# Supporting young women's physics engagement

## Evidence from an intervention in the context of the Physics Olympiad

Dissertation
zur Erlangung des Doktorgrades
der Mathematisch-Naturwissenschaftlichen Fakultät
der Christian-Albrechts-Universität zu Kiel

vorgelegt von
Peter Wulff

Kiel, 2019

Erster Gutachter: Prof. Dr. Knut Neumann

Zweite Gutachterin: Prof.in Dr. Ilka Parchmann

Prüfungsvorsitzender: Prof. Dr. Stanislav Gorb

Viertes Prüfungsmitglied: Prof. Dr. Jeffrey Nordine

Tag der mündlichen Prüfung: 8. August 2019

Zum Druck genehmigt: 8. August 2019

## Abstract (English)

Science, technology, engineering, and mathematics (STEM) are vital for innovativeness, for economic prosperity, and for tackling of global problems (such as climate change, population growth, and poverty). Consequently, STEM literacy is important to the individuals and the society. For example, emancipation in more and more technology reliant societies hinges on STEM literacy for the individual. On the other hand, large numbers of unfilled STEM positions and a continuing growth of STEM jobs require efforts to recruit and retain talented students in STEM domains. As a means to identify and promote talented students in STEM, many nations developed enrichment programs such as the Science Olympiads. However, a closer examination of enrollment patterns, especially in math-intensive enrichment programs such as the Physics Olympiad, indicates that young women are largely underrepresented in these enrichment programs, such that these programs fail to identify and promote all talented students in STEM. Today, intervention measures that effectively tackle the problem of female underrepresentation in physics coexist and evidence-based strategies for interventions that raise gender equity in these programs are needed. This dissertation seeks to identify viable strategies in order to support young women's engagement in the Physics Olympiad and inform evidence-based strategies for gender inclusive physics.

Implementing and evaluating effective interventions requires a comprehensive study of the existing literature. Thus, chapter 2 in this dissertation presents a literature review on female underrepresentation in physics on the basis of which a situated agency model that outlines potential mechanisms that impair physics engagement for young women was outlined. On the basis of this model principles for interventions were deduced that proved effective for raising gender equity in physics in the past. These principles alongside the situated agency model comprised the framework for designing four empirical studies that were meant to inform the overarching research question of how gender equity in the Physics Olympiad environment can be raised such that young women are supported in their physics engagement.

In order to explore facets of the physics engagement for young women in the Physics Olympiad, in study 1 high-achieving young women ($N = 9$) in two subsequent Physics Olympiads in Germany were interviewed in order to examine facets of physics engagement through a personal narratives approach. The goal of this explorative study was to identify aspects of physics engagement for these successful young women. A common theme amongst the narratives of the young women was the perceived competence and the intrinsic motivation for physics. The young women portrayed themselves as confident problem solvers and expressed an interest and appreciation for physics and the physics problems in the Physics Olympiad. Furthermore, the physics engagement of the young women appeared in supportive environments, where teachers, parents, and/or peers were supportive for the young women. However, the young women also explained female underrepresentation in the Physics Olympiad on the basis of stereotypical notions of society and some reported experiences of social ostracism when engaging in physics, such that the physics engagement of these successful young women was impaired at times.

On the basis of these findings, a closer examination of possible effects for altering the Physics Olympiad's environment towards more gender equity was

necessary. Consequently, two studies examined the effectiveness of considerately designed learning materials and social settings for physics learning. In study 2 specifically designed learning materials were utilized in an intervention in a university course in order to probe effects for challenging the traditional physics image with regards to empathizing features and fixed ability notions. The evaluation of this intervention documented that the learning materials (case study of Rosalind Franklin and the discovery of the DNA, Active-learning instruction for physics) were effective to challenge traditional notions that students hold of physics, i.e., that physics is free of empathizing features. In study 3 the adaptation of the social context (equal gender ratio, cooperative group-work) was probed in the context of the Physics Olympiad. This intervention functions as a proof-of-concept for the main intervention (study 4). It was shown that particularly the female students increased some of their physics identity resources, namely competence beliefs and interest.

Finally, in study 4 a half-year intervention was implemented and evaluated in the context of the Physics Olympiad. The students participated in two in-person seminars and two online seminars. The following design features were implemented: female in-group experts as mentors, equal-sex group constellation, and gender-considerate learning materials. A control group received four online seminars with similar learning materials. Dependent variables were two physics identity resources, namely competence beliefs and recognition. Overall, $N = 39$ students participated and persisted until the end of the intervention. No time effects appeared for the students with regards to recognition (as operationalized through sense of belonging to the physics community) and competence beliefs (as operationalized through expectancy of success). At the same time, the control group, starting from an initially lower sense of belonging, improved their sense of belonging over time. Young women and men in the treatment group rated the intervention as very positive. In particular, the situational interest of the students affected the development of sense of belonging for the students, such that students with a higher situational interest for the intervention had a more positive development of sense of belonging compared to students with a lower situational interest, regardless of gender. The instructors were rated particularly high by both males and females. Overall, the students in the treatment and control group were found to be more likely to subscribe to the next year's competition compared to the general olympian population.

The empirical research in this dissertation sought to inform evidence-based strategies that tackle the problem of female underrepresentation in the Physics Olympiad. The findings indicate that it was possible to design learning environments in the Physics Olympiad context that supported young women's physics engagement. For example, young women's physics identity resources could be increased through an intervention and the participation in the Physics Olympiad could be stabilized. However, some effects did not appear as would be expected from the literature (e.g., improving young women's sense of belonging through an intervention). In summary, supporting high-achieving young women's physics engagement in the context of the Physics Olympiad seems to require concerted efforts that reflect the constraints for young women's physics engagement as outlined in the situated agency model.

