Greenfield, 1995; Jones, 1991; Lawton & Bordens, 1995; Sonnert et al., 2013). Males in all but one publication (Adamson et al., 1998) preferred physical science projects. Furthermore, in the aforementioned U.S. Science and Engineering Fair (Sonnert et al., 2013), no significant gender differences were found for biochemistry, chemistry, math and physics projects.

In sum, Mathematics and Science Fairs seem to attract female and male adolescents alike, yet as expected clear differences exist according to subject area, with females preferring topics regarding biology and life sciences, and males preferring physics topics.

Mathematical and Science Olympiad participation rates

Many Mathematical and Science Olympiads start with a national competition in which achievement determines participant selection for the upcoming international competition. Overall participation rates of national Mathematical and Science Olympiads did not show striking gender differences, although females mainly chose biology topics. On the international level, however, we found dramatically low female rates from 0% to 14% in the Mathematical, Chemistry, and Physics Olympiads. This was not only true for male-preferred topics; a gender gap in the international Biology Olympiad, albeit smaller in comparison to the other Olympiads, could also be observed.

On the national level, participation rates in Mathematical and Science Olympiads are comparable

to those of Mathematics and Science Fairs. Female participation rates in U.S. Science Olympiads, for instance, were around 40% (Abernathy & Vineyard, 2001; Jones, 1991). Participation rates in the Australian Science Olympiad (for students age 15 to 17) were reported according to different subjects; similar to the Mathematics and Science Fairs, females were well represented in the Biology Olympiad, but underrepresented in the Physics Olympiad (Oliver & Venville, 2011). Furthermore, in the Australian Mathematical Olympiad from Grade 7 to 10 more female than male students took part, whereas the majority of the Grade 11 and 12 participants was male (Leder & Taylor, 1995).

Compared to national Olympiads, female rates at international Olympiads are far lower. Petersen and Wulff (2017) and Nick (2017) describe female rates dramatically declining during the national selection rounds of the German Physics and Chemistry Olympiad, ultimately resulting in female rates between 0% and 14% (*Mdn* = 8.5%) in international Mathematical, Physics, and Chemistry Olympiads (Cho & Lee, 2001; Ellison & Swanson, 2010; International Mathematical Olympiad, 2018; Lengfelder & Heller, 2002; Petersen & Wulff, 2017; Verna & Feng, 2002). Differences could be observed depending on the topic of the Olympiad, the country delegating the team, and the year in which the Olympiad took place (see Appendix A). For instance, at an international level we found female rates to be higher in Biology Olympiads compared to Mathematical, Physics, and Chemistry Olympiads (for example 37% and 55% female rates in the 2016 international biology competition).

Table 2 gives an exemplarily overview of the gender compositions of the Finnish, German, Latvian, and U.S. teams³ that participated in the international Biology, Chemistry, and Physics Olympiads from 2008 to 2017. Although female underrepresentation exists in all three Olympiads, this is particularly pronounced in the Chemistry and Physics Olympiad.

4.6.2 Gender Differences in Mathematics and Science Competition Achievement

Nine systematically selected publications and four websites reported information on achievements in mathematics and science competitions broken down by gender. We found no gender differences at the Mathematics and Science Fairs, whereas gender differences were clearly present at the Olympiads. Thereby, differences in the Biology Olympiad were smaller than in the Mathematical, Physics and Chemistry Olympiad.

Some publications reported no gender differences in achievement (for example in three U.S.

³ Teams were selected based on data availability and national gender differences in mathematics and science education. In the United States and Germany males significantly outperform females in both mathematics and science (Martin, Mullis, Foy, and Hooper (2016); OECD (2016). In Finland and Latvia females significantly outperform males in science (OECD, 2016).

Science Fairs for students from Grades 1 to 12 and in the German Mathematical, Physics, Chemistry, and Biology Olympiad; (Adamson et al., 1998; Lengfelder & Heller, 2002; Sonnert et al., 2013; Stang et al., 2014).

Table 2. Gender composition of different international science Olympiad teams

Selection	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	Total (%)
Finland											
IBO											
Male	4	2	4	3	4	2	1	3	4	0	27 (68)
Female	0	2	0	1	0	2	3	1	0	4	13 (33)
IChO											
Male	3	4	4	3	3	4	4	3	3	4	35 (88)
Female	1	0	0	1	1	0	0	1	1	0	5 (13)
IPhO											
Male	5	5	5	5	5	5	5	5	5	5	50 (100)
Female	0	0	0	0	0	0	0	0	0	0	0 (0)
Germany											
IBO											
Male	3	2	1	4	1	1	3	3	4	2	24 (60)
Female	1	2	3	0	3	3	1	1	0	2	16 (40)
IChO											
Male	4	4	4	3	4	4	4	4	4	4	39 (98)
Female	0	0	0	1	0	0	0	0	0	0	1 (3)
IPhO											
Male	5	5	5	4	5	5	5	5	5	4	48 (96)
Female	0	0	0	1	0	0	0	0	0	1	2 (4)
Latvia											
IBO											
Male	2	2	3	1	4	4	1	1	2	3	23 (58)
Female	2	2	1	3	0	0	3	3	2	1	17 (43)
IChO											
Male	3	3	4	4	4	3	4	4	3	4	36 (90)
Female	1	1	0	0	0	1	0	0	1	0	4 (10)
IPhO											
Male	5	5	5	5	5	5	4	5	5	5	49 (98)
Female	0	0	0	0	0	0	1	0	0	0	1 (2)
United States											
IBO											
Male	3	4	3	4	3	4	1	2	4	4	32 (80)
Female	1	0	1	0	1	0	3	2	0	0	8 (20)
IChO											
Male	4	3	3	4	4	4	4	4	4	2	36 (90)
Female	0	1	1	0	0	0	0	0	0	2	4 (10)
IPhO											
Male	4	5	5	5	5	5	4	4	4	5	46 (92)
Female	1	0	0	0	0	0	1	1	1	0	4 (8)

Note. IBO = International Biology Olympiad; IChO = International Chemistry Olympiad; IPhO = International Physics Olympiad.

Yet most data on achievement in mathematics and science competitions showed considerable gender differences in favor of males. For instance, in a 1985 U.S. university physics competition, gender was found to be a predictor for physics achievement (Harpole & Gifford, 1985). Furthermore, test performance of German female 10th to 13th grade students was lower than that of male students in the penultimate selection round of the 2011 Chemistry Olympiad (Urhahne et al., 2012). Also in a 2007 U.S. mathematics competition (Grade 11 and 12), only 20% of all high scoring participants were female (Ellison & Swanson, 2010). Furthermore, Table 3 presents worldwide gender differences in final competition scores at the 2016 International Biology Olympiad, the 2016 International Junior Science Olympiad, and the 2014, 2015 and 2016 International Mathematical Olympiads. Female participants scored significantly lower than male participants in all Olympiads, with medium effect sizes ranging from $d = 0.35$ to 0.70 (International Biology Olympiad, 2018b; International Mathematical Olympiad, 2018).

Table 3. t-test results comparing male and female achievements in different international science Olympiads

Competition	Male			Female			t-test	Effect size (d)
	n	M	SD	n	M	SD		
IBO 2016	158	52.55	18.33	94	46.41	16.29	2.68**	0.35
IJSO 2016	129	82.19	10.01	38	76.33	8.92	3.24**	0.60
IMO 2016	531	15.58	9.56	71	8.82	6.92	7.36***	0.70
IMO 2015	525	13.40	8.25	52	8.79	7.62	3.87***	0.63
IMO 2014	504	16.68	9.46	56	10.52	8.73	4.66***	0.66

Note: N = Number of participants in IBO and IMO and number of medal winners in IJSO; M = Mean; SD = Standard Deviation; IBO = International Biology Olympiad; IJSO = International Junior Science Olympiad; IMO = International Mathematical Olympiad; IBO and IJSO scores range from 0 to 100; IMO scores range from 0 to 42.

** $p < .01$. *** $p < .001$.

A detailed look at the publications revealed that gender differences in achievement varied with the age of the students. For instance, data on performance in the Australian Mathematical Olympiad for Grades 7 to 12 students from 1987 to 2000 showed more pronounced gender differences in Grades 10 to 12 than in Grades 7 to 9. Also, there seemed to be a progression over time as these gender differences in favor of males were decreasing (Leder, Pederson, & Polland, 2003; Leder & Taylor, 1995).

Table 4 shows the medal distribution of Finnish, German, Latvian and U.S. male and female participants in the Biology, Chemistry and Physics Olympiads from 2008 to 2017. Overall, male participants outperformed female participants even though gender differences were generally smallest in the Biology Olympiad and largest in the Physics Olympiad. Gender differences appeared smaller in the United States and Germany in comparison to Finland and Latvia.

Table 4. Total medal distribution in different international science Olympiad teams from 2008 to 2017 (percentage of total male or female participants)

Selection	Gold	Silver	Bronze	No medal
Finland				
IBO				
Male	0 (0)	2 (7)	21 (78)	4 (15)
Female	0 (0)	1 (8)	7 (54)	5 (38)
IChO				
Male	0 (0)	2 (6)	16 (46)	17 (49)
Female	0 (0)	0 (0)	1 (20)	4 (80)
IPhO				
Male	0 (0)	7 (14)	15 (30)	28 (56)
Female	0 (n.a.)	0 (n.a.)	0 (n.a.)	0 (n.a.)
Germany				
IBO				
Male	8 (33)	10 (42)	6 (25)	0 (0)
Female	3 (19)	11 (69)	2 (13)	0 (0)
IChO				
Male	6 (15)	14 (36)	18 (46)	1 (3)
Female	0 (0)	0 (0)	1 (100)	0 (0)
IPhO				
Male	8 (17)	28 (58)	12 (25)	0 (0)
Female	0 (0)	0 (0)	1 (50)	1 (50)
Latvia				
IBO				
Male	0 (0)	3 (13)	17 (74)	3 (13)
Female	0 (0)	1 (6)	4 (24)	12 (71)
IChO				
Male	1 (3)	7 (19)	17 (47)	11 (31)
Female	0 (0)	0 (0)	2 (50)	2 (50)
IPhO				
Male	0 (0)	3 (6)	12 (24)	34 (69)
Female	0 (0)	0 (0)	0 (0)	1 (100)
United States				
IBO				
Male	30 (94)	2 (6)	0 (0)	0 (0)
Female	7 (88)	1 (13)	0 (0)	0 (0)
IChO				
Male	15 (42)	18 (50)	3 (8)	0 (0)
Female	0 (0)	2 (50)	2 (50)	0 (0)
IPhO				
Male	28 (61)	17 (37)	1 (2)	0 (0)
Female	1 (25)	2 (50)	1 (25)	0 (0)

Note. IBO = International Biology Olympiad; IChO = International Chemistry Olympiad; IPhO = International Physics Olympiad.

4.6.3 Variables Used to Explain Participation and Achievement in Mathematics and Science Competitions

Thirty-five publications explicitly investigated one or more variables and the extent to which they explained participation and achievement. Table 5 shows these variables organized into eight main categories following the expectancy-value framework (Eccles et al., 1983) as utilized by Urhahne et al. (2012). According to this framework we identified a broad array of social and cultural factors (gender roles and stereotypes, social environment, person and family characteristics, school type and facilities, and previous experiences) that influence a participant's task-specific beliefs (goals and self-schemata), which in turn affect expectancies and values (competition values and expectancy of success). As can be observed in Table 5, by far most publications report on social and cultural factors. Campbell and Feng (2010) for instance, found the most successful Mathematics, Physics and Chemistry Olympiad participants to be motivated by a conducive home atmosphere. Remarkably fewer studies reported on task-specific beliefs, expectancies, and values. As an example among these publications, Dionne et al. (2012) found interest, self-efficacy, perceived gratification, social aspects, and acquired learning strategies to be motivators for participation in a Canadian science fair. In general, all variables, with a few exceptions, had a positive influence on participation and achievement in mathematics and science competitions.

Some variables influenced male and female participants differently. The effect of a participant's social environment for example, was strongly influenced by cultural stereotypes and gender roles (McGarty et al., 2002). In all of the publications we found, gender roles and stereotypes had a negative influence on female participation and achievement, and a neutral or positive influence on male participation and achievement (Feng et al., 2002; Jones, 1991; Lengfelder & Heller, 2002; Petersen & Wulff, 2017; Verna & Feng, 2002). Additionally, home atmosphere as well as parental, teachers' and peers' beliefs and behaviors, can also have a negative effect on females, when influenced by gender stereotypes.

4.6.4 Theories Used to Explain Participation and Achievement in Mathematics and Science Competitions

In general, it was remarkable that the majority of empirical investigations on effects of mathematics and science competitions did not—explicitly or implicitly—refer to a theoretical framework. That is, most of these investigations did not assume an underlying theoretical mechanism that guided the research. Most studies either, only reviewed prior empirical findings and set up a similar investigation rationale and model (e.g., Ellison & Swanson, 2010; Lawton & Bordens, 1995; Sonnert et al., 2013), or did not specify any theoretical approach (e.g., Petersen

& Wulff, 2017; Verna & Feng, 2002).

Table 5. Variables explaining participation and achievement at mathematical and science Olympiads

Variable	Source
Gender roles and stereotypes	
Gender stereotypes	Jones (1991) ^P ; Lengfelder & Heller (2002) ^P ; Petersen & Wulff (2017) ^P
Social roles and expectations	Feng et al. (2002) ^P
Stereotypes about mathematics and science	Feng et al. (2002) ^P ; Verna & Feng (2002) ^a
Social environment	
Home atmosphere	Campbell & Feng (2010) ^a ; Campbell & O'Connor-Petruso (2008) ^a ;
Parental beliefs and behaviors	Bellipanni (1994) ^a ; Cho & Lee (2001) ^P ; Czerniak (1996) ^a ; Dagani (1990) ^a ; Feng et al. (2002) ^P ; McDonough (1995) ^P ; Pyle (1996) ^a
Teacher beliefs and behaviors	Cho & Lee (2001) ^P ; Finnerty (2013) ^P ; Fisanick (2010) ^P ; Pyle (1996) ^a ; Sonnert et al. (2013) ^a ; Verna & Feng (2002) ^a
Peer beliefs and behaviors	Verna & Feng (2002) ^a
Support from scientists	Bellipanni (1994) ^a ; Grinnell, Dalley, Shepherd, & Reisch (2018) ^P ; Jackson (1995) ^a
Social and cultural capital	Bencze & Bowen (2009) ^P
Person and family characteristics	
GPA, ACT, grades	Czerniak & Lumpe (1996) ^P ; Harpole & Gifford (1985) ^a ; Höffler et al. (2017) ^P
Aptitude	Dagani (1990) ^a
Socioeconomic status	Bencze & Bowen (2009) ^P ; Campbell & Feng (2010) ^a ; Campbell & O'Connor-Petruso (2008) ^a ; Ellison & Swanson (2012) ^a ; Jackson (1995) ^a ; Wu (1996) ^P ; Wu & Chen (2001) ^P
School type and facilities	
Private school	Baird et al. (1989) ^a ; Czerniak & Lumpe (1996) ^P
Excellent mathematics or science program	Dagani (1990) ^a ; Ellison & Swanson (2016) ^a ; Harpole & Gifford (1985) ^a ; Longo (2012) ^a
Availability of extracurricular activities	Edge (1989) ^a
Previous experiences	
Participation in mathematics or science program	Baird et al. (1989) ^a ; Blankenburg, Höffler, Peters et al. (2016) ^P ; Czerniak & Lumpe (1996) ^P ; Dagani (1990) ^a ; Urhahne et al. (2012) ^a ; Wu (1996) ^P ; Wu & Chen (2001) ^P ; Wulff et al. (2018) ^P
Prior knowledge	Baird et al. (1989) ^a ; Cho & Lee (2001) ^P ; Edge (1989) ^a
Goals and self-schemata	
Goals	Höffler et al. (2017) ^P
Self-beliefs	Blankenburg, Höffler, Peters et al. (2016) ^P ; Chang & Lin (2017) ^a ; Czerniak (1996) ^a ; Czerniak & Lumpe (1996) ^P ; Dionne et al. (2012) ^P ; Höffler et al. (2017) ^P ; Lengfelder & Heller (2002) ^P ; Wu (1996) ^P ; Wu & Chen (2001) ^P
Interests and incentives	Blankenburg, Höffler, Peters et al. (2016) ^P ; Czerniak (1996) ^a ; Czerniak & Lumpe (1996) ^P ; Dagani (1990) ^a ; Dionne et al. (2012) ^P ; Edge (1989) ^a ; Jackson (1995) ^a ; Stang et al. (2014) ^a
Competition values	Dionne et al. (2012) ^P
Expectancy of success	Stang et al. (2014) ^a

Note. ^aVariable explaining achievement. ^PVariable explaining participation.

The authors explicitly referred to, and drew on, a clear and established theoretical approach to explain participation and achievement in mathematics and science competitions in only five publications. Chang and Lin (2017) used the big-fish-little-pond-effect (Marsh, 1987) as the main theory in their study, Stang et al. (2014) as well as Urhahne et al. (2012) based their research on Eccles' (1983) expectancy-value model of achievement motivation, Campbell and Feng (2010) explained their results through the Munich Model of Giftedness (Heller, 1991), whereas Czerniak and Lumpe (1996) and Fisanick (2010) predicted students' attitudes by referring to the theory of planned behavior (Ajzen, 1991).

Social-cognitive theory and big-fish-little-pond-effect

One major theoretical approach in educational psychology was introduced by Bandura in 1989 as the social-cognitive theory. It emphasizes that an individual's achievement outcomes do not develop in isolation, but are dependent on, and are constantly interacting with the individuals' predispositions and the social environment. Within this framework, the big-fish-little-pond effect (BFLPE) predicts that students in high average ability schools have lower academic self-concepts than students with similar academic abilities in a lower ability school (Marsh, 1987). The BFLPE is based on the assumption that students assess their achievements within their personal frame of reference by comparing them to the ability level of their group. This causes students with comparable abilities to have disparate self-concepts. Self-concepts in turn, are consequently to the social-cognitive theory, strongly related to an individual's achievement (Denissen et al., 2007). A wide range of studies have not only corroborated the BFLPE, but also found this positive relation of self-concept with achievement in mathematics and science (Antunes & Fontaine, 2013; Cvencek et al., 2015; Jansen et al., 2014; Lee & Kung, 2018; Ma & Kishor, 1997; Sahranavard, Hassan, Elias, & Abdullah, 2012; Wang, Oliver, & Staver, 2008). Guided by this theoretical framework, Höffler et al. (2017) and Chang and Lin (2017) found that also within a Science Olympiad reference framework, participants' academic self-concept was significantly correlated with their academic achievement.