## Abstract (German)

Mathematik, Ingenieurwissenschaft, Naturwissenschaft und Technik (MINT) sind für die Innovationsfähigkeit, den wirtschaftlichen Wohlstand und die Bewältigung globaler Probleme (wie Klimawandel, Bevölkerungswachstum und globale Armut) von entscheidender Bedeutung. Daher ist MINT-Bildung sowohl für das Individuum als auch für die Gesellschaft von großer Bedeutung. Zum Beispiel hängt die Emanzipation des Individuums in zunehmend technologiebasierten Gesellschaften auch von der Kompetenz in MINT des Individuums ab. Ebenso erfordern die Anzahl unbesetzter Stellen in MINT Fächern und das kontinuierliche Wachstum der Arbeitsplätze in MINT Fächern Anstrengungen, um hochleistende Schülerinnen und Schüler für MINT Fächern zu identifizieren und zu fördern. Um talentierte Schülerinnen und Schüler zu identifizieren und zu fördern, die potentiell in einer Karriere in MINT Fächern erfolgreich sein werden, entwickelten viele Nationen Enrichmentprogramme wie die Science Olympiaden. Eine Untersuchung der Teilnehmendenzahlen, insbesondere in mathematikintensiven Programmen wie der PhysikOlympiade, zeigt jedoch, dass junge Frauen in diesen Programmen stark unterrepräsentiert sind, so dass diese Programme nicht alle hochleistenden Schülerinnen und Schüler in MINT Fächern identifizieren und fördern. Deshalb sind Interventionsmaßnahmen erforderlich, die theorie- und empiriegeleitet Strategien implementieren und evaluieren, die das Problem der Unterrepräsentation von Frauen in der PhysikOlympiade wirksam angehen. Diese Dissertation widmet sich der Identifikation von Strategien, um Engagement junger Frauen in der PhysikOlympiade zu stärken und Anregungen für geschlechterinklusive Physik zu generieren.

Das Design und die Implementierung wirksamer Interventionen erfordert die Sichtung vorhandener Forschung. Daher wird in Kapitel 2 eine Literaturrecherche zur Forschung, die sich mit Ursachen der Unterrepräsentation von Frauen in der Physik beschäftigt, durchgeführt, um ein Modell für Agency (Handlungsfähigkeit) abzuleiten, in dem mögliche Mechanismen beschrieben werden, die Agency für junge Frauen in Physik beeinträchtigen. Auf der Grundlage dieses Modells werden Prinzipien für Interventionen abgeleitet, die sich als wirksam erwiesen haben, um geschlechterinklusive Physik umzusetzen. Diese Prinzipien bilden zusammen mit dem Modell situierter Agency den Rahmen für die empirischen Studien dieser Arbeit, die die übergreifende Forschungsfrage aufgreifen, wie Geschlechterinklusion im Umfeld der PhysikOlympiade erreicht werden kann.

Um Facetten des Physikengagements für junge Frauen in der PhysikOlympiade zu untersuchen, wurden in Studie 1 hochleistende junge Frauen ($N = 9$) bei zwei aufeinander folgenden PhysikOlympiaden in Deutschland mittels eines narrativen Ansatzes befragt. Ziel dieser explorativen Interviewstudie war es, Aspekte des Physikengagements dieser erfolgreichen jungen Frauen zu identifizieren. Ein gemeinsames Thema in den Antworten der jungen Frauen war die wahrgenommene Kompetenz und die intrinsische Motivation für Physik. Die jungen Frauen zeigten sich als selbstbewusste Problemlöserinnen und zeigten Interesse und Wertschätzung für die Physik und die Physikaufgaben bei der PhysikOlympiade. Darüber hinaus erwiesen sich unterstützende Umgebungen als ein gemeinsamer Aspekt des Physikengagements junger Frauen, in denen Lehrkräfte, Eltern und/oder Peers die jungen Frauen unterstützten. Die jungen Frauen erklärten jedoch auch die Unterrepräsentation von Frauen in der

Physikolympiade auf der Grundlage stereotyper Geschlechterbilder. Einige der hochleistenden jungen Frauen berichteten Erfahrungen sozialer Ausgrenzung in ihrem Physikengagement, sodass das Physikengagement dieser erfolgreichen jungen Frauen beeinträchtigt war.

Auf der Grundlage dieser Ergebnisse wurde weiter der Frage nachgegangen, welche Effekte Veränderungen der Physikumgebung im Rahmen von Interventionen im Kontext der PhysikOlympiade haben, die geschlechterinklusiv gestaltet waren. In den Studien 2 und 3 wurde die Wirksamkeit spezifisch gestalteter Lernmaterialien und sozialer Kontexte auf das Physikengagement junger Frauen untersucht. In Studie 2 wurden insbesondere die Lernmaterialien bei einer Intervention in einem Universitätskurs verwendet, um Effekte zu untersuchen, die das traditionelle Physikimage in Bezug auf Empathizing Features und Fixed Abilities hin verändern. Ergebnisse zeigen, dass die Lernmaterialien (Fallstudie von Rosalind Franklin und die Entdeckung der DNA, Active-learning physics instruction) eher traditionelle Vorstellungen der Studierenden in Bezug auf Empathizing Features hin verändern können. In Studie 3 wurde zusätzlich zu den adaptierten Lernmaterialien die Anpassung des sozialen Kontextes (ausgeglichenes Geschlechterverhältnis, kooperative Gruppenarbeit) im Rahmen der PhysikOlympiade untersucht. Diese Intervention stellt einen Proof-of-Concept für die Hauptintervention dar (Studie 4). Es zeigte sich, dass insbesondere die Schülerinnen in ihren physikbezogenen Identitätsressourcen Kompetenzüberzeugungen und Interesse von der Intervention profitierten.