Expectancy-value theory of achievement motivation

Eccles' (1983) expectancy-value theory of achievement motivation aims to explain the mechanism behind choices and achievements, which allows for systematic analysis of concepts underlying decision-making (Eccles, 1994; 2005; Wigfield & Eccles, 2000). According to the theory achievement and achievement-related choices are influenced by achievement-related expectations and values, which in turn are shaped by a student's cultural environment, socializers' beliefs and behaviors, personal and family characteristics, and previous experiences. Urhahne et al. (2012) used the expectancy-value theory of achievement motivation to explain female underrepresentation in the Chemistry Olympiad and found large gender differences in

favor of males, in parental support, motivation, and emotion. According to the model, these expectations and values are important predictors for performance, thereby explaining the large and significant gender difference in test performance and subsequent female underrepresentation in the Olympiad. Furthermore, Stang et al. (2014) tested several factors that function as predictors of achievement according to the expectancy-value theory and were able to identify boredom and expectancy of success as predictors for participants' success at the Biology and Chemistry Olympiad, respectively.

Munich model of giftedness

The Munich model of giftedness was designed by Heller (1991) in order to identify and promote gifted students. The multifactorial model describes the interrelationship of potential for giftedness and actual performance within a framework of non-cognitive and environmental moderators (Heller, Perleth, & Lim, 2005). Campbell and Feng (2010) used this model to emphasize the importance of the learning environment created by parents of Mathematics and Science Olympiad participants and found at-home learning environment to be a significant predictor of success.

Theory of planned behavior

The theory of planned behavior (Ajzen, 1991) postulates that individual belief-based factors play a role in influencing people's intentions and behaviors. According to the theory, behavioral beliefs, normative beliefs, and control beliefs interact with each other, affecting intention and subsequent human behavior. Czerniak and Lumpe (1996) used the theory of planned behavior to examine factors that predicted secondary school students' attitudes toward participating in a Science Fair and found participation in a gifted class, and normative beliefs, to be predictors of behavioral beliefs. Furthermore, behavioral beliefs, the requirement to complete a Science Fair project, and the parents' level of education, significantly predicted normative beliefs. In a similar vein, Fisanick (2010) investigated the role of teacher behavior in motivating students to participate in Science Fairs but found that these behaviors had no impact on students.

In sum, of these four theories, the theory of planned behavior was used to explain participation, whereas success during and after participation in a competition were explained within the other three theoretical frameworks.

4.7 Discussion and Implications

The present study offers a literature review on participation and achievement in mathematics and science competitions. We analyzed potential gender differences as well as variables and mechanisms explaining participation and achievement based on four research questions.

4.7.1 Gender Differences in Participation and Achievement

The initial two research questions of this review attempted to identify gender differences in mathematics and science competition participation and achievement. Overall participation and achievements in Mathematics and Science Fairs were equal for male and female participants, which is comparable with findings in secondary education (e.g., Bursal, 2013; Devine, Fawcett, Szűcs, & Dowker, 2012; Felson & Trudeau, 1991; Larson, Stephen, Bonitz, & Wu, 2013; Lee & Kung, 2018; OECD, 2016; Reilly, Neumann, & Andrews, 2015). In Mathematical and Science Olympiads on the other hand, we found large gender differences in favor of males in both participation and achievement that cannot be explained by typical gender differences in secondary school (OECD, 2016; UNESCO, 2017). However, since content levels at Mathematical and Science Olympiads are exceptionally high, we expect a large number of Olympiad participants to also be top performing students in school (Campbell & O'Connor-Petruso, 2008; Lengfelder & Heller, 2002). Following this train of thought, gender differences in Mathematical and Science Olympiads should be similar to gender differences found in the group of top performing students in mathematics and science education. For the top science performers, strikingly low female rates were reported among 12 to 19 year-old students in the United States and several other countries (Dimitrov, 1999; Fan, Chen, & Matsumoto, 1997; OECD, 2016; Reilly et al., 2015; Stewart et al., 2016). In Finland and Latvia on the other hand, no significant gender differences were found in science achievement among 15-year-old students in the 90th percentile group (OECD, 2016). More remarkably, Finland even had significantly more top performing females than males (OECD, 2016). This stands in contrast to our data that showed that Finnish and Latvian Biology, Chemistry, and Physics Olympiad teams consisted of fewer females than males (Table 2). These numbers suggest that low female participation rates in Mathematical and Science Olympiads cannot be explained by gender differences among regular or top performing students in mathematics and science education alone. We therefore assume that the role of gender, as well as the mechanisms explaining gender patterns, are different in informal learning opportunities in comparison to educational environments.

4.7.2 Gender-Mathematics and Gender-Science Stereotypes

In accordance with global findings on participation in secondary mathematics and science education (Martin et al., 2016; Mullis, Martin, Foy, & Hooper, 2016), we found that male participants in mathematics and science competitions mostly gravitate towards physics projects and competitions, whereas females favor biology. This dichotomy between biology and physics was also described by Jones (1991) in the context of a U.S. state-wide science competition. In his study Jones (1991) suggested that masculine associations with physics and feminine associations

with biology explain the uneven distribution of male and female participants. These associations related to the fields of mathematics and science are known as gender-mathematics and gender-science stereotypes, which are generally endorsed beliefs that males are naturally more talented and interested in mathematics and science than females (Cvencek et al., 2011; Cvencek et al., 2015; Farrell, Cochrane, & McHugh, 2015; Farrell & McHugh, 2017; Hyde & Linn, 2006; Liu et al., 2010; Nosek et al., 2007; Nosek et al., 2009; Smyth & Nosek, 2015; Spencer, Steele, & Quinn, 1999; Steffens & Jelenec, 2011).

Not only do gender-mathematics and gender-science stereotypes imply that males are more talented at mathematics and science, they also suggest that these fields are generally considered to be masculine (Kelly, 1985). The foundation of gender-mathematics and gender-science stereotypes can be partly explained by the perceived lack of communal goals in mathematics and science, which are more strongly endorsed by women than men (Diekman et al., 2010). Specifically, expectations about communal goals in mathematics, physics, chemistry, and biology could explain the uneven participation of females in these subjects and corresponding Olympiads (Diekman et al., 2017). The relationship between stereotypes and achievement was confirmed among secondary school students by Nosek et al. (2009) in a large-scale study among 34 countries: a country's average gender-science stereotype was found to predict gender differences in mathematics and science achievement. In addition, stronger gender-mathematics stereotypes were also associated with poorer mathematics performance in females (Song, Zuo, & Yan, 2016). In sum, gender-science stereotypes could not only explain low female participation rates in science competitions (i.e., in physics and chemistry), but also suggest that the mechanisms they trigger (e.g., stereotype threat; Deemer, Lin, & Soto, 2016) should adversely affect females but not males, thus resulting in lower achievement of females. Yet, even though we found clear achievement-related gender differences in the mathematical, physics and chemistry Olympiads, no study explicitly addressed or investigated the relation between gender stereotypes and gender differences in achievement in mathematics and science competitions.

Not only have stereotypes been found to influence achievement of secondary school students, they are also related to a student's self-concept: In mathematics, stronger gender stereotypical beliefs were found to correlate with weaker self-concepts in females than in males (Cvencek et al., 2011; Cvencek et al., 2015; Steffens et al., 2010).

Self-concept and achievement

In the wider context of social-cognitive theory (Bandura, 1989), students' mathematics and science self-concepts have been found to positively influence mathematics and science achievement. For instance, in a large-scale study Jansen et al. (2014) investigated biology-, chemistry-, and physics-specific self-concept among over 6,000 15-year-old German students

and found a substantial positive relation between self-concept and achievement for each of these subjects (see also Sahranavard et al., 2012; Wang et al., 2008). This was also found for mathematics (e.g., Antunes & Fontaine, 2013; Cvencek et al., 2015; Lee & Kung, 2018; Ma & Kishor, 1997). In line with these findings, several studies identified self-concept, among other self-beliefs, to be a variable that influences participation and achievement in mathematics and science competitions.

Resulting from gender stereotypes and in line with theoretical assumptions, among secondary school students gender differences in mathematics and science self-concept in favor of males are found (Jansen et al., 2014; Lee & Kung, 2018; Makwinya & Hofman, 2015; Manger & Eikeland, 1998; Nagy et al., 2010; Rinn, Miner, & Taylor, 2013; Sax, Kanny, Riggers-Piehl, Whang, & Paulson, 2015; Skaalvik & Skaalvik, 2004). These gender differences also existed in German and Singaporean top-performing students (Cvencek et al., 2015; Preckel et al., 2008). Accordingly, Höffler et al. (2017) found lower female than male self-concept for equally successful participants of a German junior Science Olympiad; hence, despite these young women getting tangible feedback of being equally able and successful, their self-concepts were still weaker than those of their male counterparts. Even though gender-science stereotypes were not addressed in this study, in light of the previously detailed findings we assume that even for these highly interested, gifted and successful young women, stereotypical beliefs still exert influence in subtle ways.

Interest and achievement

A third variable affecting participation and achievement in mathematics and science competitions was interest. A lack of mathematics and science interest among secondary school students could explain why females seem less keen than males to participate in mathematics and science related activities. In fact, in a PISA study among 15-year-old students from 70 countries, even though a majority of all students reported an interest and enjoyment in learning science, males tended to report a greater interest than females (OECD, 2016). In addition, male students participated in science-related activities such as attending a science club, reading science magazines, and visiting scientific websites twice as often as females (OECD, 2016).

4.7.3 Theoretical Frameworks Explaining Participation and Achievement

Against the background of gender science stereotypes and their pernicious effect on female—but not male—achievement, self-concept and interest, the lack of theoretical framing in most of the studies we reviewed was striking. The lack of theory possibly stifles systematic investigations and ultimately the addressing of the gender gap in mathematics and science competitions. From the four theories that were referred to in investigations on mathematics and science competitions, we suggest that Eccles' expectancy-value theory of achievement motivation would

be most suitable for explaining gender differences in mathematics and science competitions. Eccles' model aims to explain the mechanism behind choices and achievements, which allows for systematic analysis of concepts underlying decision-making (Eccles, 1994; 2005; Wigfield & Eccles, 2000); it thereby addresses and includes a complex and interdependent set of factors (on the individual, familiar and societal level) predicting individuals' beliefs of expectancy and value and thereby determining choices and achievement outcomes. It was initially designed to explain a person's expectations for success particularly in the field of mathematics, physics, and engineering but has been widely applied beyond these fields (Eccles, 2005). Most importantly, it has been used extensively to study the causes explaining female underrepresentation in mathematics and science (Eccles, 1994; Eccles, 2005; Eccles, 2011; Eccles & Wang, 2016). Considering the multiple determinants of gender differences in mathematics and science in general and in academic competitions, combining the expectancy-value theory and rich findings on (gender) stereotypes and the mechanisms they trigger (Ceci & Williams, 2011; Deemer et al., 2016; Leslie, Cimpian, Meyer, & Freeland, 2015; Marchand & Taasobshirazi, 2013; Spencer, Logel, & Davies, 2016), seems a promising method to advance research in this field.

4.7.4 Mathematical and Science Olympiad as Gender Equity Measures

The first academic Science Olympiad, aiming to identify and foster interested and talented students, was established in 1934 (Campbell, 2002). Even though social norms and values, especially regarding gender stereotypes, changed since then, Olympiads may not have changed accordingly. Rather, Olympiads seem to ingrain gender disparities because they (a) target students in their adolescence when adverse gender stereotypes have already taken effect, and (b) are designed for the promotion of talented students with an interest in mathematics and science. Consequently, Olympiads perpetuate already existing patterns instead of opposing them. In their current form, Olympiads do not seem suited to support gender equity, mainly because they were never developed with that purpose in mind. Whether they can be adapted to suit this purpose, or complemented by other mathematics and science measures that do stimulate gender equity, is an open question. Yet, irrespective of whether Olympiads contribute to gender equity or not, they could certainly benefit from attracting a wider and more diverse student audience.

4.7.5 Recommendations for Further Research and Limitations of the Current Study

In this review we determined female underrepresentation and underachievement in mathematics and science competitions, as well as various variables and models that explain participation and achievement. Still, several limitations make it hard for us to fully explain the mechanisms behind these gender differences. Since we expanded our scope to also include

literature not published in peer reviewed journals, we are unable to guarantee the quality of all reviewed publications. This also resulted in a relatively small number of theory-based studies. Furthermore, we included literature from all over the world, and even though we attempted to solely compare studies with similar educational conditions and age groups, cultural differences may have affected the studies' findings, especially when discussing stereotypes. Additionally, our decision to include all publications independent of publication date may have led to inaccurate comparisons since in the time that passed between the oldest and newest publication social gender roles may have changed, thereby influencing stereotypical beliefs. However, in the studies reviewed here, there are no indications regarding such a change.

4.7.6 Recommendations for Further Practice and Policy

A better understanding of the gender-mathematics and gender-science stereotypes could help improve conditions under which mathematics and science competitions foster females. Based on research on gender stereotypes in mathematics and science competitions and beyond, a strong assumption exists that these stereotypes adversely influence females in mathematics and science competitions. Since changing stereotypes on a societal level remains difficult, it seems more appropriate to first soften these beliefs at an individual level and in doing so, undermine their negative effects on women on a larger scale. In order to change individual or cultural stereotype endorsement, parents, teachers, or administrations could potentially strengthen young women's mathematics and science self-concept. Parents and teachers for example, could actively stimulate both males and females to take part in informal mathematics and science activities. Countries' gender mainstreaming policies could also support increasing rates of females in mathematics and science competitions, whilst simultaneously increasing the number of female role models. These measures on all different levels are important steps towards paving the road for interested girls to start their own successful journey in the fields of mathematics and science.

In conclusion, based on our findings several questions remain unanswered. Currently, research on mathematics and science competitions cannot fully explain the gender differences in participation and achievement, but considering the wider picture as detailed earlier, we cannot rule out negative effects of these competitions on gender equity in mathematics and science. To find answers to these questions we suggest both cross-sectional and longitudinal theory-based research on a selection of different national and international mathematics and science competitions with different age groups and in different countries. Especially longitudinal studies could give valuable input on the progression and interrelatedness of influential variables throughout the competitions. Additionally, young women trying to qualify for a mathematics or science competition are in many ways comparable to women worldwide choosing to pursue a

career in mathematics or science. This made us consider whether the mechanisms explaining female representation during a national selection competition are comparable to those in a mathematics or science career. In other words, could academic competitions serve as a possible prototype for a mathematics and science career? We would recommend a longitudinal evaluation of former successful and unsuccessful participants' study and career paths in order to get a better understanding of the predictive value of mathematics and science competitions. With more insight into the exact underlying mechanisms, additional substantiated and appropriate steps can be taken so that talented girls all over the world can compete on a level playing field, and become the Nobel Laureates of the future.

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Chapter 5

First Steps Toward Gender Equity in the Chemistry Olympiad: Understanding the Role of Implicit Gender-Science Stereotypes

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5.1 Introduction

“There are very few jobs that actually require a penis or vagina.

All other jobs should be open to everybody.”

– Florynce Kennedy, lawyer and activist (1916-2000)

In theory, nearly all professions are open to everyone nowadays. In reality, though, cultural beliefs about differences among the genders still create barriers in the pursuit of professions in various vocational fields. These gendered beliefs are associated with biased self-assessment, directing men and women towards gender-specific interests, studies, and vocations (Correll, 2001). It is well known that most scientific fields are culturally gendered. In those fields, gender-science stereotypes, common beliefs that science is more naturally the domain of men, are negatively linked with female representation (Hill et al., 2010; Miller et al., 2015). Additional culturally gendered phenomena are attitudes towards competitiveness and beliefs about competition. A multi-method study on boys’ and girls’ play by Lever (1987) described competitiveness as an important attribute of a masculine interaction style that encourages boys to be competitive from an early age. Consequentially, women are less inclined to engage in competitions than men are (Ahlgren & Johnson, 1979; Gupta et al., 2013) and men attribute more positive outcomes to competition than women do (Kesebir, Lee, Elliot, & Pillutla, 2019). At the interface of science and competition are the science Olympiads, worldwide academic competitions that aim to identify and encourage interested and talented secondary school students (e.g., International Biology Olympiad, 2018a; International Chemistry Olympiad, 2018; International Physics Olympiad, 2018). When participating in a science Olympiad—a typically masculine activity within a masculine environment—many girls find themselves in a particularly disadvantaged position. Not surprisingly, female secondary school students are underrepresented and underperforming in these competitions (Steegh, Höffler, Keller, & Parchmann, 2019). This is highly problematic in terms of gender equity, but also on a more practical level since taking part in a science Olympiad has been connected to the reinforcement of participants’ plans to pursue a major in science, technology, engineering, or mathematics (Cho & Lee, 2001; Sahin et al., 2015). A study by Campbell and Walberg (2011) showed that over fifty percent of 345 former U.S. math and science Olympiad participants earned a doctoral degree and many remained employed in academia after that. The reason many science Olympiads are supported by government funding (European Commission, 2018b; Wellcome Trust, 2018) is that they complement gifted education. Even though Olympiad participants’ chosen field of study and later career success seem to support this concept, they may, in fact, perpetuate gender inequity.

The current paper is part of the WinnerS-project (Garrecht, Bruckermann, & Harms, 2018; Garrecht, Eckhardt, Höffler, & Harms, 2020; Steegh et al., 2019; Wulff et al., 2018; Wulff, 2019), which aims to examine factors determining success and failure in academic competitions, as well as the impact of success and failure in students' cognitive and affective development and their respective career choices. This project monitored the development of successful and unsuccessful participants in three major senior science competitions: Biology, Chemistry, and Physics Olympiads. Similar research on factors predicting a career in science by Holmes, Gore, Smith, and Lloyd (2018) showed that especially female secondary school students without familial STEM influences were most unlikely to pursue a career in STEM. Furthermore, Kanny, Sax, and Riggers-Piehl (2014) reviewed literature of the past forty years explaining the gender gap in STEM majors and found it related to factors such as race and socioeconomic status, self-beliefs, values, family influences, and understandings and perceptions of STEM fields. Moreover, within the different STEM majors and vocations, research on gendered interests showed girls to be generally more interested in biology, whereas boys placed higher value on physics and chemistry (Buccheri, Gürber, & Brühwiler, 2011; Jugović, 2017; Krapp & Prenzel, 2011; OECD, 2016; Su & Rounds, 2015; UNESCO, 2015). Previous publications on science Olympiads also revealed that female participants are vastly underrepresented and outperformed by male participants, which is especially pronounced in the Chemistry and Physics Olympiads (Cho & Lee, 2001; International Biology Olympiad, 2018b; Lengfelder & Heller, 2002; Petersen & Wulff, 2017; Steegh et al., 2019; Verna & Feng, 2002). These competitions may appear adverse and frustrating to girls and therefore fail to attract them. This is a particularly grave problem since chemistry and physics communities could potentially benefit more from attracting girls than boys, who may be more inclined to enter these fields anyway. Moreover, male-dominated science events underscore existing gender-science stereotypes, thereby doing more harm than good in promoting gender equity in science.

Preliminary results in the WinnerS-project show that female participation rates dramatically decline over the course of the selection competition and that gender-science stereotypes play a crucial role, especially in the German Chemistry Olympiad. According to Eccles et al.'s (1983) expectancy-value model of achievement-related choices, these gender-science stereotypes negatively influence female self-beliefs and values (Bonnot & Croizet, 2007; Eccles, 2009; Ertl et al., 2017), which, in turn, negatively affect science and mathematics study and career decisions (Lane et al., 2012; Miller et al., 2015; Steffens et al., 2010).

Even though research on gender-science stereotypes is largely available and growing (e.g., Miller et al., 2015; Miller, Nolla, Eagly, & Uttal, 2018; Nosek et al., 2009), we are not aware of any studies on gender stereotypes in the context of academic science competitions. The present

paper investigates the role of gender-science stereotypes on representation and achievement in the Chemistry Olympiad, and offers suggestions on improving the promotion of science, particularly for female participants. We performed moderated mediation analysis to specify the effects of implicit gender-science stereotypes on continued participation and achievement via expectancy (self-concept) and value beliefs (topic interest). The Chemistry Olympiad could thereby potentially serve as a prototype for other informal learning opportunities to promote gender equity.

5.2 The Present Study

The Chemistry Olympiad, among numerous other informal learning opportunities, was designed to heighten participants' chemistry-related self-beliefs and interests. However, gender stereotypes, which are linked to female students' low expectancies and values in science, are also believed to play a role in chemistry competitions. Thus, we asked whether gender-science stereotypes are associated with differences between female and male participation and achievement in the Chemistry Olympiad, and, if so, whether the influence of these stereotypes is mediated by the participants' expectancies and values. The objective of this study is to utilize multi-group structural equation modeling to address the following research questions:

1. What influence do gender-science stereotypes have on Chemistry Olympiad participants' performance, their willingness to continue participating in the next round of the competition, and in next year's competition?

We expected gender-science stereotypes to have a negative effect on female performance and participation, and a non-negative effect on male participants in the Chemistry Olympiad.

2. To what extent do Chemistry Olympiad participants' expectancies (self-concept) and values (topic interest) mediate the influence of gender-science stereotypes on competition performance or continued participation?

Based on findings from studies investigating self-concept and topic interest we expected that all variables are positively related to future participation and performance for both male and female participants. Nevertheless, the influence of interest on performance may be smaller in female participants than male participants. Furthermore, we expected gender-science stereotypes to have a negative influence on female self-concept and topic interest and to have a non-negative influence on male self-concept and topic interest.

5.3 Theoretical Background

5.3.1 The Chemistry Olympiad and female underrepresentation and underachievement

The Chemistry Olympiad is a renowned worldwide annual competition that aims to identify and foster talented secondary school students (Sirota & Putala, 2018). In 2019, student teams from 80 different countries participated in the International Chemistry Olympiad (51st IChO, 2019a). Countries participating in an international Olympiad are free to select their representing team as they desire, but many choose to do so based on the results of one or more theoretical and practical tests among voluntarily participating students (Petersen & Wulff, 2017; 2012; Verna & Feng, 2002). Even though international Olympiads revolve around assessment situations, they also entail extensive social activity programs. These programs often focus on informal science learning activities, such as science museum visits and workshops (i.e., 50th IChO, 2018; 51st IChO, 2019b). Furthermore, since participating countries want their students to be successful, Olympiads provide numerous forms of learning and training opportunities on a national level. Countries' national selection programs usually consist of training courses and seminars (e.g., U.S. IChO, 2020; UK IChO, 2020). Therefore, these programs provide valuable out-of-school learning experiences that also reach many students who do not get selected for the international competition.

Germany has been a regular participant in the International Chemistry Olympiad since 1975 (Sirota & Putala, 2018). The selection of the German national team starts approximately one year before the international competition takes place. It consists of two theoretical selection exams followed by two week-long seminars (IChO Deutschland, 2017; Urhahne et al., 2012). After the last seminar, the four best performing participants will represent Germany at the International Chemistry Olympiad. German female students who take part in selection competitions for the Chemistry Olympiad hardly ever make it onto international Olympiad teams (IChO Deutschland, 2017). An illustrating example is the 2017 German selection competition: Even though 48% of the 1282 students of the first selection round were female, the rate of female participants dropped dramatically after each selection round, resulting in an all-male team competing in the International Chemistry Olympiad in Thailand (Nick, 2017). A few years prior, female participants' test performance in the penultimate selection round of the German Chemistry Olympiad was significantly lower than that of male students, with an effect size of 1.50 (Urhahne et al., 2012). Overall, from 2008 to 2016, German Chemistry Olympiad teams consisted of only 3% girls (IChO Deutschland, 2017). Comparable female rates from 1% to 14% were reported in other countries' Chemistry Olympiad teams (Lengfelder & Heller, 2002; Verna & Feng, 2002). These figures clearly suggest that girls are having difficulties qualifying

for international Olympiad teams. Furthermore, female students who did managed to become part of an international team scored lower than their male counterparts (Nick, 2017; Steegh et al., 2019). This is demonstrated by the medal distribution of the U.S., German, Finnish, and Latvian Chemistry Olympiad teams from 2008 to 2017. Combined, 14% of the male participants in these teams won a gold medal versus none of the female participants, whereas 26% of the boys won a silver, and 34% a bronze medal, compared to 1% and 4% of the girls, respectively (Steech et al., 2019).

5.3.2 Science Olympiads as gendered structures

As mentioned in the introduction, based on culturally gendered convictions, competitions are generally associated with the male gender. Some studies on gender bias in science competitions describe the very structure of science Olympiads, i.e., the type and the content of the test papers, general communication style, and social activity programs, as specifically appealing to boys and therefore less appealing to girls (Feng et al., 2002; Verna & Feng, 2002). Interviews with U.S., German, and Korean Olympiad participants showed that girls generally prefer cooperative tasks over individualist competition. Hence, many would find it unappealing to participate in an Olympiad (Cho & Lee, 2001; Feng et al., 2002; Lengfelder & Heller, 2002). Furthermore, participants noted that low female participation rates were possibly related to teachers' gender biased student selection (Cho & Lee, 2001; Feng et al., 2002; Lengfelder & Heller, 2002), a lack of support from parents, teachers, and peers, as well as a lack of female role models in science (Cho & Lee, 2001; Jones, 1991).

Even though some Olympiads make efforts to attract more girls by offering special workshops and project days with the intent to help girls adapt to their program (Blankenburg, Höffler, Peters et al., 2016; Wulff et al., 2018), we are not aware of any publications regarding Olympiads modifying their own structures to create a program that appeals equally to male and female participants. Moreover, we did not find any publications on Olympiads intending to use their program to reconstruct existing gender-science stereotypes.

5.3.3 Expectancy-value model of achievement-related choices

Eccles et al.'s (1983) expectancy-value model of achievement-related choices explains gender differences in achievement and participation. It states that achievements and choices are predicted by expectancies and values, whereby expectancy is usually operationalized by ability self-concept. A person's expectancies and values, in turn, are influenced by gender role stereotypes, previous achievement-related experiences, as well as cultural norms and socializers' beliefs and behaviors (Wigfield & Eccles, 2000).

The model has been widely used in various educational and vocational fields, such as science,

mathematics, reading, music, and sports (Cheng, Wu, Liao, & Chan, 2009; Eccles, 2005; Eccles & Harold, 1991; Wigfield & Eccles, 2000). Moreover, the expectancy-value model has been extensively used as a framework to study informal learning contexts, including Olympiads, which, in part, represent informal learning opportunities. Nagengast et al. (2011), for example, found that science self-concept, the enjoyment of science, and the interaction between self-concept and enjoyment all positively influenced both extracurricular engagement in science and the intent to pursue a scientific career, whereas AbiGhannam et al. (2015) used the model to investigate the expectancies and motivations that attracted an audience to a university science lecture series. Furthermore, Schnittka, Brandt, Jones, and Evans (2012), Weinberg, Basile, and Albright (2015), and Todd and Zvoch (2019) all evaluated the link between out-of-school learning programs and constructs such as interest, motivation, and science identification. The expectancy-value framework was also used by Cox and Whaley (2004) in an of out-of-school competitive sports context, demonstrating that basketball identity predicted effort and persistence, which was mediated by interest, attainment, and utility value. Moreover, the expectancy-value model was previously applied in the context of science Olympiads by Stang et al. (2014) to identify factors predicting success in the German Biology and Chemistry Olympiads. Due to the size and complexity of the entire model, which links clusters of several related predictors to one or more other predictor groups, our research specifically focuses on a selection of motivational constructs. With respect to the original models' expectancy and value pathways, we selected the constructs self-concept and topic interest, thereby representing both motivational branches. Moreover, these constructs were found among the best predictors for science-related choices and achievements (Andersen & Ward, 2014; Jansen, Lüdtke, & Schroeders, 2016; Liou, 2017).

5.3.4 The influence of gender-science stereotypes on girls in science

Gender-science stereotypes are generally endorsed cultural beliefs that boys are naturally more talented and interested in science than girls (Farrell & McHugh, 2017; Lane et al., 2012; Smyth & Nosek, 2015). These beliefs are related to weaker science identification among girls (Cundiff et al., 2013), which negatively affects female students in two ways. First, gender-science stereotypes are negatively associated with female science and mathematics achievement (Cvencek et al., 2015; Steffens et al., 2010). In fact, gender-science stereotype endorsement measured in 34 countries predicted gender differences in science performance in favor of boys (Nosek et al., 2009). Second, gender-science stereotypes explain the gender gap in students' intentions to pursue a career in science and mathematics (Lane et al., 2012; Steffens et al., 2010). In a study across 66 countries worldwide, Miller et al. (2015) found that female science education

enrollment is linked to gender-science stereotype endorsement. Accordingly, women are generally thought to possess fewer of the qualities needed to be successful scientists (Carli, Alawa, Lee, Zhao, & Kim, 2016), and an increasing feminine appearance has been found to decrease the perceived probability of being a scientist or mathematician (Banchefsky, Westfall, Park, & Judd, 2016; Kiefer & Sekaquaptewa, 2007; Miller, Nolla et al., 2018). Additionally, a study from Cheryan et al. (2017) introduced a lower sense of belonging, lack of early hands-on experience with 'hard sciences,' and lower self-beliefs as the main factors associated with low female participation. Several studies in the context of science Olympiads also mentioned gender-science stereotypes and social roles as factors linked to female underrepresentation and underachievement (Feng et al., 2002; Jones, 1991; Lengfelder & Heller, 2002; Petersen & Wulff, 2017; Verna & Feng, 2002). Not only did these studies describe stereotypes as having a direct influence on female participants, the stereotypes were also believed to exercise influence via parents, teachers, and peers (Cho & Lee, 2001; Dagani, 1990; Feng et al., 2002; Verna & Feng, 2002).

5.3.5 The role of self-concept in science

To measure the expectancy part of the expectancy-value model we chose self-concept, a person's perception of the self with regard to a specific topic or field (Marsh, 1990). Self-concept is an established construct and has a stable nature (Nagy et al., 2010; Rieger et al., 2017). Moreover, numerous studies found both male and female self-concept to be positively related to science achievement and participation in both secondary school (Jansen et al., 2014; Jansen et al., 2015; Liou, 2017; Nagengast & Marsh, 2012) and science Olympiads (Blankenburg, Höffler, Peters et al., 2016; Chang & Lin, 2017). In line with the expectancy-value model, however, stronger gender stereotype endorsement was found to correlate with lower female science and mathematics self-concept among primary and secondary school students (Bonnot & Croizet, 2007; Cvencek et al., 2015; Ertl et al., 2017; Steffens et al., 2010). Furthermore, female secondary school students were found to have lower science self-concepts than equally performing male students (Blankenburg, Höffler, & Parchmann, 2016; Jansen et al., 2014; Makwinya & Hofman, 2015). Additionally, Lengfelder and Heller (2002) reported that low self-concept among Mathematical, Physics, and Chemistry Olympiad participants likely prevented female students from participating in the first place.

5.3.6 Task value: Topic interest

To determine the value component of the expectancy-value model, we selected topic interest. This concept was classified by Eccles et al. (1983) as a task value component. With regard to this study, topic interest measures the enjoyment of engaging in chemistry contents (Daniels, 2008).

Interest is characterized by feelings of enjoyment or involvement regarding a certain topic, task, or activity (Schiefele, 1991). The construct can be subdivided into individual and situational interest within a specific domain (Krapp & Prenzel, 2011). Topic interest is a part of individual interest and especially applicable to our study since it is an evaluative, long-term, and stable variable that measures the feeling-related and value-related valences in the context of a specific topic or subject (Schiefele, 1992; Schiefele, 1996). These feelings and values are shaped under the influence of a student's social surroundings and are comprised of, among others, beliefs about appropriate gender roles and gender stereotypes (Eccles, 2009). In line with this, STEM interest and stereotype endorsement were found to be positively associated among male secondary school students, and negatively associated among female secondary school students (Blažev, Karabegović, Burušić, & Selimbegović, 2017).

Task values and achievement

In line with the expectancy-value model, undergraduate chemistry students with low levels of competence beliefs and task values were found to complete fewer courses and to have lower grades than students with more positive beliefs and higher task values (Perez et al., 2019). Furthermore, several studies reported a positive relationship between science and mathematics interest and achievement (Denissen et al., 2007; Höft, Bernholt, Blankenburg, & Winberg, 2019; Köller et al., 2001; Krapp et al., 1992), whereby Jansen et al. (2016) specifically found the interest-achievement relation in chemistry and physics to be stronger than in biology. In a meta-analysis of sixteen papers, Krapp et al. (1992) also found interest and achievement in science to be correlated, albeit with a clear gender effect: female achievement was less associated with interest than male achievement. Consistent with this, Denissen et al. (2007) found that being a girl was negatively associated with the coupling between achievement and interest.

Task values and participation

Not only achievement but also participation in science activities and science-related career decisions were found to be positively affected by interest (Aeschlimann et al., 2016; Sadler et al., 2012; Taskinen, Schütte, & Prenzel, 2013). PISA studied participation in science-related activities such as attending a science club, reading science magazines, and visiting scientific websites, and found that boys reported regular participation in such activities almost twice as often as girls (OECD, 2016). Furthermore, when asked about their future profession, 25% of the male students reported that they expected to go into the field of science. Even though female students expressed less interest in science activities, still 24% expected their future profession to be in science (OECD, 2016).

Interest in science was also reported to be associated with participation in science competitions (Blankenburg, Höffler, Peters et al., 2016). Accordingly, a lack of interest was linked to female

underrepresentation in U.S. Chemistry, Physics, and Mathematical Olympiad teams (Feng et al., 2002). Not only did interest have an effect on students' willingness to participate, chemistry interest also positively correlated with achievement in the German Chemistry Olympiad (Stang et al., 2014).

5.4 Method

5.4.1 Data collection

In the fall of 2017, after participation in the first selection round but before receiving feedback about their achievements, all 1974 participants of the German Chemistry Olympiad were asked to participate in our study. The online survey was accessible from computer and mobile devices and entirely in German. In total, $N = 445$ participants from all over Germany completed the survey (mean age = 16.50 years, $SD = 0.92$, 51% female). The sample consisted of 90% of students attending the academic track of the German secondary school system (*Gymnasium*), 5% attending other school types (mostly mixed-track schools), and 5% did not specify their school type. Students were in Grades 8 to 13, but most were in the 11th (38%) and 12th grades (44%). Besides age, grade, and previous participation in science competitions, the survey contained instruments measuring implicit gender-science stereotypes, as well as subject-specific self-concept and topic interest.

5.4.2 Instruments

Implicit gender-science stereotypes

The Implicit Association Test (IAT; Greenwald, McGhee, & Schwartz, 1998) was used to obtain implicit measures of gender-science stereotype endorsement. This test uses reaction times to measure cognitive associations between the concepts male and female in combination with science and liberal arts. Participants were asked to assign words associated with male (*man, boy, father, male, grandfather, husband, son, uncle*), female (*girl, female, aunt, daughter, wife, woman, mother, grandmother*), science (*biology, physics, chemistry, mathematics, geology, engineering*), and liberal arts (*philosophy, arts, history, literary studies, linguistics, music*) to one of two category-pairs (either male/science and female/liberal arts, or male/liberal arts and female/science). The test is based on the principle that participants assign words fastest when they associate the two words in the category-pair with each other. The IAT consisted of seven trial blocks and was scored with the D1 algorithm according to Greenwald, Nosek, and Banaji (2003). Positive scores indicated association of male with science and female with liberal arts, whereas negative scores indicated association of female with science and male with liberal arts.

Mediator variables

Self-concept was measured with the complete self-concept scale from the German national questionnaire of the PISA studies (OECD, 2006). In order to measure chemistry-specific self-concept we adapted all six items by replacing the words <school science> with <chemistry> (e.g., “I learn <school science> topics quickly” became “I learn <chemistry> topics quickly”). Topic interest was assessed with the complete topic interest measure developed by Daniels (2008). We adopted all four items by replacing the word <physics> with <chemistry> (e.g., “I would not want to miss out on occupying myself with <chemistry>, simply because it brings me joy”). Since the scale had been originally developed for biology, physics, mathematics, English and German, we did not expect our adaptation to have any impact on individual item validity. In both measures students were asked to rate the accurateness of each statement on a 4-point Likert scale (“I completely agree,” “I somewhat agree,” “I somewhat disagree,” “I completely disagree”). Even though an even number response scale has been criticized in the past (Johnson, Wood, & Blinkhorn, 1988), we specifically chose this strategy for two reasons. Given the content of the measures, our main concern was that participants would feel inclined to respond in a socially acceptable way. We therefore chose a forced-choice scale since it avoids mid-point bias and may prevent socially desirable score inflation (Cao & Drasgow, 2019). Furthermore, we used the self-concept scale from the PISA studies and decided to adapt their four-point forced-choice strategy among both measures for the sake of uniformity.

Internal consistencies in terms of Cronbach’s α and McDonald’s ω as estimates of reliability were good to excellent ($\alpha = .93$, $\omega = .93$, 95% CI [.91, .94] for self-concept and $\alpha = .87$, $\omega = .87$, 95% CI [.84, .89] for topic interest; Dunn, Baguley, & Brunsten, 2014).

Outcome variables

Students’ willingness to continue participating in the competition was measured with two items (“Assuming that you can take part in this competition again next year: Will you participate again in this competition next year?” and “Granted that you qualify for the next round in this competition: Will you continue to participate?”). The accurateness for both statements was assessed by using a 4-point Likert scale (“Very likely,” “Rather likely,” “Rather unlikely,” “Very unlikely”).

In the first selection round of the Chemistry Olympiad, participants had to complete one theoretical task. The task was assessed by the respective school teacher, after which the score was sent to the competition management. Participants who correctly solved at least half of the questions qualified for the second selection round.

5.4.3 Statistical analysis

Moderated mediation analysis

We performed moderated mediation analysis (see Figure 3) with Mplus Version 8.0 (Muthén & Muthén, 2017). As recommended by Ryu and Cheong (2017), we used a multi-group approach for testing group difference in indirect effects with gender as the categorical moderator. To assess the model fit we used the comparative fit index (CFI > .95 indicating acceptable, CFI > .97 indicating good fit), the root-mean-square error of approximation (RMSEA < .08 indicating acceptable, RMSEA < .06 indicating good fit), and the standardized root mean square residual (SRMR < .10 indicating acceptable, SRMR < .08 indicating good fit; Browne & Cudeck, 1992; Hu & Bentler, 1999; Schermelleh-Engel, Moosbrugger, & Müller, 2003). Furthermore, the expectancy-value measures were applied as latent factors, whereas the willingness to participate in the next round/competition, competition score, as well as the three background measures (age, grade, and previous participation in an academic science competition) were evaluated as manifest variables. We controlled for the background variables by including directional paths to the input, mediator and outcome variables.