Schließlich wurde in Studie 4 eine über ein halbes Jahr angelegte Intervention durchgeführt und im Rahmen der PhysikOlympiade evaluiert. Die Teilnehmenden durchliefen zwei Vor-Ort-Seminare und zwei Online-Seminare. Folgende Gestaltungsmerkmale wurden hierbei umgesetzt: gruppeninterne Expertinnen als Mentorinnen, gleichgeschlechtliche Gruppenkonstellation und geschlechtergerechte Lernmaterialien. Eine Kontrollgruppe erhielt vier Online-Seminare mit ähnlichen Lernmaterialien. Abhängige Variablen waren zwei physikbezogene Identitätsressourcen, nämlich Komeptenzwahrnehmung und Anerkennung. Insgesamt nahmen $N = 39$ Schülerinnen und Schüler bis zum Ende an der Intervention teil. Für die Schülerinnen und Schüler ergaben sich keine Zeiteffekte in Bezug auf Anerkennung (operationalisiert durch das Gefühl der Zugehörigkeit zur Physikgemeinschaft) und Kompetenzüberzeugungen (operationalisiert durch die Erwartung des Erfolgs). Gleichzeitig verbesserte die Kontrollgruppe ausgehend von einem anfänglich geringeren Zugehörigkeitsgefühl ihr Zugehörigkeitsgefühl im Laufe der Zeit. Junge Frauen und Männer in der Interventionsgruppe bewerteten die Intervention als sehr positiv. Insbesondere das situationale Interesse der Schülerinnen und Schüler vermittelte die Entwicklung des Zugehörigkeitsgefühls für die Studierenden, sodass Studierende mit höherem situationalen Interesse für die Intervention eine positivere Entwicklung des Zugehörigkeitsgefühls aufwiesen als Studierende mit geringerem situationalen Interesse, unabhängig vom Geschlecht. Die weiblichen Seminarleiterinnen wurden sowohl von Männern als auch von Frauen als besonders positiv bewertet. Insgesamt wurde festgestellt, dass die Schülerinnen und Schüler in der Intervention- und Kontrollgruppe im Vergleich zur Gesamtpopulation der Olympionikinnen und Olympioniken verstärkt am Wettbewerb des nächsten Jahres teilnahmen.

Die empirischen Studien in dieser Dissertation zielten darauf ab, evidenzbasierte Strategien zu entwickeln, die das Problem der Unterrepräsentation von Frauen in der PhysikOlympiade angehen. Die Ergebnisse zeigen, dass es möglich war, geschlechtsgerechte Lernumgebungen im Kontext der PhysikOlympiade zu implementieren, die junge Frauen in ihrem Physikengagement unterstützten. Zum Beispiel konnten sowohl einige physikbezogenen Identitätsressourcen der jungen Frauen positiv beeinflusst werden als auch die Wiederteilnahme an der Physik stabilisiert werden. Einige Effekte traten jedoch nicht wie aus der Literatur zu erwarten auf (z.B.: Verbesserung des Zugehörigkeitsgefühls junger Frauen durch eine spezifische Intervention). Die Unterstützung von leistungsstarken jungen Frauen im Kontext der PhysikOlympiade scheint gebündelte Anstrengungen zu erfordern, die den komplexen Einschränkungen für das Physikengagement junger Frauen gerecht werden, wie sie im Modell der situierten Agency angedeutet sind.

# Contents

# List of Tables

# List of Figures

# Chapter 1

# Introduction

Economic sustainability, healthcare advancement, and many other features of modern societies are intricately linked to the advancement of science, technology, engineering, and mathematics (STEM) (e.g., Pinker, 2018; Rosling & Rosling Rönnlund, 2018). Consequently, STEM literacy amongst the citizens in modern societies is imperative to societal progress and individual life chances. However, participation in STEM is patterned by social groups. For example, historically women were underrepresented in STEM and remain underrepresented today (e.g., Hodapp & Hazari, 2015). The biggest gender gaps in participation are observed in physics-related STEM subjects (e.g., Handelsman et al., 2005). Female underrepresentation in physics-related STEM subjects constitutes a problem both for society and individual young women, because, amongst other, modern societies that rely on human resources are hampered in advancing STEM fields and life chances for young women are constrained in increasingly technology-reliant societies (Lubinski & Benbow, 2006). Several major institutions in physics endorse the goal of raising gender equity in the physics community. The General Assemby of the International Union of Pure and Applied Physics (IU-PAP), for example, states: ”Primary and Secondary Schools should have policies and procedures that give the same opportunities and encouragement to the study of physics by girls and boys” (DPG, 2002), which is endorsed, amongst others, by the German Physical Society (DPG). Or, quoting a statement launched by the American Physical Society (APS): ”The APS urges its members, physics leaders and policy makers to take action to improve the recruitment, retention and treatment of women in physics at all levels of education and employment” (APS, 2015).

Ignorant of these goals, the proportion of female bachelor students in physics fluctuates (Hodapp & Hazari, 2015), while a coherent and testable framework for raising gender equity ”in physics at all levels of education and employment” is pending. Female participation in physics remains below the expected female share in the public work-sphere, and below the expected numbers from ability distributions (e.g., reasoning skills, spatial thinking) in the population. Therefore, empirical research (Will, Winteler, & Krapp, 1987) is needed to systematically develop, implement, and evaluate strategies for raising gender equity in physics. As a means to do so, the overarching goal for this dissertation is to probe strategies that facilitate physics engagement for young women. This research, in the context of physics education, has to be based on, amongst others, gender research, and general psychological research, accumulating knowledge on means to challenge the status quo in society and raise gender equity. However, the physics education community is only at the beginning of adopting these studies into their repertoire.

In order to unpack the term inequity and motivate the usefullness of the term for the problem of female underrepresentation in public sphere and STEM, section 1.1 of this introduction will gloss over central ideas related to equity. Section 1.2 concretizes the inequity problem and frames it around gender inequity in societies. Paradigms of gender-related research will be outlined in order to derive the theoretical underpinnings for this dissertation, namely that systemic biases (e.g., biased procedures) constrain female engagement in the public sphere. STEM engagement will then be revisited through the lens of systemic biases (section 1.3), where it will be motivated that in STEM and physics gender inequity is a particular problem. Section 1.4 will provide the reasons why a society should care that STEM becomes more inclusive. This will be done through emphasizing three motivations for why STEM is essential for modern societies. However, the fact that STEM subjects remain rather marginal in public and even high-achieving students in STEM rarely consider STEM careers as possible future occupations, section 1.5 will motivate STEM enrichment programs that are a potential means to raise public recognition of STEM subjects and identify and promote high-achieving students for STEM. In particular, female underrepresentation in these programs will be highlighted as the central problem that this dissertation is engaged with. Section 1.5 concludes with emphasizing the overarching research goal for this dissertation: probing strategies that facilitate physics engagement for young women in the context of the Physics Olympiad.

## 1.1 Inequity in modern societies

Nussbaum (2000) lists fundamental capabilities that every individual should be given the opportunity to exercise upon in modern societies, ranging from health, safety, to more evolved capabilities such as aesthetic pleasure and opportunities to reflect on and engage in one's own conception of a good life (also: Sen, 2000). An individual shall have the positive freedom to act upon this conception of a good life, free of external constraints (Berlin, 1969; Hume, 2012). This freedom can be limited, amongst others, through constrained access to resources (e.g., knowledge, finances, valueable goods, ...) that might result from systemic procedures or social contexts that are biased against certain individuals (e.g., Steele, 1997). Systemic procedures include biased institutional perceptions of certain individuals and social contexts include stigmatization, marginalization, dehumanizing, or social exclusion (Goffman, 1963). Oftentimes, individuals are constrained in their positive freedom when they do not align with the mainstream expectations for what counts as a prototypical representative in a social context (Goffman, 1963). Instances where individuals are constrained in their positive freedom based on mechanisms such as stigmatization or stereotype threat comprise issues of inequity. Examples of inequity are numerous and include deprived access to academic resources for students from low economic background to biased perception of female students in STEM subjects. The bedrock principle of equality of opportunity, i.e., equal potential access for individuals to valued resources regardless of their identities (e.g., Dawson, 2017), can be violated.

While it was claimed that procedures have to be equal for all individuals, today a model for relational justice is embraced where differences amongst individuals are recognized and valued, and where institutions are meant to incorporate differences (Dawson, 2017; Purdie-Vaughns, Steele, Davies, Ditlmann, & Crosby, 2008). In particular, a mere cognitive view on inequity is not reconcilable with relational justice, because individual cognitions are largely a product of the social environment. As such a more holistic perspective is embraced, where the social context is attributed to constitute a primary driver of inequitable practices, was argued for (Carlone, Haun-Frank, & Webb, 2011).

In past decades, social psychological research demonstrated that group identities are a salient feature in social environments which intricately relate to inequity (Tajfel, 1982). Groups form along distinctive characteristics of individuals such as gender, ethnicity, race, or socioeconomic status, and are non-essential to an individual. Non-essential refers to the social construction of group identities, e.g., group identities are largely learned affiliations through socialization processes. In general, individuals treat others and will be treated by others according to their salient group identities (e.g., Tajfel, 1982; O. Lee, Fradd, & Sutman, 1995)–especially in adolescence (Sapolsky, 2018). Group identities get "under the skin" and have much bearing on psychological and biological development of an individual in a society, because social processes such stereotype-threat and stigmatization lead to constraints of an individual's positive freedom (Rosenthal, 2016; Goffman, 1963; Sapolsky, 2018).

Alliances amongst individuals are formed partly in reference to group identities (e.g., J. C. Turner, 1987). Consequently, over historical periods of time, group identities are ingrained in individuals and in mainstream institutions (Saltzmann Chafetz, 1990). Allocation and access to resources is thus linked to group identities. Institutions have also different perceptions of individuals based on the individual's salient group identity, because mainstream institutions adopted different perceptions of individuals that potentially result in marginalization of groups through rules, regulations, or traditions (e.g., Rawls, 1971). For example, a rule was instantiated in the 19th century (and earlier) that forbade women to make their voice count through voting or political campaigning.

In summary, it is noted that inequity forms around social groups and manifests itself in differences in allocation and potential access to valued resources. Treating everybody the same does not constitute equitable practices. Rather, mainstream institutions need to embrace differences amongst individuals who identify with different groups. It is the necessity to understand the specific conditions and motivations of historically marginalized groups and organize institutions to be considerate of the particular motivations for members of historically underserved groups. The assertion is that challenging inequitable practices that form around social groups is a complex problem that intricately relates to social environemnts individuals act in.