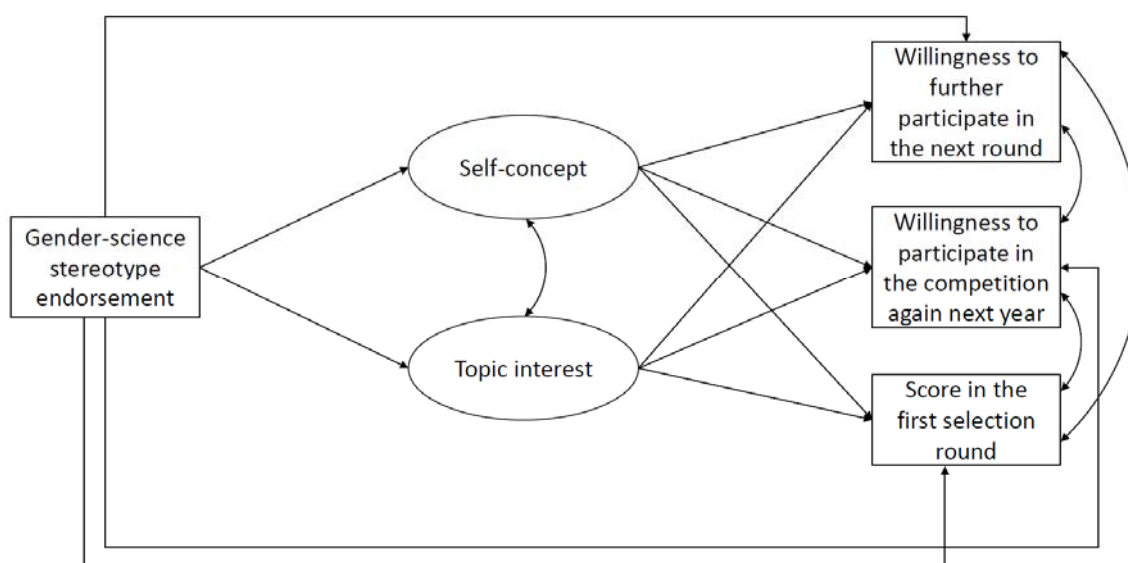


Figure 3. Schematic path diagram modified from the expectancy-value model for achievement-related choices according to Eccles et al. (1983). Latent variables are represented by circles and observed variables by squares. Directed arrows depict regressions whereas bidirectional arrows stand for correlations.

Our first analysis was the baseline model, for which we calculated multi-group total effects of gender-science stereotypes on the outcome variables when controlling for covariates. Even though we chose to calculate total effects, we did, however, take into account that solely focusing on these effects might be overly restrictive and could lead to false conclusions (Rucker, Preacher, Tormala, & Petty, 2011). Differences in regression coefficients between the two groups were

specified using the likelihood-ratio test.

After the baseline model calculations we proceeded with multi-group mediation analyses for which we performed a likelihood-ratio test to establish group differences in a path, in the indirect effect, and in the total effect. Furthermore, as recommended in the methodological literature (Shrout & Bolger, 2002), a bootstrap estimation approach with 10000 samples was used to measure confidence intervals in the direct and indirect effect.

Measurement invariance

To examine invariance of the latent variables (self-concept and topic interest), we tested both variables simultaneously in increasingly restrictive models across the gender groups by utilizing multi-group CFA. The strictest model we tested was at the level of scalar invariance, requiring equal factor loading as well as intercepts among the single items in both gender groups (Putnick & Bornstein, 2016). Subsequently, we compared model fit as recommended by Chen (2007). Loading invariance with adequate (total $N > 300$) and equal sample sizes across groups would be ruled out by a change of $\geq .010$ in comparative fit index (CFI), in combination with a change of $\geq .015$ in root mean square error of approximation (RMSEA), or $\geq .030$ in standardized root mean square residual (SRMR). Non-invariance in residual invariance would be indicated by a change of $\geq .010$ in CFI, supplemented by a change of $\geq .015$ in RMSEA, or $\geq .010$ in SRMR. We chose to not rely upon the chi-square difference test because it was found overly sensitive to sample size (Schermelleh-Engel et al., 2003).

Missing data

The proportion of missing values per single item varied between 0.0% and 10.8%, whereas 30.8% of the IAT data was missing. We used full information maximum likelihood estimation to handle missing data, since, in contrast to traditional methods such as listwise or pairwise deletion, estimates are less biased without the reduction of statistical power (Enders, 2010; Enders & Bandalos, 2001).

5.5 Results

5.5.1 Preliminary analysis

General gender-science stereotype endorsement

Overall, participants of the Chemistry Olympiad endorsed gender-science stereotypes ($M = 0.27$, $SD = 0.46$; $t(307) = 10.05$, $p < .001$, Cohen's $d = 0.59$), but male participants' gender-science stereotypical beliefs ($M = 0.43$, $SD = 0.39$) were significantly stronger than female beliefs ($M = 0.11$, $SD = 0.48$) with an effect size of $d = 0.73$; $t(301.16) = 6.42$, $p < .001$.

Descriptive statistics

Descriptive statistics and correlations are depicted in Table 6. The means for the 4-point-scale instruments (self-concept, topic interest, willingness to participate in the next round, and willingness to participate in the next competition) ranged from 3.13 to 3.57 with $0.62 < SD < 0.89$.

Table 6. Means, standard deviations, and correlations between all variables

Variable	M^{\dagger}	SD	α	ω	ST	SC	TI	NR	NC	SR
ST	0.27	0.46				-.05	-.20**	-.13*	-.14*	-.02
SC	3.36	0.62	.93	.93 [.91, .94]			.60**	.38**	.49**	.24**
TI	3.13	0.73	.87	.87 [.84, .89]				.50**	.50**	.18**
NR	3.32	0.89							.53**	.15**
NC	3.57	0.80								.15**
SR	43.38	24.40								
Gender*					-.34**	-.17**	-.05	.00	-.03	-.10*
Grade					.11	-.21**	-.11*	-.23**	-.14**	.13**
PP					-.06	.10*	.06	.22**	.23**	.19**

Note. Means, standard deviations, and correlations were computed on a manifest level for all variables. ST = gender-science stereotype endorsement; SC = self-concept; TI = topic interest; NR = willingness to participate in next round; NC = willingness to participate in next competition; SR = score in first selection round (maximum score = 100 points); PP = previous participation; M = mean; SD = standard deviation.

[†]Higher values indicate stronger implicit gender-science stereotype endorsement and willingness to participate in the next round/next competition as well as higher self-concept and topic interest.

*Gender: male = 0, female = 1

* $p \leq .05$; ** $p \leq .01$

The relationships between stereotype endorsement and the other variables were all negative but of small magnitude. In contrast, the relations among the latent variables were all positive and of high magnitude. Correlations between the two ‘willingness to participate further’ variables (NR and NC) and the two latent variables were positive and of moderate to high magnitude. Participants’ scores correlated positively with the two latent variables but correlations were of small magnitude. Furthermore, we found participants’ gender to be negatively correlated with stereotype endorsement, self-concept, and score with small to moderate magnitudes. Higher grade levels correlated negatively with both latent variables and the outcome variable measuring willingness to participate further in the competition. All these correlations were of small magnitude. Previous participation in a science competition, on the other hand, was positively correlated to chemistry-related self-concept and all three outcome variables, albeit with small magnitudes.

Prior to the main analysis, we established measurement invariance of the latent variables (self-concept and topic interest) across gender groups. Metric (constrained factor loadings) and scalar (constrained factor loading and intercepts) models showed acceptable ΔCFI , $\Delta RMSEA$, and

Δ SRMR, which indicated measurement invariance (see Appendix B).

5.5.2 Mediation analysis

Baseline model

Prior to the main analysis, we examined the total effects of gender-science stereotypes on the outcome variables in a multi-group model (CFI = 1.000, RMSEA = .000, SRMR = .014). Gender-science stereotype endorsement negatively predicted female participants' willingness to participate in the next round and the next competition, but not competition score (next round / next competition / score: $\beta = -.20^{**} / -.19^{**} / -.03$). In the male group, gender-science stereotype endorsement did not predict any of the outcome variables (next round / next competition / score: $\beta = -.13 / -.08 / -.04$). The likelihood-ratio test showed no significant differences between the two gender groups in the multi-group model.

Mediated structural equation model

Our next step was to estimate the full mediated multi-group structural equation model (Figure 4). The model yielded an acceptable fit to the data (see Table 7). Gender-science stereotypes negatively predicted topic interest in the female group, but not in the male group. Furthermore, self-concept positively predicted the competition score in both gender groups. Girls' willingness to participate in the next competition round was predicted by self-concept, whereas boys' willingness was predicted by topic interest. In addition, topic interest positively predicted willingness to participate in the next competition in both gender groups. Furthermore, the model also showed a negative indirect effect of gender-science stereotype endorsement, mediated by topic interest, on the willingness to participate in the next competition among female participants (see Table 7). Taken together, gender-science stereotype endorsement had a direct negative effect on female participants' topic interest, which in turn affected the willingness to continue participation in the next competition.

5.5.3 Significant differences between gender groups

We tested for significant differences in gender group comparisons by contrasting the unconstrained version of the mediated model with a similar model in which cross-group equality constraints were imposed. Gender differences between the two compared models were significant ($\Delta\chi^2 (56) = 138.92, p < .001$). Therefore, we subsequently calculated each effect separately in the mediated model and found two significantly different paths. Between the male and female group, the effect of gender-science stereotype endorsement on topic interest was significantly different ($\Delta\chi^2 (1) = 4.38, p = .036$), as well as the effect of topic interest on the willingness to participate in the next selection round ($\Delta\chi^2 (1) = 7.13, p = .008$).

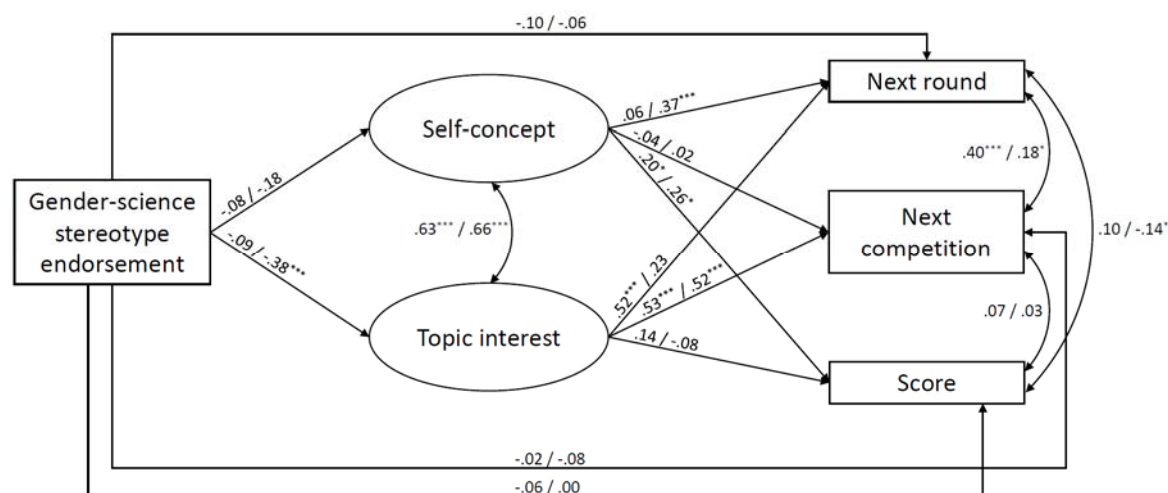


Figure 4. Schematic path diagram with standardized path coefficients. Representation: male / female. Latent variables are represented by circles and observed variables by squares. Directed arrows depict regressions whereas bidirectional arrows stand for correlations.

Table 7. Standardized indirect effects and fit indices from mediated multi-group model

	MG:m [95%-CI]	MG:f [95%-CI]
<i>Indirect effect</i>		
ST→SC→NR	-.01 [-.05, .02]	-.07 [-.16, .01]
ST→SC→NC	.00 [-.03, .04]	-.00 [-.05, .05]
ST→SC→SR	-.02 [-.07, .02]	-.05 [-.13, .01]
ST→TI→NR	-.05 [-.16, .05]	-.08 [-.21, .01]
ST→TI→NC	-.05 [-.16, .05]	-.18** [-.32, -.08]
ST→TI→SR	-.01 [-.06, .12]	.03 [-.27, .11]
<i>Fit indices</i>		
CFI		.964
RMSEA		.047
SRMR		.083

Note. f = female; m = male; MG = multi-group; NC = willingness to participate in next competition; NR = willingness to participate in next round; SC = self-concept; SG = single-group; SR = score in first selection round; ST = gender-science stereotype endorsement; TI = topic interest.

Confidence intervals and standard errors for the indirect effect were calculated based on a bootstrap estimation approach with 10000 samples.

* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

5.6 Discussion

This study aimed to examine the extent to which implicit gender-science stereotypes interacted with gender differences in participation and achievement in the Chemistry Olympiad, and to which extent these interactions were mediated by expectancies and values.

5.6.1 Main effects of gender-science stereotypes on outcome variables

As expected, we found gender-science stereotypes to negatively predict female participation in

the Chemistry Olympiad, while male participants were not affected by stereotypical beliefs. Achievement in the Chemistry Olympiad, however, was not linked to gender-science stereotypes for either gender. Once we had established these main relationships, we continued with the calculation of the mediation analysis.

5.6.2 Relationship between mediators and outcome variables

Topic interest positively predicts further participation

The right half of our multi-group structural equation model (see Figure 4) demonstrated the positive influence of topic interest on further participation. We found this to be consistent with comparable studies identifying task values as substantial predictors of course-taking decisions in secondary and tertiary mathematics and science education (Dabney et al., 2012; Eccles, Barber, & Jozefowicz, 1999; Nagy et al., 2006; Taskinen et al., 2013; Uitto, 2014).

Gender differences in topic interest predicting further participation

The finding that topic interest predicted the willingness to participate in the next selection round for male participants, but not for female participants could be explained by previous studies examining gender differences in science interest. Although science interest in secondary education was found to be positively related to science career aspirations (Maltese & Tai, 2011), boys generally showed more interest in science than girls, particularly in Germany (OECD, 2016). Moreover, within the science subject areas, female students were found to show less interest in the ‘hard’ sciences, such as chemistry and physics, than male students (Eccles & Wang, 2016; Krapp & Prenzel, 2011; OECD, 2016; UNESCO, 2015). Interestingly, the predictive power of interest on participation in the next round was significantly stronger for male than female participants. This difference may be explained by the diverse interests of top performing female students, which might then, under the influence of social and gender roles, lead to favoring other areas over natural sciences (Vock, Koller, & Nagy, 2013). Another explanation might be that female students who, compared to male students, were generally found to have lower science ability beliefs such as self-concept and self-efficacy (Cvencek et al., 2015; Höffler et al., 2017; Jansen et al., 2014; Preckel et al., 2008; Recber, Isiksal, & Koc, 2018) replied rather hesitantly to the item that measured their willingness to participate in the next competition round. They may have been under the assumption that their competition score was too low to qualify for the next round anyway (even though the item started with: “Assuming that you qualify for the next round in this competition...”). All German students, independent of school grades or previous achievements, are allowed to participate in the first selection round of the national Chemistry Olympiad. Our finding that participation in the next competition was predicted by topic interest for male and female participants equally therefore supports our

previous explanation. Moreover, our rationale is in accordance with this study's current finding that female, but not male, participants with strong self-concepts were also more willing to participate in the next round of the competition.

Self-concept predicts competition score

In accordance to our expectations, we found that self-concept predicted competition score for both male and female participants. The results were consistent with previous studies' findings that self-concept was the main predictor of academic achievements, whereas study choices and academic engagements were mainly predicted by task value (Eccles et al., 1999; Perez et al., 2014; Trautwein & Lüdtke, 2009). Additionally, for the female group, our results are consistent with research from Vincent-Ruz and Schunn (2017) which showed that girls' science learning is linked to a high self-concept.

5.6.3 Relationship between gender-science stereotypes and mediators

Stereotype endorsement does not predict self-concept

As for the left part of the model, we found that self-concept was not predicted by stereotype endorsement in either the male or female group. The outcome in the male group was consistent with studies reporting stronger stereotypical beliefs in boys to be either positively, or not correlated with self-concept (Cvencek, Meltzoff, & Kapur, 2014; Steffens et al., 2010). In the female group, on the other hand, our results were in contrast to previous studies which suggested that stronger gender-science and gender-mathematics stereotypical beliefs in female students correlated with weaker self-concepts (Cvencek et al., 2011; Cvencek et al., 2015; Ertl et al., 2017; Steffens et al., 2010). Yet, self-concept was found heavily dependent on a students' frame of reference (see review by Marsh, 2005). This has been theorized as the big-fish-little-pond effect which predicts that students in high ability school environments often have lower academic self-concepts compared to equally able students in low ability schools (Bandura, 1989; Dicke et al., 2018; Marsh, 1987). In addition, gender-mathematics stereotypes are believed to develop early in life, influencing emerging self-concepts prior to ages at which gender differences in actual mathematics achievement emerge (Cvencek et al., 2011; Cvencek et al., 2014). Thus, we suggest that gender stereotypes play an important role in participants' earlier lives when they affect the development of self-concepts and consequent achievements. Based on those achievements, participants might have established an interplay between their frame of reference and self-concept, which may have overpowered the relationship between self-concept and present gender stereotypical beliefs.

Gender-science stereotypes predict female topic interest

In accordance with our expectations and prior studies, we found that gender-science stereotype

endorsement negatively predicted topic interest in the female group, but not in the male group. These results are consistent with a study from Makarova and Herzog (2015), which states that male students positively relate chemistry to the male gender, as well as large international studies from Nosek et al. (2009), Miller et al. (2015), and Smyth and Nosek (2015) which demonstrate that IAT participants implicitly associate science more with male than with female attributes. Therefore, Olympiad participants who identify as female (me = girl) whilst at the same time endorsing gender-science stereotypes (science = male) may, in accordance with Cvencek et al.'s (2012) balanced identity theory, experience difficulties identifying with science (me \neq science).

5.6.4 Topic interest mediates the effect of stereotype endorsement on further participation

Not only did we find gender-science stereotypes to be negatively associated with female participants' topic interest, we also found that interest mediated the negative relationship between stereotype endorsement and the willingness to further participate in the next round of the competition. This indirect effect makes a novel contribution to the literature. Hence, the present research adds to existing expectancy-value research in the context of mathematics and science (Andersen & Ward, 2014; Lauermaun, Tsai, & Eccles, 2017; Lykkegaard & Ulriksen, 2016; Perez et al., 2019; Wang & Degol, 2013) by verifying patterns between gender stereotypes and achievement-related choices and, beyond that, the mediating effect of topic interest, as well as the moderating role of gender.

5.6.5 Limitations

Before discussing the implications, some of the shortcomings of our study should be addressed. First, this study's cross-sectional design does not permit causal interpretations, nor does it say anything about the way the relationships between variables develop over time. Therefore, some of the relations assumed in the model may very well be reciprocal. Other studies which based their research on Eccles et al.'s (1983) theoretical framework found mathematical self-concept and interest to interact in predicting course and study selection (Guo, Marsh, Morin, Parker, & Kaur, 2015; Guo, Parker, Marsh, & Morin, 2015), and mathematical self-concept and interest to have reciprocal effects with academic achievement (Guo, Marsh et al., 2015). Still, a longitudinal study on the relations between expectancies and values, and achievements and choices in the context of science, or more specifically chemistry, would be desirable.

Second, generalizations of the outcomes of this study should be made with caution since the sample consisted of a specific segment of German secondary school students. Still, the transferability of this study's findings to the context of gifted education and other Olympiads can

be made based on shared characteristics such as strong chemistry-related self-concept and interest.

5.6.6 Implications

The findings of this study add to a growing body of research on how stereotypes predict expectancies, values, and subsequent achievements and choices. Moreover, our study is the first to show that topic interest mediated the effect of gender-science stereotypes on participation in the Chemistry Olympiad.

Expanding to educational and international contexts

The finding that gender-science stereotypes play an important role in female participation in the Chemistry Olympiad may help us understand the influence of these stereotypes within the broader context of secondary school science, specifically in gifted science education and career aspirations. Additionally, as gender-science stereotypes are culturally dependent (Miller et al., 2015; Nosek et al., 2009), our findings could be used in a comparable study among Chemistry Olympiad participants worldwide, which could lead to a more in-depth and elaborate picture of the current situation.

Female attitudes toward competitiveness

Considering our first findings regarding gender-science stereotypes within the Chemistry Olympiad, further research should be undertaken to investigate the role of gendered attitudes regarding competitiveness. In a study among secondary school students, Ahlgren and Johnson (1979) found that girls showed more positive attitudes regarding collaboration, whereas boys were more positive towards competition. More importantly, girls were found to associate entering a competition with the goal of winning (versus competing to excel) with negative attributes such as feelings of depression and loneliness, and having fewer and less close friendships (Hibbard & Buhrmester, 2010). In contrast, more men than women attributed positive outcomes such as improved performance, character-building, and developing creative problem-solving skills to competition (Kesebir et al., 2019). It therefore appears that not only gender-science beliefs, but also gender-competition beliefs play a potentially significant role in science Olympiads. Thus, further studies are essential to examine the possibly discriminating influence of competition on science Olympiad participants.

Exploring altruistic values × gender-science stereotypes

Olympiads are held in other science subjects besides chemistry such as physics and biology. Physics is generally male-dominated (Handelsman et al., 2005; National Science Board, 2018; Petersen & Wulff, 2017; Smith, 2011; Wulff et al., 2018) whereas biology is generally perceived as fairly gender neutral (Handelsman et al., 2005; National Science Board, 2018). Interestingly,

Eccles and Wang (2016) stated that a career in biology and life sciences, in contrast to physics, was best predicted by altruistic values (e.g., people-oriented, caring, helping). Fittingly, girls were found to place especially high value on professions they associate with helping others and society (Abele & Spurk, 2011; Eccles et al., 1999), also within STEM domains (Su & Rounds, 2015; Yang & Barth, 2015). With regards to biology and physics, Bruun et al. (2018) found that biology professions were viewed as having more altruistic opportunities compared to professions in physics. In light of our current findings, it would therefore be particularly interesting to examine the interactions of gender-science stereotypical beliefs with self-beliefs, values, participation, and achievement in differently gendered science competitions such as the Biology and Physics Olympiads.

The role of social environment in science Olympiads

As mentioned before, a positive and supportive social environment is important for participation in science Olympiads (Cho & Lee, 2001; Feng et al., 2002; Jones, 1991; Lengfelder & Heller, 2002). In a systematic literature review on science competitions, Steegh et al. (2019) identified several categories explaining participation and achievement. The category social environment, encompassing variables such as parental, teacher, and peer beliefs and behaviors, as well as social and cultural capital, was most frequently reported. Even though a majority of the categories (e.g., person characteristics, previous experiences, and competition values) were assumed to affect male and female students in a similar manner, the influence of social environment was found to be strongly connected to cultural stereotypes and gender roles (McGarty et al., 2002). The importance of this factor, in combination with its gendered influence, makes it a significant issue for future research.

Explanatory model for male gender-science beliefs

Even though our findings did not show a link between male gender-science stereotype endorsement and any of the mediator or outcome variables, we did find that male participants generally had significantly stronger gender-science stereotypical beliefs than female participants. This gender difference proved to be consistent with existing literature in a scientific context (Blažev et al., 2017; Lane et al., 2012). Further examination of the group of male science Olympiad participants, or male secondary-school students, could therefore prove worthwhile as first steps toward an explanatory model for male gender-science beliefs.

Assessment of Olympiad structures and interventions

Because we found aspects within the Chemistry Olympiad to be especially unwelcoming for girls, a redesign of the competition structure could drastically improve conditions for female participants. As a first step, an assessment among Olympiad organizers from different countries

could give insight into specific changes already made and considered successful. Furthermore, interventions resembling the U.S. Posse program (The Posse Foundation, 2019), a peer-group model supporting outstanding students from diverse backgrounds through the enhancement of their sense of belonging, could serve as an approach for enhanced sense of belonging in national selection competitions and international Olympiads.

Since we found an indirect effect from gender-science stereotypes on female participation, modifying stereotypical beliefs and alleviating stereotype threat (Johns, Schmader, & Martens, 2005; Shapiro & Williams, 2012; Spencer et al., 2016) might be beneficial to female Chemistry Olympiad participants. Stereotype interventions have not always proven effective (Hoffman & Kurtz-Costes, 2018) and should be carried out with great care in order to avoid unintended negative consequences (Pietri et al., 2019). Nevertheless, several successful measures have been published (e.g., Good, Aronson, & Inzlicht, 2003; Johns et al., 2005; Ramsey, Betz, & Sekaquaptewa, 2013). Besides attempting to modify stereotypical convictions, interest could be heightened by using effective interventions as well (Harackiewicz, Canning, Tibbetts, Priniski, & Hyde, 2016; Häussler & Hoffmann, 2002; Hulleman, Godes, Hendricks, & Harackiewicz, 2010; Miyake et al., 2010; Wulff et al., 2018).

Finally, our findings showed that female self-concept, which was not linked to stereotypes, was positively associated with competition score and participation in the next competition round. Therefore, interventions directly strengthening female self-concept (e.g., Häussler & Hoffmann, 2002; Stout, Dasgupta, Hunsinger, & McManus, 2011) could also make for promising methods fostering both achievements and participation for female Chemistry Olympiad participants.

In summary, our findings underline previous work on the expectancy-value model in informal science learning contexts (e.g., Nagengast et al., 2011) and build on this by elaborating on the interaction of students' gender-science stereotype endorsement and expectancy-value constructs. Furthermore, the connection we identified between stereotypical beliefs, values, and participation can be integrated into existing science Olympiad interventions such as the workshop described by Wulff et al. (2018). Our contribution to the expanding knowledge on the influence of gender-science stereotypes can be utilized to develop specific programs which aim to diminish harmful gender roles. These programs may give science Olympiad boards, parents, teachers, and governments the tools they need to create a welcoming, inclusive, and supportive environment for girls to comfortably enjoy science activities in the future.

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Chapter 6

Exploring Science Competition Participants' Expectancy-Value Perceptions and Identification: A Latent Profile Analysis

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6.1 Introduction

Science Olympiads are out-of-school activities that identify and foster motivated and talented secondary school students. They have been positively linked to students' intentions of pursuing studies in science, technology, engineering, or mathematics (STEM) and facilitate entry at top universities in many countries (Miller, Sonnert et al., 2018; Sahin et al., 2015). Strategies improving gender equity in science competitions are crucial because female rates rapidly decline during Olympiad team selection (Petersen & Wulff, 2017). Male and female students participating in science Olympiads may feel differently motivated and appraised by their surroundings. We therefore need a better understanding of achievement motivation and domain identification. According to Eccles et al.'s (1983) expectancy-value model of achievement-related choices, motivational beliefs are positively associated with achievements (Wigfield & Cambria, 2010). The same goes for domain identification, operationalized by feelings of belonging within a certain domain, which plays a particularly important role in highly gendered structures such as science Olympiads (Good et al., 2012; Steele, 1997). So far, numerous motivational factors explaining student participation and success in science competitions have been identified (Steeh et al., 2019), with several studies proposing gender stereotypes as a fundamental factor explaining differences in male and female participation and achievement (Lengfelder & Heller, 2002; Petersen & Wulff, 2017). However, to date, prior research exclusively focused on variable-centered approaches concentrating on investigating separate relations between constructs and comparing motivational factors within individuals. Yet, a more holistic approach may be better suited due to the complexity and interplay of stereotypical beliefs, motivational processes, and their intricate relationship with the influence of the competition's environment. We therefore executed the first study in this research area using a person-centered approach characterizing groups of science Olympiad participants with similar patterns of expectancy-value beliefs and domain identification to uncover potential approaches toward gender equity.

This study aimed to establish a holistic representation of motivational structures within the German Chemistry Olympiad, a prototypical science Olympiad, by: 1) identifying and characterizing motivational profiles resulting from the interplay between expectancy-value beliefs and domain identification, 2) establishing the differences in profile membership based on gender, implicit gender stereotypes, and support from parents and teacher, and 3) investigating the relationship between different motivational types and achievement in the Olympiad.

6.1.1 The Chemistry Olympiad

The Chemistry Olympiad is an international annual out-of-school competition that fosters

talented and interested secondary school students (Sirota & Putala, 2018). Participants are selected by their respective home country, usually based on a national competition consisting of several theoretical and practical test rounds (Verna & Feng, 2002). The Chemistry Olympiad is situated between two rather masculine areas, chemistry (Cousins, 2007) and competitions (Gupta et al., 2013), where girls may feel less motivated to participate in such events. A recent study based on the same data as the current research project underlined this assumption by showing that female Chemistry Olympiad participants' stereotypes negatively predicted their willingness to further engage in the competition (Steegh, Höffler, Höft, & Parchmann, 2020).

6.1.2 Expectancy-value model of achievement-related choices

For this study, we chose Eccles et al.'s (1983) expectancy-value model of achievement-related choices as a theoretical framework. The model links achievements and choices to expectancies and values, which in turn are shaped by cultural environment, socializers' beliefs and behaviors, personal characteristics, and previous experiences (Eccles, 2005). It has been extensively used to explain gender differences (Eccles & Wang, 2016) and as a theoretical backdrop for latent profile analysis studies on motivational achievement in secondary school STEM education (e.g., Häfner et al., 2018; Watt, Bucich, & Dacosta, 2019). Furthermore, two prior studies on predictors of success in the Chemistry Olympiad were based on the expectancy-value theory (Stang et al., 2014; Urhahne et al., 2012).

6.1.3 Profile defining constructs

Career goals, self-efficacy and interest

As science Olympiads aim to identify talented and interested students in an effort to guide them toward STEM careers, we selected the corresponding expectancy and value components self-efficacy, interest, and career goals for profile definition. Although these constructs have been well-researched within the context of STEM education, a lack of similar studies within science competition frameworks remains. Despite differences between secondary school STEM education and science competitions, such as the out-of-school aspect and the element of competition, numerous similarities exist: participants of science Olympiads are secondary school students, the topics overlap, and the activities and outcomes are similar. Prior studies by Steegh et al. (2020) and Urhahne et al. (2012) showed comparable psychological mechanisms underlying the investigated constructs in educational settings and science Olympiads. Thus, we reviewed expectancy-value literature in the context of secondary school STEM education as a basis for our study.

Gender-STEM stereotypes, convictions that men fit better into STEM fields than women, were found to be negatively associated with female secondary school students' career goals (Deemer

et al., 2014). Gender stereotypes were also negatively linked to actual female science education enrollment (Miller et al., 2015). Furthermore, girls' self-efficacy was low within male stereotyped fields and was positively affected by exposure to female STEM experts (Schuster & Martiny, 2017; Stout et al., 2011). Likewise, female STEM interest was negatively linked to STEM-stereotypes (Master et al., 2017; Shapiro & Williams, 2012). In the Chemistry Olympiad, implicit gender-STEM stereotypical beliefs had a negative influence on interest and further participation of female participants (Steeh et al., 2020).

While career goals, self-efficacy and interest are connected to gender-STEM stereotypical beliefs on the one hand, they are also linked to STEM achievement on the other. The only study that investigated the role of self-efficacy and interest within a science Olympiad context found them to be uncorrelated with Olympiad score of participants that made it into their country's final selection round (Urhahne et al., 2012). In STEM education, however, all three constructs, career goals, self-efficacy and interest, were repeatedly empirically validated as positively linked to achievement (Guo, Parker et al., 2015; Jansen et al., 2015).

Domain identification

According to Steele's (1997) theory of domain identification, personal perceptions of a domain, such as interests, skills, and opportunities to be successful, shape feelings of belonging. These feelings are important for the formation of domain identification, which translates into sustainable higher achievements. Expectancy-value model is interlinked with theory of domain identification in such a way that identity formation is an ongoing interaction between relative competences (such as career goals and self-efficacy), relative subjective task values (such as interest), and current identity (Eccles, 2009).

Female students often experience a reduced sense of acceptance, and heightened feelings of negative affect in STEM fields (Cheryan et al., 2017; Good et al., 2012). Comparatively, recent studies on science competitions suggested that girls felt their personal identity did not match the Olympiad's identity (Boucher, Fuesting, Diekman, & Murphy, 2017; Petersen & Wulff, 2017). We assume the two main characteristics distinguishing science Olympiads from regular education, namely, their out-of-school setting and competition element, play an important role in the formation of a specific science Olympiad identity. Generally, out-of-school science activities are male-dominated (OECD, 2016). Additionally, competitiveness has been described as a culturally gendered phenomenon and an essential part of the masculine interaction style by Kesebir et al. (2019). We therefore expect domain identification in STEM competitions specifically manifesting itself in lacking sense of acceptance and stronger negative affect for female participants. Thus, we selected these two constructs for profile definition.

Prior research revealed close associations of STEM domain identification with gender

stereotypes (Good et al., 2012; Master, Cheryan, & Meltzoff, 2016) and achievement (Dasgupta & Stout, 2014; Howard, 2015). In negatively stereotyped domains, strong connections between competition and poor performance were especially pronounced (van Loo, Boucher, Rydell, & Rydell, 2013).

Not only was domain identification linked to gender stereotypes and achievement, but also to STEM career goals (Good et al., 2012; Wilson et al., 2015), self-efficacy (Cheryan et al., 2017) and interest (Tellhed, Bäckström, & Björklund, 2017). Furthermore, self-efficacy, interest, and career goals were all found to be associated with each other (Guo, Parker et al., 2015; Nugent et al., 2015; Uitto, 2014). Still, prior studies independently examined career goals, self-efficacy, interest, and domain identification, and mainly focused on providing a linear representation of the constructs. Latent profile analysis could also generate evidence supporting a more comprehensive image of possible occurring interactions between the constructs.

6.1.4 Predictors of profile membership

Parents and teachers were found to greatly affect children's attitudes towards science competitions (Forrester, 2010; Verna & Feng, 2002). Low female participation rates in Olympiads were connected to less support from parents and teachers (Lengfelder & Heller, 2002; Urhahne et al., 2012).

Several studies in STEM learning linked support from parents and teachers to children's career expectations (Lazarides, Viljaranta, Aunola, Pesu, & Nurmi, 2016; Lazarides & Watt, 2015), self-efficacy (Sha, Schunn, Bathgate, & Ben-Eliyahu, 2016), interest (Nugent et al., 2015; Sha et al., 2016), and achievement (Holzberger, Praetorius, Seidel, & Kunter, 2019; Ing, 2013). Furthermore, parents and teachers were not only found to play a direct but also an indirect role in influencing student behavior. As described in Section 1.3.1, female gender-science stereotypes were connected to lower levels of interest, self-efficacy, and career perspectives. Additionally, a study from Shapiro and Williams (2012) showed parents' and teachers' gender-mathematics beliefs were also transferred to girls, thereby indirectly influencing attitudes and interests. Thus, we decided to include gender, stereotypical beliefs, and support from parents and teachers as predictors for profile membership.

6.1.5 The Present Study

In this study we aimed to investigate how participants' characteristics influence performance, and how profile membership was predicted by gender, stereotypical beliefs and socializers' support. Herein, we performed latent profile analysis to answer the following research questions:

1. How do career goals, self-efficacy, topic interest, sense of acceptance, and negative affect define profiles for Chemistry Olympiad participants?

Based on the interconnectivity of the selected constructs, we expected to find at least three distinguishable profiles: one profile with ‘pessimistic’ participants (strong negative affect combined with low motivation and sense of acceptance), one profile with ‘average’ participants (average negative affect combined with average motivation and sense of acceptance), and one profile with ‘optimistic’ participants (low negative affect combined with high levels of motivation and sense of acceptance).

2. How do gender, implicit gender-science stereotypes, and support from parents and teachers predict differences in profile membership?

Regardless of gender, we expected less support from parents and teachers would be linked to less motivated participants. As girls in Olympiads reported receiving less support from parents and teachers (Cho & Lee, 2001), we expected the female gender to be connected to profiles with low motivation and domain identification.

3. How does profile membership predict a participant’s score in the Chemistry Olympiad?

As goals, motivations, and domain identification have been positively connected to achievement, we expected participants in profiles with the highest levels of expectancies, values, and domain identification to score higher than participants in other profiles.

6.2 Method

6.2.1 Participants and procedure

After the first selection round of the German Chemistry Olympiad, 445 from a total of 1974 participants completed our study (fall 2017; mean age = 16.50 years, $SD = 0.92$, 51% female). The online survey was entirely in German.

All participants attended German secondary school: 90% attended academic track (*Gymnasium*), 5% attended other school types (mostly mixed-track schools), and 5% did not state their school type. Within a range from 8th to 13th grade, most students were in 11th (38%) and 12th grade (44%). The survey contained age, gender, and instruments measuring implicit gender-science stereotypes, support from parents and teacher, career goals, self-efficacy, topic interest, sense of acceptance, and negative affect.

6.2.2 Measures

With the exception of the Implicit Association Test, participants were asked to rate the accurateness of each statement on a 4-point Likert scale ranging from “I completely disagree” to “I completely agree” in all measures (see Table 8 for reliabilities).

Table 8. Means, standard deviations, reliabilities, and latent correlations of variables

Measure	<i>M</i>	<i>SD</i>	α	1	2	3	4	5	6	7
1. Implicit stereotypes	0.27 [†]	0.46								
2. Parental support	2.08	0.80	.75	.00						
3. Teacher support	3.23	0.66	.72	-.13*	.33***					
4. Career goals	3.03	0.84	.92	-.16**	.28***	.09				
5. Self-efficacy	3.04	0.63	.84	.01	.13*	.15**	.36***			
6. Topic interest	3.13	0.73	.87	-.22***	.26***	.22***	.78***	.52***		
7. Sense of acceptance	2.87	0.68	.86	-.01	.30***	.25***	.35***	.47***	.52***	
8. Negative affect	1.58	0.58	.78	-.02	-.03	-.09	-.23***	-.31***	-.30***	-.27***

Note. *M* = mean; *SD* = standard deviation; α = Cronbach's alpha.