## 1.2 Equity and gender

Amongst the social group identities, one of the most salient group identities in terms of political, economic, social, and scientific interest is gender. Gender effectively splits humanity in two equal-sized halves. Gender, in this dissertation, refers to a binary categorization[1] (female and male) of individuals into groups where certain values, goals, role-requirements, and motivations are attributed with each instance of the category and affiliations with each instance of the category in social contexts influence behavior (e.g., Hannover, 2000). The differentiation of individuals according to binary gender and the different allocations of resources and responsiblities is prevalent in all scientifically studied societies. D. E. Brown (1991) characterized "Universal People" through scrutinizing ethnographic archives of all studied societies and found "division of labor by sex," "more child care by women," "more aggression band violence by men," and "domination by men in the public political sphere" as human universals. Historically, the hunter-gatherer-organization of ancient tribes (Pinker, 2003), and the *pater familias*-organization of industrialized society, where the man in the household was responsible for productive duties (politics, finance, ...) and the women for reproductive duties (food, childrearing, ...) (see: Beck, 1986), have much bearing on the gendered organization of modern societies. Many thinkers some 100 years ago were convinced of the insurmountable differences between women and men. Take Max Planck's statement of gender differences in physics in the late 19th century where he wrote: "die Natur selbst [hat] der Frau ihren Beruf als Mutter und als Hausfrau zugeschrieben" (Kleinert, 1978).[2] Not least since the Age of Enlightenment, males are associated with rationality, whereas females are associated with intuition (discussed in: Gigerenzer, 2008). Immanuel Kant said about women that "Ihre Weltweisheit nicht Vernünfteln, sondern Empfinden [sei]" (Schiebinger, 1993, p. 381).

Besides these essentialistic characterizations of women and men, scholars also ideated different arrangements of cohabitation of women and men. For example, the ancient Greek philosopher Plato engaged some millenia before Immanuel Kant and Max Planck in the debate (see: Freudiger, 1995). In *Politeia* Plato put forth a vision of future society:

> Also, o Freund, gibt es gar kein Geschäft von allen, durch die der Staat besteht, welches der Frau als Frau oder dem Mann als Mann angehörte, sondern die natürlichen Anlagen sind auf ähnliche Weise in beiden verteilt, und an allen Geschäften kann die Frau teilnehmen ihrer Natur nach, wie der Mann an allen. (Platon, 2012, V. 455)

John Stuart Mill, a pioneer of liberalism and Enlightenment, stood up for women's rights. He was the first member of parliament in England to succeed with a bill for women's suffrage in July 1866 where he received support from a third of the members of parliament (Reeves & Haidt, 2018).

Today, research documented the malleability for gender patterns in modern societies. For example, female participation in the public political sphere increased constantly: while approximately 100 years ago women were not allowed to vote in all countries but one (New Zealand), today women are allowed to vote in all countries but one (Brunei; see: Pinker, 2018). These developments include that women participate in public schools and universities (OECD, 2015), women engage in politics, and are freed of abusive work (such as textile fabrics

---

[1] Note that there are more than two gender identifications. Due to the prevalence of female and male identities, no other gender identities were considered in this dissertation, though more research on other identities is necessary.

[2] Later on, alas, Max Planck met Lise Meitner and might have changed his mind.

in third world countries). Gender stereotypes began to change and are in motion nowadays (Gigerenzer, 2008; Eagly & Diekman, 2004). Important waves of feminism accompanied changes in the juridical systems such as that women may own property in marriages in the first wave of feminism or that women are allowed a proper education and share equal portions compared to men at universities in the second wave of feminism (Pinker, 2003). Modern economies and life styles required a rethinking and reorganization of ancient traditions, and an overcoming of gendered stereotypes (Hirschauer, 2014).

However, modern societies are far from having reached gender equity (Bourdieu, 2005; Beck, 1986). Resources remain unequally distributed amongst the genders (e.g., gender pay-gap) such that females are put at a disadvantage for embracing life chances in modern societies (Eagly, Beall, & Sternberg, 2004; OECD, 2015). The influential positions (leaders in companies, universities, schools, etc.) in modern societies remain male dominated (DeSilver, 2018).

In order to raise gender equitable practices in modern societies, multiple research paradigms evolved that differ in their theoretical underpinnings for conceptualizing gender and gender differences. For example, "Gender Studies" and "Geschlechterforschung" were identified as research paradigms that differ in motivations and research goals. On the one hand, "Gender studies" observed the differentiation of the genders as a phenomenon. A critical question was whether and how societies used the gender category as a differentiation (Hirschauer, 2014). "Geschlechterforschung," on the other hand, used gender as an analytic category and empirical variable in order to document phenomena with the help of the differentiation of the genders. It documented biological, social, psychological, or linguistic differences. In the anglosaxon culture, a similar differentiation of gender research was made between the schools of "gender feminism" and "equity feminism." On the one hand, "gender feminism" assumed that women continue to be "enslaved by a pervasive system of male dominance" (Pinker, 2003, p. 341). "Gender feminism" emphasized that an individual's gender is socially constructed. "Equity feminism," on the other hand, opposes sex discrimination and is rooted in the Age of Enlightenment-tradition and modern understanding of human nature, founded on rigorous empirical research (Pinker, 2003, p. 341). This dissertation (in its theoretical underpinnings, assumptions, and goals) is in keeping with what was called "Geschlechterforschung" and "Equity feminism," because gender will be utilized as an analytical category in order to devise insights on gender equitable practices that are founded in empirical research.