[†]Higher values indicate stronger implicit associations between males and science.

* $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

Career motivation, self-efficacy and interest

Career motivation was assessed using a scale measuring long-term goals developed by Urhahne et al. (2012). Originally, the scale consisted of four items but due to low internal consistency we omitted one item and used the following three for the statistical analysis: "I would like to work in a profession related to chemistry", "After graduation, I would like to study something related to chemistry", "I would like to spend my life occupying myself with chemistry at an advanced level".

Self-efficacy was measured with the mathematics self-efficacy scale from PISA-Konsortium Deutschland [Eds.] (2006). All four items were adapted by replacing the word <mathematics> with <chemistry> (e.g., "I am convinced that I can solve even the most complicated <chemistry> tasks").

Topic interest was measured with the physics topic interest measure developed by Daniels (2008). We adapted all four items by replacing the word <physics> with <chemistry> (e.g., "I would not want to miss out on occupying myself with <chemistry>, simply because it brings me joy.").

Domain identification

Sense of acceptance and negative effect were measured with the 'sense of belonging to math' scale developed by Good et al. (2012). Based on the confirmatory factor analysis by Good et al. (2012) we selected the three items measuring sense of acceptance, and the three items measuring negative affect with the highest factor loadings. We then adapted these items by replacing the word <math> with <chemistry> ("When I am in a <chemistry> setting, I feel accepted / respected / valued" and "When I am in a <chemistry> setting, I feel anxious / tense / nervous").

Implicit gender-science stereotypes

Implicit gender with science associations were measured with the Implicit Association Test (Greenwald et al., 1998). This online test measures the speed of cognitive associations between the concepts male versus female in combination with science versus liberal arts. Scoring was done with the D1 algorithm according to Greenwald et al. (2003). Male with science associations are indicated by a positive score and female with science associations by a negative score.

Support from teachers and parents

Support from teachers and parents was measured with the ‘support by teachers’ and ‘support by parents’ scale from Wulff et al. (2018). In both scales all three items were adapted for chemistry by replacing the word <physics> with <chemistry> (e.g., “I can ask my teacher for help when I have problems or questions regarding <chemistry>”, “My parents actively support me in my <chemistry> engagement”).

Achievement

Achievement in the first selection was based on a theoretical test assessed by the respective school teacher.

6.2.3 Statistical analysis

We conducted a preliminary confirmatory factor analysis (CFA; $M = 0$, $SD = 1$, z-standardized scales) to estimate factor scores and the handling of missing data. Factor scores were used for the interpretation of subsequent latent profile analysis (LPA) and as a partial control for measurement errors (Morin, Boudrias, Marsh, Madore, & Desrumaux, 2016). The proportion of missing values per single item ranged from 0.71% to 6.35%, whereas 30.6% of the IAT data was missing.

Identification of profile membership

Profile membership identification was determined by means of latent profile analysis using the factor scores calculated in the previous CFA. For the analyses we used Mplus Version 8.4 (Muthén & Muthén, 2017) with non-normality robust standard errors using the MLR estimator (Asparouhov & Muthén, 2005). We let the variances vary freely and residual covariances were fixed to zero according to Marsh, Lüdtke, Trautwein, and Morin (2009). We addressed the potential problem of local maxima by estimating the one- to five-profile models with 5,000 random starts and 100 iterations per random start. The best 100 solutions went through final-stage optimization (Hipp & Bauer, 2006).

We considered a number of statistical and theoretical conditions for the identification of the optimal number of profiles. First, we calculated the following information-based criteria: Akaike information criteria (AIC; Akaike, 1973), Bayesian information criteria (BIC; Schwarz, 1978), and

sample-size adjusted BIC (SABIC; Sclove, 1987). Lower AIC, BIC, and SABIC values indicate better model fit. Second, we used two statistical model comparison likelihood ratio tests, the Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR; Vuong, 1989), and the Lo-Mendell-Rubin likelihood ratio test (LMR; Lo, 2001). A significant result on the LMR and LMR indicates the corresponding model has better model fit compared to a model with one less profile. Third, we evaluated classification accuracy by means of the model entropy (value ranging from 0 to 1). A higher entropy value suggests a more accurate classification, with values of $> .80$ indicating 'good' classification of individual cases into profiles (Clark & Muthén, 2009). Of the above criteria, we put the most importance on BIC, SABIC, VLMR, and LMR, since AIC and entropy were found less suitable for selecting optimal profile solutions (Tein, Coxe, & Cham, 2013). Fourth, we considered the size of the latent profiles per model. A greater imbalance in relative profile size and very small classes (with a size of $< 5\%$ of the total sample) are unfavorable for model performance (Tueller & Lubke, 2010). Finally and most importantly, we selected the optimal composition and number of profiles based on theoretical reasonableness and suitability for meaningful interpretation.

Prediction of profile membership

For our second research questions we predicted profile membership by implicit gender-science stereotypes, support from teachers and parents, gender, and age we used a modified three-step approach as developed by Vermunt (2010; see Appendix C for a detailed description).

Profile membership as predictor of score

Next, we explored how profile membership predicted participants' score in the first competition round by performing equality tests comparing the mean participants' score per profile across all latent profiles using the Bolck-Croon-Hagenaars method (Bakk & Vermunt, 2016; see Appendix D for a detailed description).

6.3 Results

6.3.1 Descriptive statistics

Means, standard deviations, reliabilities and intercorrelations of all variables are summarized in Table 8.

6.3.2 Preliminary analysis

We started our statistical analysis by conducting preliminary CFA for the estimation of each latent factor and the handling of missing data. Based on the values of model fit indices, the CFA resulted in an excellent fit to the data (Hu & Bentler, 1999).

6.3.3 Identifying participant profiles with LPA

Models with up to five latent profiles were fit to the data (see Table 9). The entropy for all models was good and VLMR / LMR tests were significant. The five-profile model suggested the best fit based on these tests and the AIC and BIC, which decreased with the increase of profiles. Yet, we found the four-profile solution optimal because the fifth profile had a small sample size ($N = 16$; 3.6%) and was similar to profiles previously identified in the three- and four-profile models.

Table 9. Model fit indices for different profile solutions

Model	AIC	BIC	SABIC	Entropy	VLMR	LMR	Profile sizes
1 profile	6291.71	6332.62	6300.89				442
2 profiles	5659.40	5745.32	5678.67	0.83	< .001	< .001	297; 145
3 profiles	5220.91	5351.83	5250.28	0.89	< .001	< .001	261; 93; 88
4 profiles	4989.21	5165.14	5028.67	0.90	< .001	< .001	169; 106; 84; 83
5 profiles	4678.09	4899.02	4727.65	0.91	< .05	< .05	157; 104; 84; 81; 16

Note. The selected model is indicated by a bold font. AIC = Akaike information criteria; BIC = Bayesian information criteria; SABIC = sample-size adjusted BIC; VLMR = p -value of Vuong-Lo-Mendell-Rubin likelihood ratio test; LMR = p -value of Lo-Mendell-Rubin likelihood ratio test.

Description of the profiles

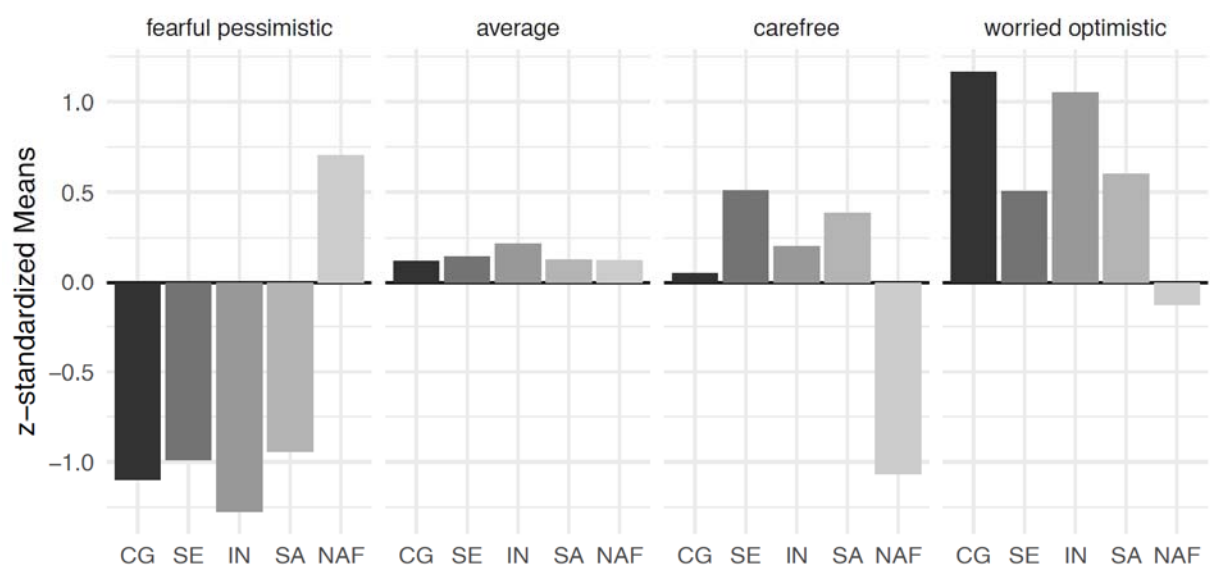
Figure 5 illustrates mean profiles of the four types of participants. We labeled the participant profiles *fearful pessimistic* ($n = 106$), *average* ($n = 169$), *carefree* ($n = 83$), and *worried optimistic* ($n = 84$; see Appendix E for ANOVA and post hoc comparisons of all five variables between the four profiles). Compared to the other three profiles, *fearful pessimists* were uninterested in chemistry and had low levels of chemistry self-efficacy and career motivation. They also showed a low sense of acceptance and high negative affect in a chemistry environment. *Average* participants were characterized by moderate levels on all expectancy, value and environmental measures. *Carefree* participants reported low negative affect, average levels of long-term career goals and interest, and moderately high levels of self-efficacy and sense of acceptance. Although the *worried optimists* were highly motivated and interested, their self-efficacy and sense of acceptance were similar to the *carefree* participants, but they experienced moderate negative affect.

6.3.4 Prediction of profile membership

Table 10 shows the results of the multinomial logic regressions for the effects of the predictor variables on profile membership. Compared to *fearful pessimistic* participants, *average* and *worried optimistic* participants had a higher probability of weaker gender-science stereotypical beliefs and more support from parents. Furthermore, participants in the *worried optimistic* and *carefree* groups had higher chances of being male compared to the *fearful pessimistic* group, and

were more likely to feel more supported by their parents compared to *average* participants. Compared to the group of *average* participants, *worried optimists* had greater chances of holding weaker stereotypical beliefs, being older and male. In addition, *worried optimists* were more likely to experience more support from parents and had weaker stereotypical beliefs compared to the *carefree* group. We found that teacher support, which was generally perceived as high ($M = 3.23$, $SD = 0.66$), was no significant predictor of profile membership.

Figure 5. Z-standardized mean scores per profile for the four-profile solution



Note. CG = career goals; SE = self-efficacy; IN = interest; SA = sense of acceptance; NAF = negative affect.

6.3.5 Competition score as outcome of profile membership

The BCH method revealed significant differences in competition score as outcome of profile membership. Participants that most likely belonged to the group of *worried optimists* ($M = 0.40$) had significantly higher scores than participants associated with the *fearful pessimist* ($M = -0.28$, $\chi^2 = 20.95$, $p \leq .001$), *average* ($M = 0.08$, $\chi^2 = 5.24$, $p \leq .05$), and *carefree* ($M = -0.18$, $\chi^2 = 12.04$, $p \leq .001$) profiles. Additionally, the competition score of participants that more likely belonged to the *fearful pessimistic* group ($M = -0.28$) differed significantly from participants with an *average* profile ($M = 0.08$, $\chi^2 = 7.08$, $p \leq .01$).

Table 10. Results of multinomial logic regressions for the effects of predictors on profile membership

Model	Non-reference profiles											
	<i>Fearful pessimistic participants</i>				<i>Average participants</i>				<i>Carefree participants</i>			
	Est. [95%-CI]	P	OR [95%-CI]	P	Est. [95%-CI]	P	OR [95%-CI]	P	Est. [95%-CI]	P	OR [95%-CI]	P
Reference profile												
<i>average participants</i>												
Implicit stereotypes	0.44 [0.05, 0.82]	.027	1.55 [1.05, 2.28]	.073								
Age	0.22 [-0.14, 0.58]	.223	1.25 [0.87, 1.78]	.275								
Gender	0.16 [-0.46, 0.78]	.611	1.17 [0.63, 2.17]	.638								
Parental support	-0.83 [-1.24, -0.42]	.000	0.44 [0.29, 0.66]	.000								
Teacher support	-0.23 [-0.57, 0.11]	.187	0.79 [0.56, 1.12]	.138								
Reference profile												
<i>carefree participants</i>												
Implicit stereotypes	0.26 [-0.17, 0.69]	.231	1.30 [0.85, 2.00]	.292	-0.17 [-0.55, 0.20]	.365	0.84 [0.58, 1.22]	.322				
Age	0.24 [-0.15, 0.62]	.223	1.27 [0.86, 1.87]	.278	0.02 [-0.31, 0.34]	.913	1.02 [0.73, 1.41]	.914				
Gender	0.70 [0.02, 1.39]	.043	2.02 [1.02, 3.99]	.146	0.54 [-0.07, 1.16]	.082	1.72 [0.93, 3.18]	.180				
Parental support	-0.38 [-0.84, 0.07]	.102	0.68 [0.43, 1.08]	.046	0.45 [0.07, 0.83]	.021	1.57 [1.07, 2.29]	.063				
Teacher support	-0.30 [-0.69, 0.09]	.129	0.74 [0.50, 1.09]	.076	-0.07 [-0.45, 0.30]	.703	0.93 [0.64, 1.35]	.693				
Reference profile												
<i>worried optimistic participants</i>												
Implicit stereotypes	0.82 [0.37, 1.26]	.000	2.26 [1.45, 3.54]	.014	0.38 [0.01, 0.75]	.046	1.46 [1.01, 2.12]	.096	0.55 [0.10, 1.01]	.017	1.74 [1.11, 2.73]	.066
Age	-0.14 [-0.54, 0.26]	.495	0.87 [0.58, 1.30]	.464	-0.36 [-0.69, -0.03]	.035	0.70 [0.50, 0.97]	.011	-0.38 [-0.78, 0.02]	.063	0.69 [0.46, 1.02]	.024
Gender	1.00 [0.28, 1.73]	.007	2.73 [1.32, 5.63]	.086	0.84 [0.20, 1.48]	.010	2.33 [1.23, 4.41]	.081	0.30 [-0.45, 1.05]	.434	1.35 [0.64, 2.87]	.500
Parental support	-1.32 [-1.79, -0.86]	.000	0.27 [0.17, 0.42]	.000	-0.49 [-0.86, -0.12]	.009	0.61 [0.42, 0.89]	.001	-0.94 [-1.40, -0.49]	.000	0.39 [0.25, 0.61]	.000
Teacher support	0.09 [-0.31, 0.48]	.674	1.09 [0.73, 1.61]	.687	0.32 [-0.05, 0.68]	.094	1.37 [0.95, 1.98]	.150	0.39 [-0.05, 0.82]	.082	1.47 [0.95, 2.28]	.150

Note. Est. = Logistic regression coefficient. These coefficients are in logit form and have to be interpreted as partial regression coefficients, adjusted for all other effects in the model; OR = odds ratios.

6.4 Discussion

This study aimed to uncover possible measures supporting gender equity by gaining a holistic understanding of the mechanisms underlying motivation and domain identification in a competitive scientific environment. We characterized four motivational profiles, analyzed the effects of gender, gender-science stereotypes and support by parents and teachers on profile membership, and examined each profile's link with achievement in the competition.

6.4.1 Participant profiles

As hypothesized, we found one profile with *fearful pessimistic* participants feeling unmotivated and anxious in a chemistry environment, as well as one with *average* participants feeling comparatively motivated and at ease. Here, the two other profiles we found were particularly noteworthy: instead of one group with optimistic and highly motivated participants, we found two separate, more intricate groups. Participants in both of these groups reported relatively high levels of self-efficacy and a strong sense of acceptance in the community but they differed with regard to negative affect, career goals, and interest. *Carefree* participants were characterized by low levels of negative affect in combination with average career motivation and interest, whereas *worried optimistic* participants had average levels of negative affect, combined with high levels of career motivation and interest. This seemed counterintuitive to us: why would participants with stronger positive emotions experience more anxiety? We found one possible explanation in control-value theory of achievement emotions (Pekrun, 2006), which states that putting higher value on a certain topic or activity is connected to a greater fear of being unsuccessful. The most recent PISA study corroborated our findings by showing that highly motivated students more often experienced feelings of anxiety (Mo, 2019). Our results therefore suggest that especially in the group of highly motivated participants a fear of failure may be linked to stronger feelings of anxiety about being in a chemistry setting.

6.4.2 Explaining differences in profile membership

We explored differences in profile membership based on gender, implicit gender stereotypes, and support from parents and teachers. As expected, we found that profiles with relatively unmotivated and anxious participants were linked to less perceived support from parents. Teacher support, on the other hand, had no influence on profile membership, probably because participants generally experienced much support from their teachers ($M = 3.23$, $SD = 0.66$).

In line with our hypothesis, we found that the female gender was connected to profiles with weaker motivation and domain identification. Interestingly, the same profiles were also linked to stronger gender-science stereotype endorsement. The balanced identity theory explains these

findings (Cvencek et al., 2012). This theory describes that girls endorsing gender-science stereotypes may feel that they may never fit into a chemistry environment due to their gender, leaving them demotivated and disconnected. Yet, gender-science stereotypes may play an even more crucial role: Not only can they trigger girls directly, they may simultaneously have a strong influence through parents. Several studies reported parents' math- and reading-related gender stereotypes affecting their children's motivation and outcome expectations (Jacobs, 1991; Muenks et al., 2020; Muntoni & Retelsdorf, 2019). Our findings suggest that differences in profile membership were explained by gender-stereotypical beliefs and support from parents, which both independent and interconnected, seemed negatively linked to female gender.

6.4.3 Relationship between profile membership and achievement

Analogous to our expectations based on motivation and interest, *worried optimists* generally had the highest competition score, whereas *average* participants had higher scores compared to *fearful pessimists*. An unanticipated finding, however, was that participants in the *carefree* profile did not score significantly higher than *fearful pessimistic* and *average* participants. Moreover, the difference in score between *average* and *worried optimistic* participants was smaller than the difference between *carefree* and *worried optimistic* participants. This was puzzling to us since *carefree* participants had higher levels of self-efficacy and experienced less negative affect compared to *fearful pessimistic* and *average* participants. *Carefree* participants were by far the least fearful of all the profiles. Perhaps this lack of negative affect was an important link to the *carefree* participants' relatively low achievements. Following control-value theory of achievement emotions (Pekrun, 2006) as we did in Section 4.1, it therefore seems plausible that *carefree* participants were not particularly invested in the competition and as a result were less successful.

6.4.4 Limitations

Some limitations should be considered when interpreting and generalizing the results of this study. First, our sample consisted of voluntary Chemistry Olympiad participants and may therefore not be representative of all German secondary school students. Thus, generalizations of this study's outcomes should be done with caution. However, based on comparable levels of interest and motivation we feel confident our findings may be transferrable to other extracurricular science programs.

Second, we did not measure parents' gender-science stereotypical beliefs and could therefore not make any statements about the mediating role of the child's gender on the relation between parents' beliefs and support. Furthermore, we measured perceived support, which may have been influenced by participants' personal convictions. Asking participants in what way and how

often they received support would have enabled more objective comparison on our part. However, in line with Eccles' expectancy-value model (2005) participants' perceptions may have more meaning than unbiased recordings, as they are directly linked to motivation and interest. Third, causal interpretations or explorations of the development of relationships over time were impossible to make because data were cross-sectional. Therefore, longitudinal studies would be required to explore the directionality of the relationships between profiles and predictor and outcome variables.

6.5 Conclusions and implications

Despite the positive link between science competitions and STEM career choices as well as admission to top universities (Miller, Sonnert et al., 2018), little research exists to date. Our study is the first to link participants' motivation, domain identification and success to gender-science stereotypes, perceived support from parents, and gender.

We have drawn three major conclusions. First, we found four profiles in which career motivation, interest, and negative affect, are essential distinguishing factors. Second, weaker gender-science stereotypes, more support from parents, and the male gender are strongest associated with the *worried optimist* profile. Conversely, stronger gender-science stereotypes, less support from parents, and the female gender are strongest associated with the *fearful pessimist* profile. Third, *worried optimists* achieved the highest competition score, and *fearful pessimists* achieved the lowest. Furthermore, *carefree* participants, distinguished by little negative affect, scored the same as *fearful pessimistic* and *average* participants.

The most successful participants, *worried optimists*, are characterized by strong career motivation and interest combined with average negative affect. Our findings clearly show that boys with weaker gender-science stereotypes and much support from parents have the greatest chance of being *worried optimists*. Girls, especially those receiving little support from their parents, have a disproportionately large chance of being in the least successful *fearful pessimistic* group. This finding builds on existing research from Lazarides et al. (2016) and Ing (2013) by adding a gendered perspective.

A pressing question raised by our findings is the extent to which gender roles negatively influence female participants. As gender-science stereotypes target boys and girls differently (Shapiro & Williams, 2012), further research in the context of science Olympiads might profit from a multi-group focus. These studies may also explore comparable competitions such as the Biology and Physics Olympiads, in which gender appears to play a different role (Steeh et al., 2019). Additionally, research on gendered attitudes towards competition, especially in stereotyped domains such as science (van Loo et al., 2013), could disclose important clues about

the disadvantages girls may experience in Olympiad environments.

Another important next step would be to explore interactions of parents' stereotypes and support (Muntoni & Retelsdorf, 2019) moderated by the child's gender (Jacobs, 1991), which could elucidate possible links to participants' self-beliefs and domain identification. On a practical level, increasing parents' awareness could be instrumental in heightening their child's self-beliefs and motivation (Simpkins, Price, & Garcia, 2015). This may prove especially effective for increasing female participation in science Olympiads. Additional approaches for attracting girls could be the enhancement of domain identification through exposure to STEM role models and identity strengthening programs (Stout et al., 2011; Wulff, 2019).

Summarizing, by actively selecting *worried optimists* as potential future scientists and role models we implicitly foster one kind of stereotype reproduction. This study enhances our knowledge on the importance of support from parents and the diminishing effect of gender-science stereotypes on feelings of belonging and enjoyment, especially for girls. By increasing gender-science stereotype awareness, we can encourage different selection principles and potentially different profiles in the future. Science Olympiad communities and parents must recognize their biased conduct, thereby hopefully encouraging parents to be more supportive of both sons and daughters, and science competitions towards being more gender inclusive.

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Chapter 7

General discussion and conclusion

The present dissertation aimed to identify the degree of underrepresentation and underachievement of girls in science competitions and explore the role of gender-science stereotypes in mechanisms explaining participation and success. Several key findings were presented. First, the existence of gender gaps in science competitions was confirmed and found to be largest in international Olympiads. Second, Eccles et al.'s (1983) expectancy-value theory of achievement motivation was recommended as the most appropriate framework for explaining gender differences in science competitions. Third, gender-science stereotypes were found to play an important role in mechanisms demotivating girls in the chemistry Olympiad and were linked to ability self-beliefs, motivation, and domain identification. The following sections will discuss the findings of this dissertation in more detail and present approaches for future research and practice.

7.1 Discussion of the results

The systematic analysis in Chapter 4 demonstrated that gender differences were particularly significant in the chemistry and physics Olympiads, and appointed the expectancy-value theory as most suitable framework for exploring gender differences in science competitions. These findings reinforced and justified the specific chemistry Olympiad focus and the use of the expectancy-value framework in Chapter 5 and 6.

The multi-group variable-centered approach described in Chapter 5 showed that gender-science stereotypes negatively influenced girls, but had no effect on boys. In accordance with expectancy-value theory, girls' interest was directly affected by stereotypes. Girls' self-concept, on the other hand, did not seem linked to stereotype endorsement. Chapter 6 presented findings from a latent profile analysis linking relatively strong gender-science stereotypes and little support from parents to unsuccessful and mostly female students.

7.1.1 Self-concept, stereotypes, and parental influences

The moderated mediation analysis in Chapter 5 revealed that self-concept was positively linked to both male and female participants' achievements. This finding supported the theoretical

assumptions made in Chapter 4. The overview in Chapter 4 also mentioned that male secondary school students and science competition participants had significantly stronger science self-concepts than their female counterparts (e.g., Höffler et al., 2017; Jansen et al., 2014; Nagy et al., 2010), and that, in line with expectancy-value theory, girls with stronger stereotype endorsement had weaker self-concepts (e.g., Cvencek et al., 2015; Steffens et al., 2010). Nevertheless, the analysis in Chapter 5 did not reveal a connection between gender-science stereotypes and participants' self-concepts. The discussion of Chapter 5 therefore focused on participants' frames of reference (Marsh, 2005) in an attempt to explain gender differences in self-concept through something other than stereotypes. An individual's frame of reference is hypothesized to have great influence on subject-specific self-concept (Ireson & Hallam, 2009). Yet, boys generally have stronger mathematics and science self-concepts, and girls have stronger language and verbal self-concepts (Ireson & Hallam, 2009; Skaalvik & Skaalvik, 2004). This indicates that the development of an individual's frame of reference is possibly affected by stereotypical perceptions in early life (Cvencek et al., 2011). Parents and teachers are additional factors playing a role in the development of self-concept, and possibly in the development of frame of reference as well. Gender stereotypes from parents were found to influence students' self-concept in mathematics (Tiedemann, 2000), and comparable results were found for teachers' gender stereotypes about reading (Retelsdorf, Schwartz, & Asbrock, 2015). Transposed to expectancy-value theory, these findings suggest that caregivers' and teachers' gender stereotypical beliefs and behaviors may have a stronger influence on the development of students' self-concepts than the gendered convictions students have themselves.

The latent profile analysis from Chapter 6 indicated that parents also played an important role in the chemistry Olympiad. Students in the top performing profile showed above average motivation and self-beliefs, and this profile had the strongest positive link with support from parents. Teacher support, on the other hand, was generally found to be so high that it made no difference for students with regard to the profile they were in.

7.1.2 The role of interest in participation and achievement

As reported in Chapter 4, the role of interest has been a major topic in several prior studies about science competitions. Blankenburg, Höffler, Peters et al. (2016) and Dionne et al. (2012) were the first to identify interest as an important motivation regarding participating in science competitions. The results of the mediation analysis in Chapter 5 were consistent with these findings: The more interested boys and girls were in chemistry, the more inclined they were to participate in the next Olympiad. In addition, gender-science stereotypes were found to negatively influence girls' interest. This was a finding that had previously been observed in the secondary school context (Blažev et al., 2017), but not yet in science competitions. Moreover, the

moderated mediation analysis was the first to show that interest mediated the relationship between female participants' gender-science stereotypes and intended participation. This means that gender-science stereotypes were negatively connected to girls' interest in chemistry, which was linked to less motivation to participate in the chemistry Olympiad again.

Chapter 6 described participant profiles that were determined based on interest among four other variables. Students in the most successful profile were also most interested in chemistry. This finding was in accordance with previous research in secondary school science education (e.g., Denissen et al., 2007; Köller et al., 2001) but had not yet been identified in the context of science competitions. In line with the findings reported in Chapter 5, the study in Chapter 6 also defined a link between interest and stereotypes. The most successful profile had the weakest link with gender-science stereotypes, whereas the weakest performing profile, composed of the least interested participants, was strongest predicted by gender-science stereotypes.

7.1.3 Anxiety and stereotype threat

In the discussion of Chapter 6, feelings of anxiety, which were experienced by the most successful students, were explained by control-value theory of achievement emotions (Pekrun, 2006). On the basis of this theory, highly motivated participants who place high value on science competitions experience anxiety possibly related to a fear of failure. Many top performing participants have a strong motivation for science, which may have spurred the development of a science-identity in the past. As a result, these participants attach high attainment value to science activities, and performing well in activities with high attainment value is of great importance for the reinforcement of their science-identity.

Yet even though control-value theory may explain how anxiety in successful participants is connected to positive emotions, the opposite seems to hold true for participants in the weakest performing profile. This profile contained the most fearful and at the same time least motivated participants. While Pekrun (2006) focusses on a comparatively positive and stimulating side of anxiety related to strong motivation, participants in the weakest performing profile seemed affected by negative and restricting emotions connected to anxiety (for a review, see Wigfield, Eccles, Roeser, & Schiefele, 2008). As participants in the weakest profile were also the most unmotivated, their anxiety was most likely connected to factors other than motivation. One possible explanation for anxiety in these participants could be the activation of stereotype threat, which occurs when negatively stereotyped individuals perform an activity in the stereotyped domain (Steele & Aronson, 1995). Anxiety when taking tests has been connected to stereotype threat in several stereotyped domains (e.g., Maloney, Schaeffer, & Beilock, 2013; Osborne, 2007). In the context of science competitions this translates to girls that believe boys are better at

science than they are, potentially being subjected to stereotype threat. Membership of the weakest performing profile was most strongly predicted by both the female gender and gender-science stereotypes. The overall strong anxiety in this profile could therefore probably be traced back to girls believing science is for boys, which triggered stereotype threat that led to feelings of anxiety.

7.1.4 Support from parents and teachers

Expectancy-value theory and data from the systematic overview in Chapter 4 identified parents and teachers as important influences on participants' values and beliefs underlying science competition participation and achievement (Cho & Lee, 2001; Feng et al., 2002). In the profile analysis in Chapter 6, teachers' support was so high overall, that it most likely did not affect students' motivation and success. Parental support, on the other hand, was confirmed to affect profile membership: Participants in the most motivated and successful profile also experienced the most support from their parents. These findings reflect Urhahne et al.'s (2012) findings in the penultimate selection round of a national Chemistry Olympiad. The authors found that parents of successful students displayed more intrinsic chemistry-value (personal enthusiasm about chemistry) than parents of students who did not qualify for the subsequent round. The same study also showed that boys' parents were more enthusiastic about chemistry, put more emphasize on the importance of chemistry in later life, and showed more chemistry expertise than girls' parents.

Thus, not only were parents found to be instrumental for success in science competitions, they were also perceived as less supportive of their daughters than their sons. These gender differences can likely be traced back to the influence of cultural gender stereotypes on parents' beliefs and behaviors (Jacobs, 1991; Jacobs, Chhin, & Bleeker, 2007; Leedy, LaLonde, & Runk, 2003; Muenks et al., 2020). Even though teachers were also found to play a role in exacerbating the gender gap in science competitions (Bunderson & Bunderson, 1996; Cho & Lee, 2001), in the analysis of Chapter 6 they were not predictive of profile membership. One possible explanation for the difference in the effect of support from parents and teachers could be the domain-specific environment teachers operate in versus the overall gendered communication many parents may use at home. While parents may paint an intricate gendered picture that possibly combines several domain- and activity-specific gender stereotypes, overall teachers may be relatively one-dimensional in their communication. Moreover, as experts in their fields, teachers may be aware of the harmful effects stereotypes can have on their students, thereby engaging in conscious communication and behavior.

7.2 Limitations

Before discussing the implications of this dissertation's findings, some limitations concerning generalizations and interpretations should be addressed.

Even though Chapter 5 and 6 of this dissertation deliberately focused on the chemistry Olympiad because of its 'neutral' positioning between biology and physics, the analysis in Chapter 4 showed that the gender gap in the biology Olympiad is the smallest in comparison to the chemistry and physics Olympiad. Furthermore, of the three science subjects, physics is considered the most masculine (Bruun et al., 2018; Kessels et al., 2006), making female participants in the physics Olympiad most exposed and targeted by gender-science stereotypes. As a result, girls participating in the physics Olympiad may be implicitly self-selected based on, for example, weak stereotype endorsement, a weak female gender identity, or an extreme interest in physics. Hence, generalizations of the results between the competitions can be made, but only with respect to, and understanding of, gender appropriate perspectives.

In line with the previous limitation, transferability of this dissertation's findings to science education settings should be done with caution for two reasons. First, results from PISA and TIMSS studies showed that general gender differences in science education do not completely match those in science competitions (Martin et al., 2016; OECD, 2018). Gender seems to play a smaller role in secondary school science education than in science competitions. However, this does not seem the case in gifted science education (Baye & Monseur, 2016). Mechanisms in gifted science education may very well overlap to a large extent with those in science competitions. The findings presented in this dissertation may therefore be partly transferable to gifted science education and could serve as a starting point for further research in this specific area.

Second, this dissertation's sample consisted of science competition participants that voluntarily took part in the research study. These students may therefore not be representative of all German secondary school students. As a result, generalizations of this dissertation's findings may not be tenable. However, the findings in this dissertation may be transferrable to other extracurricular science programs based on comparable participant characteristics such as strong self-beliefs and motivation.

Lastly, the cross-sectional designs in Chapter 5 and 6 do not allow for causal interpretations. They also do not permit statements about the way in which relationships between variables develop over time. For this reason the relations assumed in the models may very well be reciprocal. A longitudinal design, for example, could enable measuring the effects of success and failure in the competition on stereotype endorsement.

7.3 Recommendations for further research

The findings of this dissertation add to the expanding body of research on science competitions by systematically analyzing the extent and nature of the gender gap in this field. Moreover, this dissertation is the first to quantitatively identify relationships between gender-science stereotypes and activity-specific beliefs, subjective task value, achievements and choices in the field of science competitions. Hence, the findings provide various leads for further research.

7.3.1 Comparison of different competitions

The analysis in Chapter 4 showed that gender gaps in the biology, chemistry, and physics Olympiad differ in size. As discussed in the previous section, this may be caused by students' decisions to participate, or rather not participate, based on personal gendered beliefs. Specific beliefs about biology, chemistry, and physics are shaped by a person's cultural environment. Therefore, detailed research focusing on the effects of gender stereotypes on participation and success in science competitions in countries other than Germany, and in science competitions covering disciplines other than chemistry, would be an important next step in the field.

Furthermore, to gain more insight into how students self-select when it comes to participation in a science competition, science competition participants could be compared with general secondary school students. Participants may have a specific profile in terms of stereotype endorsement, ability beliefs, values, and identity compared to non-participants.

7.3.2 Comparing science competitions to science education

Average achievements in science education are not gendered the same as achievements in science competitions, yet gender differences at the variable level seem comparable. For example, even though girls generally outperform boys in regular science education (OECD, 2018), they still have lower science self-concept (Jansen et al., 2014; Makwinya & Hofman, 2015) and are less interested in science than boys (Denissen et al., 2007; OECD, 2016).

Several educational studies have used the expectancy-value framework to identify expectancies and value components connected to achievements in general science education (Putwain, Nicholson, Pekrun, Becker, & Symes, 2019; Robnett & Thoman, 2017). Comparable to this dissertation's findings, Guo, Parker et al. (2015) reported that both mathematics self-concept and interest among secondary school students were predictive for achievement and course selection. This could mean that even though gender differences in average science achievement are not comparable to those in science competitions, students' expectancy and value systems in school-related activities may still have similarities to those in science competitions. Therefore, reproducing the research in Chapter 5 and 6 in a science education context could identify

different nuances in, for example, the relationship between self-concept and achievement, or interest and achievement. These findings could then serve as possible starting points for follow-up research, interventions, and changes in science competitions.

7.3.3 Comparing science competition participants to top performers

As mentioned in the theoretical background, the system of consecutive selection rounds in science competitions leads to an increasingly better-performing group of students participating in each subsequent round (Campbell & O'Connor-Petruso, 2008; Lengfelder & Heller, 2002). Hence, top performers in science competitions are very likely also top performers in school, making them a particularly interesting group of students. Comparing top performing science students with successful science competition participants and with average-performing science students could contribute to understanding decision-making regarding participation in science competitions and subsequent success in the competition. Cross-sectional study designs could provide insight into existing expectancy and value profiles students may need to participate in a science competition, whereas longitudinal studies could predict how these expectancy and value profiles are influenced by success or failure in the competition.

7.3.4 The influence of participation on expectancies and values

The second aim of the WinnerS-project was to explore effects of success and failure in science competitions on participants' cognitive and affective traits. Success and failure, especially as the competition progresses, may have an effect on participants' self-beliefs, values, identities, expectations and choices. In Chapter 5, self-concept and interest measured at the start of the competition were found positively related with further participation and achievements. But how do success or failure in the competition affect self-concept and interest the other way around? Does it matter in which selection round a participant is disqualified? Participants meet for the first time during the third selection round. This may trigger new mechanisms, such as the big-fish-little-pond effect (Marsh, 1987). Do achievements in the third and fourth selection rounds influence self-concept in a different way than in the first and second rounds? Are there gender differences in how success and failure are attributed and how they affect beliefs and values? Do gender-science stereotypes play a role in the attribution of success and failure? All these questions about the effects of science competitions on participants have not yet been answered, but they could help make science competitions more valuable for all participants. That is why these questions could be the basis for important follow-up research.

7.3.5 The influence of parents and teachers on participation

As established in Chapter 4 and 6, parents influence their children's ability beliefs and values.

The findings in the profile analysis of Chapter 6 did, however, not point toward teachers as an influence on motivation and success. Still, several publications that were identified in Chapter 4 indicated a lack of support from teachers as a possible explanation for the low female participation rates in science competitions. In science educational context, teachers were found to have a gender bias toward their own students as well (Hand, Rice, & Greenlee, 2017; Tiedemann, 2000). This bias was particularly pronounced among top performing students (Pesu, Viljaranta, & Aunola, 2016) and could possibly be traced back to a combination of ‘boys are science’ and ‘boys are brilliant’ beliefs (Deiglmayr, Stern, & Schubert, 2019). Teachers therefore might provide more explicit support for male students, and in particular for male top performers. Students that chose to take part in an Olympiad may feel comfortable enough to participate because of the support they received from their teachers, whereas students that did not choose to participate in a science competition may not have received enough support from their teachers. The analysis in Chapter 6 specifically focused on support from teachers among participants, not among non-participants. Yet, perceived support among non-participants could help obtain a more complete picture of the effects of support from teachers on participation. Furthermore, the role of teachers and parents in the development of stereotypical views, self-beliefs and values could be investigated among science competition participants and among science students in general. This kind of research might give insight about when and in what way important factors that affect decision-making processes concerning science activities are formed. Thereby, they can support possible adaptations that may help science competitions to be more inclusive.