The gender-related research paradigms deduced implications from their research for the understanding of gender patterns in societies. For once, gender is not an ontological category, but rather an epistemological category: "One is not born, but rather becomes, a woman" (de Beauvoir, 1949, translation: PW). Knowledge about gender and gender stereotypes intricately shapes the life of every individual and enables the individual to gain knowledge about herself or himself concerning behaviors. The perspective on the performance aspects of gender (Butler, 1990) motivates the careful analysis of societal and social contexts that present relevant gender-related knowledge and make gender salient under certain circumstances.

In summary, women were historically marginalized and underpriviledged in societies which has ramifications until today, where gender discrepancies in allocation and access to resources put women at a disadvantage regarding life chances. Gender-related research shed light into the universality of these patterns of inequity.

## 1.3 Female underrepresentation in STEM

As an integral part of the academic realm in evolving societies, STEM subjects, until the end of the 19th century, had almost no female participants and remain females remain underrepresented until today (Osborne, Simon, & Collins, 2003). Large gender differences in vocational aspiration and enrollment numbers in STEM have been documented around the globe (OECD, 2015). In particular, in a study by Schoon (2001) with a UK sample merely about one in sixty of the girls at the age of 16 aspired a job in STEM (compared to around one in twenty for the boys). Even though young women comprise half the workforce in industrialized countries and 58 percent of college-bound population in the United States (Chen, 2013), young women only comprise 25 percent of the entire US STEM workforce (U.S. Department of Commerce, 2011). The numbers are most concerning in physical sciences. Compared to young men, only 25 percent of the students in introductory physics are females. This proportional share of female bachelor degrees in physics in the United States is even in decline again (Hodapp & Hazari, 2015; Stoet & Geary, 2018).[3] Further in the pipeline, a mere 20 percent graduating students at bachelor level are female (Hodapp & Hazari, 2015; Matzdorf & Düchs, 2013; Quaiser-Pohl, 2012). Focusing on the top 50 departments for physics, Handelsman et al. (2005) calculated that about 15 percent of the PhD positions in physics in these top departments are held by women, dropping to about 5 percent of full professor positions (see also: Chen, n.d.; D. J. Nelson & Brammer, 2010; Quaiser-Pohl, 2012; Smith, 2011). Only about 10 percent of physics faculty are females in the US (Gates, 2006) and 13 percent in Germany (IW Köln, n.d.). The cusp is the Nobel Prize in physics. After the award of the 2018 Nobel prize to one women (of overall three laureates), it took more than half a century since the last female physicist, Maria Goeppert-Mayer, received the physics Nobel Prize in 1963. The term ”leaky pipeline” has been coined to encapsulate the women’s constant (disproportional) drop-out towards the higher echelons in physics. Researchers conclude that gender equity is not realized today (Ferreira, 2002). A quote from 1975 remains true today: ”sex is probably the most significant variable related towards pupils’ attitudes to science” (cited in: Archer et al., 2012b) ... and physics in particular ... and physics in industrialized, democratic nations in particular (see: gender-equality paradox in Stoet & Geary, 2018).

This large underrepresentation of women in STEM and physics in particular is an individual and societal problem that should be solved. The motivations for why stakeholders and decision makers should care about these discrepancies in enrollment numbers in STEM between women and men will be introduced in the following section.

---

[3] Note that this does not mean that fewer females participate in physics compared to earlier days. However, relative to males the proportion of females is in decline again.

## 1.4 Motivation for STEM engagement

Modern societies have been attributed to be knowledge based, technological, and international (Friedman, 2005; Bereiter & Scardamalia, 2003). Today, innovative technologies and scientific findings shape individual lives and have the potential to enrich the human condition (e.g., Pinker, 2018; Rosling & Rosling Rönnlund, 2018) or destroy it (e.g., S. Harris, 2017). For the enriching potential, the synthesis of general relativity based on all prior theorizations (e.g., Newtonian mechanics, Euclidean space, ...) integrated novel mathematical concepts and physical ideas, and arrived at more fundamental principles for explaining phenomena that appear in the universe. Such a development constitutes societal progress and advances the individual thinking and problem-solving capabilities for good (see: Pinker, 2018; Rosling & Rosling Rönnlund, 2018). A variety of technical and medical applications evolved from the STEM domains, such as GPS from relativity theory, cancer therapies from DNA studies and refraction experiments, and many more. The bio-chemist and writer Isaac Asimov attributed technical innovations (compass, press, transistor, ...) as the greatest events in human history (Asimov & White, 1992). For the destructive potential, scientific discovery and engineering efforts such as nuclear power and nuclear warfare have the potential to destroy civilization. STEM literacy comprise part of the solution to enrich the human condition through technology and deal with destructive potentials of technology.

STEM literacy was attributed to be a potential solution for problem of global inequity. Economists and developmental pundits proposed that STEM subjects are amongst the primary factors to achieve a promotion of underdeveloped countries to catch up with more developed countries and thus raise global equity (Radelet, 2015; Deaton, 2013; Rosling & Rosling Rönnlund, 2018). With the words of the political theorist Hannah Arendt: ”[E]s ist lediglich dem Aufkommen der modernen Technik und nicht irgendwelchen modernen politischen Vorstellungen, darunter auch revolutionären Ideen, geschuldet, dass sich diese Situation der Menschen [i.e., die Menschen von den Lebensnotwendigkeiten zu emanzipieren; author] zumindest in einigen Teilen der Welt geändert hat” (Arendt, 2018).

Educational institutions in modern societies need to educate and engage individuals in STEM, because a STEM literate citizenry enables modern societies to tackle global problems and participating in STEM opens life chances to individuals. Consequently, Tate (2001) proposed STEM education to be a civil right. Half a century earlier, Snow (1958) argued that science knowledge is a ”moral imperative” because of the potential to alleviate suffering and tackle global problems. Enriching the STEM communities as a literate member is thus a contribution to the proliferation of modern societies and the human condition, and a personal advancement for life chances. In order to unpack this idea further, three motivations will be presented that are relevant to STEM engagement (see also: Wiesner, Schecker, & Hopf, 2011). First, the societal motivation for STEM engagement, followed by a personal motivation and an intrinsic motivation for STEM engagement. While the intrinsic motivation is probably the most compelling reason for STEM engagement (Deci & Ryan, 2000), all three motivations are tied to the goal of ameliorating the human condition and ensuring the prosperity for modern societies.

The societal motivation recognizes that STEM engagement is vital for prosperity of modern societies. This motivation is often mentioned in sidenotes in popular textbooks of practicing scientists. Many of these scientists explicitly say that this is not the main reason why they pursue science (e.g., Butterworth, 2015; NOVA, 2004). Yet, the appeal of this motivation is a grasp for the impact STEM has in modern societies. Kaku (2012) mentions a finding by Oxford Encyclopedia of Economic History where it is claimed on the basis of a review of studies that technical innovations account for as much as 85-90 percent of income increases in England and the United States since 1780 (also: Committee on Prospering in the Global Economy of the 21st Century, 2005). Today, alone one third of the world's gross national product is based on applications of quantum theory (Fritzsch, 2008), and estimates say that a single cell phone yields another USD $3,000$ to the GDP of a developing country advancing underdeveloped countries in particular (Pentland, 2007). Another aspect is the economical wealth and public health that results from STEM. For example, in 1909 the chemists Carl Bosch and Fritz Haber improved a process to harvest methane of animal feces and are meant to have saved the lives of 2.7 billion people with this technique (many other interesting numbers about STEM innovations in: Woodward, Shurkin, & Gordon, 2009). Furthermore, the Institute of Physics analyzed that physics-related vocations yield a quarter of the British economic productivity and workers in physics-related sciences yield double the gross net value compared to an average worker in industry (IOP, 2012) and the US Department of Commerce submitted that the future earnings of workers in STEM fields are, on average, 26 percent higher than salaries from workers in non-STEM fields (Langdon, McKittrick, Beede, Khan, & Doms, 2011). This economic side of STEM and physics is the visible effect of the potential of STEM to advance human knowledge and theory (Farmelo, 2009). Consequently, STEM subjects are the backbone of health, wealth, prosperity, progress, innovation and development of modern societies (e.g. Diamond, 1997; Sowell, 1997; Randall, 2011; Pinker, 2018). Business experts agree that STEM is vital for the well-being and (economic) growth of industrialized nations (BusinessEurope, 2011) and a cornerstone to adequately responding to future challenges, like climate change, outsourcing of natural resources, or population growth (European Commission, 2014; Wieman & Perkins, 2005).

The personal motivation entails the level which recognizses the opportunities and potentials that STEM engagement brings to the individual in the form of external rewards. Policy makers recognized that STEM domains have a high demand of workers entering these domains. Future work opportunities will be dominated by STEM. It is expected that much of future job growth will be in STEM (National Academies, n.d.). For example, the European Commission anticipated an overall 9 percent employment growth for STEM between 2010 and 2020 (European Commission, 2012). However, dire prospects were drawn with respect to the available future STEM workforce. The fact that relatively fewer young people entering tertiary education in the future (changes in demographics) and the approaching retirement of high numbers of current labor market participants in STEM are but two reasons for why a shortage of skilled workers in STEM will appear (Dobson, 2014). Though the concept of shortage of workforce in STEM is debated (National Science Foundation, 2015), some researchers estimated a need for 1 million more college graduates in STEM fields in the next decade in the US to maintain high living-standards and prosperity (PCAST, 2012). In Germany, in 2016 over $400,000$ positions in STEM were vacant (IW Köln, 2016), and this increased with an all-time high in 2018 with 486, 600 open positions (IW Köln, 2018).

Finally, the intrinsic motivation for STEM engagement recognizses the fullfulment that STEM professionals experience in their engagement with STEM subjects. The criticism of the societal and personal motivations as they are outlined here is the inclination to instrumental reasoning for recruitment of students. This is not to say, from a moral philosophical stance, that such instrumental reasoning is wrong, because instrumentalization can be for beneficial purposes. However, organizational researchers have pointed to the fact that the mere inclusion of career chances, work capabilities, and economic motivations are less reflective of social justice theory (Martin, n.d.). For example, individuals that are brought into a domain under such auspices are dehumanized and objectified. The intrinsic motivation for STEM engagement seems also reflective of researchers' accounts for why they pursue STEM. A psychological research base can even buttress the intrinsic motivation for STEM engagement (Ryan & Deci, 2000). The pursuit and commitment to scientific thinking and progress is attributed as amongst the deepest satisfying activities for humans (Csikszentmihalyi, 2005, p. 253). Personal ancedotes and interviews of scientists provide examples for the expressed satisfaction that seems to come along with STEM engagement. The famous cosmologist Vera Rubin described her developing interest to become a scientist in an interview. She highlighted the following "It [her interest in physics] really came from the sky. In the late 1930's, I remember, there was an alignment of five planets. That impressed me. I didn't realize at that time how likely such a thing was. Then there were several auroral displays. It was those things that really [captured my interest]. It was the visual experience," and further "The only motivation that I can point to is just plain old curiosity. That really has motivated an enormous amount of my work." (Lightman, 1989). Albert Michelson, who devoted his later life to measuring the speed of light to then unprecedented precision, was responding to the question on his motivations to devote his later life to measuring the speed of light to such precision with the words: "it was fun" (Chandrasekhar, 1987, p. 25). Henri Poincaré speculated about the scientists' motivations to pursue science:

> Der Wissenschaftler widmet sich dem Studium der Natur nicht, weil es nützlich ist. Er studiert sie, weil sie ihm Freude bereitet. Und sie bereitet ihm Freude, weil sie schön ist. Wenn die Natur nicht schön wäre, wäre sie es nicht wert, verstanden zu werden, und das Leben wäre nicht lebenswert ... Ich meine die intime Schönheit, die aus der harmonischen Ordnung ihrer Teile erwächst und die eine reine Intelligenz erfassen kann (Chandrasekhar, 1987, p. 59).