7.3.6 Comparing girls to other minorities in science

Besides the gender problematic in science and science competitions, many STEM fields have issues attracting students with ethnic minority backgrounds and students with low socioeconomic status. Even though this is highly problematic, general research on equity in science education is still a rather new field of research, particularly in Europe. Internationally published research mostly stems from the United States. A recent study by Perez et al. (2019), for example, showed that U.S. ethnic minorities such as African American, Native American, and Latino students were underrepresented in STEM courses and outperformed by White and Asian students. In another study by Perry, Link, Boelter, and Leukefeld (2011) ethnicity was linked to socioeconomic status. The authors found that African American and Latino boys had less positive science attitudes than girls, White boys, and boys with higher socioeconomic status. Betancur, Votruba-Drzal, and Schunn (2018) focused on parents’ socioeconomic status and level of education, which was linked to their child’s science achievement. Their study showed that less educated parents provided fewer informal science learning experiences for their child, which

was linked to the child's mathematics achievement (Betancur et al., 2018). Andersen and Ward (2014) investigated group differences in expectancies and values among top performing students in mathematics and science. They found that subjective task value was linked to STEM persistence, but the individual variables did function differently among Black, Hispanic, and White students.

This research shows that a next vital step in strengthening equity in science competitions and science in general would be to investigate other minority groups. Based on the assumption that minorities in science, whether girls, students with certain ethnic backgrounds, or students with low socioeconomic status, are having trouble identifying with science (according to balanced identity theory; Cvencek et al., 2012), mechanisms explaining the gender gap in science competitions may be similar to mechanisms explaining underrepresentation and underachievement of other minority groups. Thus, the findings in this dissertation could be used to draw comparisons between mechanisms explaining the gender gap and mechanisms explaining ethnic and socioeconomic gaps in science competitions. This research could then not only help improve science competitions but also other informal science learning experiences.

7.3.7 Gender-competition stereotypes versus gender-science stereotypes

As described in the theoretical background of this dissertation, girls may have a hard time identifying as competitive due to the masculine association many people have with competition (Lever, 1987). This may be a reason for girls to place less attainment value on competitive activities, particularly in stereotyped domains. This assumption was substantiated by several publications mentioning a lack of competitiveness as one possible explanation for the lack of girls in science competitions (e.g., Cho & Lee, 2001; Jones, 1991). A main difference between science competitions and science education is the competitive nature of science competitions which is not explicitly present in science education. Hence, follow-up research on gender-competition stereotypes could provide an important key to explaining differences between gender gaps in science education and science competitions.

7.3.8 Are science competitions predictive of science careers?

Students who not only show strong science interest and performance but are also competitive may more likely have a successful science career (Buser et al., 2012). The same holds true for participants in science Olympiads. Accordingly, several studies linked participation in a science competition to a successful career in science (e.g., Sahin et al., 2015; Schmidt, 2014). Moreover, in Chapter 6 of this dissertation, students in the most successful profile were uniquely distinguished by strong career goals. Although there is evidence of a link between science competitions and science careers, it is still unclear whether science competitions are predictive

of science careers. If this were the case, science competitions could be powerful tools in predicting the progression of girls through science careers.

In many ways, girls participating in the selection rounds of a science Olympiad are comparable to students at the start of a science career. Both groups actively choose to participate in science, where they are challenged with continuously higher levels of scientific content and increasing competitive pressure. Furthermore, students in both groups are confronted with a 'leaky pipeline'-environment, which means they are surrounded by disproportionate amounts of unsuccessful female colleagues. Not only are science competitions shorter than science careers, they mirror factors causing female underrepresentation in science, and do so several years before a student starts pursuing a science career. As such, it might be predicted that future research could identify in what way science competitions provide insight on participants' pursuit of a career in science, and the influence participation in a science competition has on participants' science aspirations.

7.4 Implications for further practice

As has become clear from the analysis in Chapter 4, science competitions, and in particular science Olympiads, are struggling to attract girls. Chapter 5 and 6 gave first insights into the role of gender-science stereotypes within the expectancy-value framework. These findings have several practical implications for science competitions, teachers, and parents.

7.4.1 Domain identification

A possible issue for girls in science competitions is a lack of domain identification, which has the potential to increase participation threshold and trigger feelings of discomfort and demotivation. Science competitions take place in relatively defined environments and could be closed-off enough to enable a competition-specific elevation of domain identification. Hence, a cost-efficient way of improving domain identification for girls could be to explicitly share stories of former female participants on the competition's offline (e.g., information packages, posters, flyers) and online (e.g., website, social media accounts) outlets. As a next step, aspiring participants could be given the opportunity to ask former participants about their experiences. Another, more immersive approach that could help elevate domain identification for girls would be through partnerships with other out-of-school STEM initiatives. Science competitions could search collaborations with informal and preferably non-competitive extracurricular science activities such as student research centers (Köhler, 2019) to help them identify interested girls and stimulate domain identification. An exemplary after-school initiative developed by Schnittka et al. (2012) provided secondary school students with opportunities to collaborate with peers

and college students. The program was found to increase participants' science identification and feelings of empowerment.

As a rather comprehensive strategy, science competitions could organize mentoring programs themselves. One example of an intervention directly connected to a science competition is an enrichment program developed by Wulff et al. (2018) among female physics Olympiad participants. This one-day program was found to successfully elevate physics identity and increase participation in the physics Olympiad. An example of an online mentoring program is *CyberMentor*, developed by Stoeger, Debatin, Heilemann, and Ziegler (2019). This year-long program consisted of weekly online interactions between gifted female students and women working in STEM fields. It was found to positively influence female participants' STEM educational capital (resources influencing learning and educational processes), performance, and intentions.

7.4.2 Self-concept and the stereotype inoculation model

Girls having uncertain feelings of belonging in the science domain often experience stereotype threat situations that weaken their performance and, over time, reduce science self-concept (Dasgupta, 2011). In this dissertation, self-concept was found to be a key factor in participation. Moreover, it was found to be disconnected from current gender-science beliefs. That is why boosting self-concept could be a promising and effective strategy to keep girls in the competition. The stereotype inoculation model proposes that successful in-group members in stereotyped environments, such as science competitions, can function as 'social vaccines' (Dasgupta, 2011). These in-group members could thereby increase social belongingness and raise fellow group members' self-concepts. In science competitions this model could be used to improve self-concept of less confident participants by connecting them to self-confident and successful participants in the early stages of the competition. An essential prerequisite of the model is that successful in-group members can only stimulate self-concept in others when framed as being similar. This practically means that when planning interventions, science competitions should be careful to stay away from framing successful female participants as brilliant nerds, socially inept, or overly masculine.

7.4.3 Involving teachers

Teachers may very well be the most important link between science competitions and potential participants. Not only do they often inform students of the possibility to participate in science competitions, they may also actively try to convince students to participate. Although participants of the chemistry Olympiad perceived their teachers to be very supportive, non-participants may have experienced this differently. A relatively cost-effective gain for science

competitions could therefore be to explicitly share their gender issues with teachers and to actively involve them in the problem. First, this could make teachers aware of any gendered communication and behavior they may express, and second, this would facilitate science competitions with teacher expertise which could help find practical solutions to the problem. At a later stage, toolkits such as the *STEM teacher training innovation for gender balance* from Bronzwaer et al. (2017) could support interested teachers to improve gender inclusiveness in their classroom.

7.4.4 Career goals

Findings in Chapter 6 revealed that the most successful students were mainly highly interested boys receiving relatively much support from their parents, with weak gender-science stereotypes and strong career motivation. Students aiming for a career in a certain domain will place great attainment value in activities reinforcing this part of their identity. Hence, career motivation may have been an important reason for students in the most successful profile to participate in the chemistry Olympiad. Moreover, successful participation in a science competition was linked to a successful science career (e.g., Campbell & O'Connor-Petruso, 2008; Sahin et al., 2015). It is therefore a problem that career information provided by parents, schools, and the media is often stereotyped (Eccles, 2005), resulting in girls steering clear from male-stereotyped domains such as science. Interventions to improve career motivation in science could provide a possible solution to this. An example of such an intervention is the *Bringing Up Girls in Science* program, which was developed by Tyler-Wood, Ellison, Lim, and Periathiruvadi (2012). This out-of-school program focused on authentic learning experiences combined with female mentoring opportunities. Participation in the program was found to increase appreciation for a career in science. In another promising intervention developed by Stamer (2019), videos of scientists at work were used to convey authentic science with a specific focus on activity interest. Participants gained more authentic views, in particular with regard to artistic and social activities which are often perceived as more communal and thus feminine.

7.4.5 Interest, stereotypes, and the role of parents

A final key outcome of this dissertation was the finding that female chemistry interest mediated the negative connection between stereotypes and achievement. Two logical practical approaches can be derived from this outcome: First, science competitions should arouse and elevate science interest in girls, and second, stereotypes need to be eradicated from an early age.

The discussion in Chapter 5 elaborated on interventions heightening STEM interest (e.g., Harackiewicz et al., 2016; Hulleman et al., 2010) and changing stereotypes (e.g., Good et al., 2003; Johns et al., 2005). In Chapter 4 and 6, however, it became clear that parents' stereotyped

behavior was connected to their child's motivation for science competitions. Parents of regular students were also found to influence their child's STEM interest and ability beliefs (Dasgupta & Stout, 2014; Muenks et al., 2020). That is why they could potentially benefit from a form of stereotype reduction, such as the training courses developed by Kawakami, Dovidio, Moll, Hermsen, and Russin (2000) and Gawronski, Deutsch, Mbirkou, Seibt, and Strack (2008). However, providing all parents with gender-science stereotype training would be practically impossible. Instead society's gendered perspectives should change as a whole.

As a response to the need for advancement of women around the world, the United Nations have boosted gender mainstreaming (the integration of a gender equality perspective at all levels of policies, programs and projects) by adopting gender equality as one of the seventeen *Sustainable Development Goals* (UN Women, 2019). To reach these goals by 2030, nations and unions around the world are developing various policies and initiatives to create stereotype awareness and stimulate gender equity (UN Women, 2019). Science competitions should thereby be no exception in striving for diversity and gender equity.

7.5 Conclusion

This dissertation revealed a gender gap in science competitions and identified gender-science stereotypes as a key instigator. German science competition participants were found to endorse gender-science stereotypes, which are highly ingrained in science competition culture.

The various strategies for follow-up research and practical improvements provided in this dissertation could help change science competitions in the future. Yet, whether they can be reformed to increase gender equity remains to be seen. This may not only depend on their own efforts but also on changes in stereotypical views in the world around them. However, in light of the current and ongoing developments with regard to gender equity, science competitions should feel called upon to accept responsibility and continuously make efforts to attract more girls. As such, they would contribute to initiatives at all levels of society and thus support global sustainable solutions. Ultimately, science competitions' step toward gender equity is the only competition no one can lose, because everybody wins if boys and girls are finally seen for what they really are: naturally equal.

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Appendix

Appendix A

Table A1. Female participation rates in mathematical and science Olympiads

Selection	Female rate (%)	Source
Mathematics		
Worldwide		
2014	10	International Mathematical Olympiad, 2018
2015	9	International Mathematical Olympiad, 2018
2016	12	International Mathematical Olympiad, 2018
Taiwan		
n.a.	6	Verna & Feng, 2002
China		
n.a.	6	Verna & Feng, 2002
United States		
1974-1997	0	Ellison & Swanson, 2010
1998-2009	8	Ellison & Swanson, 2010
Mathematics & Science		
Korea		
1988-2001	6	Cho & Lee, 2001; Verna & Feng, 2002
Mathematics, Physics & Chemistry		
Germany		
1977-1997	3	Lengfelder & Heller, 2002
United States		
1977-1997	10	Lengfelder & Heller, 2002
Finland		
1977-1997	9	Lengfelder & Heller, 2002
Physics & Chemistry		
Taiwan		
n.a.	9	Verna & Feng, 2002
Physics		
Germany		
n.a.	7	Petersen & Wulff, 2017
Chemistry		
United States	14	Verna & Feng, 2002
n.a.		

Appendix B

Table A2. Tests of measurement invariance for self-concept and topic interest

	CFI	RMSEA	SRMR	Δ CFI	Δ RMSEA	Δ SRMR
Configural	.972	.061	.032			
Metric Invariance	.965	.064	.075	.007	.003	.043
Scalar Invariance	.965	.061	.080	.000	.003	.005

Appendix C

Detailed description of prediction of profile membership

For the prediction of profile membership by implicit gender-science stereotypes, teacher support, and parental support, gender, and age we used a modified three-step approach as developed by Vermunt (2010) existing of the following three steps: 1) estimation of the latent profile model using only indicator values, 2) classification of the participants based on highest profile membership probability, 3) multinomial logistic regression of participants' most likely profile (as nominal variable) on the predictors. In the third step of the procedure the classification error probabilities were taken into account as the nominal variables were linked to the latent profiles. Furthermore, we used a bootstrap estimation approach with 10000 samples to measure confidence intervals.

Appendix D

Detailed description of the prediction of participants' score by profile membership

For the prediction of participants' score by profile membership, we performed equality tests that compared the mean participants' score per profile across all latent profiles using the Bolck-Croon-Hagenaars method (Bakk & Vermunt, 2016).

The BCH approach consisted of three steps, similar to the R3STEP described in Appendix A. The main advantage of the BCH approach is that it applies an analysis of variance (ANOVA) that computed individual weights, which were used as an imperfect latent profile indicator, instead of the modal profile assignment (nominal variable), in the third step of the method.

Appendix E

Table A3. ANOVA results using heteroscedasticity-corrected (Huber-White) covariance matrices and post hoc comparisons across the four profiles

Variable	1. <i>Fearful pessimistic</i> (<i>n</i> = 106)		2. <i>Average</i> (<i>n</i> = 169)		3. <i>Carefree</i> (<i>n</i> = 83)		4. <i>Worried optimistic</i> (<i>n</i> = 84)		ANOVA <i>F</i> (3, 438)	<i>p</i>	Post hoc comparisons ^a
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
Career goals	-1.13	0.88	0.11	0.59	0.03	0.79	1.17	0.03	469.35	≤ .001	1 < 2, 3, 4; 2 < 4; 3 > 4
Self-efficacy	-1.01	1.03	0.15	0.71	0.49	0.70	0.48	0.82	55.28	≤ .001	1 < 2, 3, 4; 2 < 3, 4
Topic interest	-1.32	0.77	0.22	0.53	0.18	0.72	1.05	0.24	353.84	≤ .001	1 < 2, 3, 4; 2 < 4; 3 > 4
Sense of acceptance	-0.95	1.01	0.13	0.67	0.33	0.93	0.60	0.77	50.73	≤ .001	1 < 2, 3, 4; 2 < 4
Negative affect	0.73	1.21	0.13	0.46	-1.07	0.06	-0.14	1.08	457.98	≤ .001	1 > 2, 3, 4; 2 > 3; 3 < 4

Note. Post hoc comparisons indicate statistical differences between the profiles 1 to 4 ($p < .05$). 1 = *Fearful pessimistic* participants; 2 = *Average* participants;

3 = *Carefree* participants; 4 = *Worried optimistic* participants

^aGames-Howell tests for post hoc comparisons was used for all variables because the assumption of homoscedasticity was violated.

Appendix F

Survey instruments

Self-concept

Chemistry-specific self-concept was derived from participants' level of agreement with the following statements: 1) learning advanced chemistry topics would be easy for me; 2) I can usually give good answers to exam questions on chemistry topics; 3) I learn chemistry topics quickly; 4) chemistry topics are easy for me; 5) when I am being taught chemistry, I can understand new concepts very well; and 6) I can easily understand new ideas in chemistry. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Topic interest

Chemistry topic interest was derived from participants' level of agreement with the following statements: 1) Occupying myself with chemical topics and objects is very important to me, regardless of school or other people; 2) I would not want to miss out on occupying myself with chemistry, simply because it brings me joy; 3) When I am occupying myself with chemistry topics, I can be really immersed in them; 4) I am willing spend my free time on occupying myself with chemistry. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Career motivation

Chemistry-related career motivation was derived from participants' level of agreement with the following statements: 1) I would like to work in a profession related to chemistry; 2) After graduation, I would like to study something related to chemistry; 3) I would like to spend my life occupying myself with chemistry at an advanced level. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Self-efficacy

Chemistry-related self-efficacy was derived from participants' level of agreement with the following statements: 1) I am sure I can understand even the most complicated chemistry content; 2) I am convinced I can solve even the most complicated chemistry tasks; 3) I am convinced I can always get good grades in Chemistry; 4) I am convinced that I can learn and master all skills that are needed to solve chemical problems. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Sense of acceptance

Sense of acceptance in a chemistry environment was derived from participants' level of agreement with the following statements: 1) when I am in a chemistry setting, I feel accepted 2) when I am in a chemistry setting, I feel respected; 3) when I am in a chemistry setting, I feel valued. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Negative effect

Negative effect in a chemistry environment was derived from participants' level of agreement with the following statements: 1) when I am in a chemistry setting, I feel anxious 2) when I am in a chemistry setting, I feel tense; 3) when I am in a chemistry setting, I feel nervous. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Support from teachers

Support from teachers was derived from participants' level of agreement with the following statements: 1) my teacher actively supported my participation in the chemistry Olympiad; 2) I can ask my teacher for help when I have problems or questions regarding chemistry; 3) my teacher actively supports me in my chemistry engagement. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Support from parents

Support from parents was derived from participants' level of agreement with the following statements: 1) my parents actively supported my participation in the chemistry Olympiad; 2) I can ask my parents for help when I have problems or questions regarding chemistry; 3) my parents actively supported me in my chemistry engagement. A four-point Likert scale with the response categories "I completely agree," "I somewhat agree," "I somewhat disagree," "I completely disagree" was used.

Outcome variables

Students' willingness to continue participating in the competition was measured with two following two questions: 1) assuming that you can take part in this competition again next year: Will you participate again in this competition next year?; 2) granted that you qualify for the next round in this competition: Will you continue to participate? A four-point Likert scale with the response categories "Very likely," "Rather likely," "Rather unlikely," "Very unlikely" was used.

Declaration of Ethical Conduct

I hereby declare that the work presented in this dissertation, apart from the advice given by my supervisor, is my own in both format and content. One review article (Chapter 4) and one research article (Chapter 5) presented in this dissertation have been published at peer reviewed scientific journals. One manuscript (Chapter 6) has been submitted for publication at a peer reviewed scientific journal. This is my first dissertation and the contents have not been used in any prior attempts to obtain a PhD. The dissertation complies with the standards for good scientific practice as proposed by the German Research Foundation. I have not been deprived of an academic degree.

Kiel, _____

Anneke Steegh