The societal, personal, and intrinsic motivation for STEM engagement are reasons for why educators should care to motivate students for STEM. The knowledge that one's actions are important for the society at large and the individual is important to emphasize. Given the importance of STEM engagement and the requirement for talented students entering the field, it can be seen as alarming that even amongst the highest achieving students in STEM subjects in school, only a tiny fraction is interested in STEM and aspires to choose a STEM career (Haste, 2004; Prenzel, Reiss, & Hasselhorn, 2009).

## 1.5 STEM enrichment programs

An educational measure to facilitate motivation for STEM and particularly encourage and test high-achieving students in STEM are STEM enrichment programs. STEM enrichment programs are implemented in educational systems around the globe (J. R. Campbell, 2000). In the spectrum of STEM enrichment programs, STEM competitions are meant to identify and promote high-achieving young students. STEM competitions have been implemented for more than 50 years. Amongst the STEM competitions, the so-called Science Olympiads employ a competitive format where in sequential stages the best students are choosen to compete on an international level. In Germany, from initially around 1000 participants from more than 300 schools in such a Science Olympiad in STEM, the five highest achieving students compete on an international level against students from more than 80 countries (for an overview see: Köhler, 2017; Petersen & Wulff, 2017). The Science Olympiads appear in adolescence, around 14 to 20 years of age (Köhler, 2017). These programs comprise subsequential stages with increasingly more complex problems and eventually contestants meet at seminars where they take experimental and theoretical exams and receive training on problem solving and science contents. This is oftentimes accompanied with a visit of a research site where the respective seminar is located. Thus, Science Olympiads tie to societal, personal, and intrinsic motivations (e.g., J. R. Campbell, Wagner, & Walberg, 2000; Pyryt, 2000; Subotnik & Arnold, 1995), because students experience societal importance of STEM during their visits in research sites, meet practicing scientists who eventually inform vocational decisions of the students, and immerse in specialized content knowledge with the urge to solve particular problems.

In some respects, the Science Olympiads meet the alleged goals of identifying and promoting high-achieving students in STEM as assessed through cognitive and affective measures. For example, participants in Science Olympiads report that they enjoy their Science Olympiad experiences (Abernathy & Vineyard, 2001). There is further evidence that particularly successful candidates report a positive impact on their future job aspirations in STEM through such programs (A. X. Feng, Campbell, & Verna, 2001; Oswald, Hanisch, & Hager, 2004; Subotnik, Duschl, & Selmon, 1993; Wirt, 2011). Also positive effects on cognitive measures are documented for such enrichment programs (Kulik & Kulik, 1992; Wai, Lubinski, Benbow, & Steiger, 2010). Furthermore, the participating students tend to contribute to society above average as measured through patents, publications and the like (J. R. Campbell et al., 2000; Wai et al., 2010; Marsh, Chessor, Craven, & Roche, 1995). With the words of talent searcher Jonathan Wai: ”Whether we like it or not, these people really do control our society” (cited in: Clynes, 2016, p. 153). It would seem that enrichments such as the Science Olympiads help promoting the STEM subjects and identify and promote high-achieving students in STEM.

However, at this points the threads in this introduction coalesce: The Science Olympiads as educational programs share the same issues of gender inequity as STEM subjects and the society at large, namely young women are largely underrepresented in these programs. This begs the question whether resources and procedures in Science Olympiads are biased against young women. If so, what and how can these gender differences in engagement be challenged through specifically designed interventions?

While all Science Olympiads share inequity amongst the genders, the inequality is most salient in the Physics Olympiad (Steegh, Höffler, Keller, & Parchmann, 2019). In physics competitions such as the Physics Olympiad a disproportional decrease in representation of young women can be registered throughout the rounds of these competitions, worldwide. For example, in the Physics Olympiad around 18 to 27 percent of participants in the initial round are females, while only 7 percent at the international final are females (Petersen & Wulff, 2017). Young women have a lower share amongst olympians in the first stage in Science Olympiads such as the Physics Olympiad, and leave the competition disproportionally over the rounds. In a news feed on the 49th Physics Olympiad in Lisbon, the European Physics Society urges: ”It should be noted that the number of girls participating in the IPhO is quite small (<10%) and it has not been significantly increasing in the last few years, reflecting the fact that in most countries there is a reduced participation of girls at the national Physics Olympiad. Also, the number of female team-leaders is small. It is urgent that this problem be addressed with positive measures to motivate girls to participate” (EPS, 2018).

The initially low participation numbers and the so called ”leaky pipeline” (i.e., disproportional dropout over the stages of the competition) are concerning for multiple reasons. For example, many STEM subjects (like biology and chemistry) raised the proportion of female participation. However, concerning is the fact that this trend is much slower in physics and the Physics Olympiad (see: Hazari, Sonnert, Sadler, & Shanahan, 2010). Furthermore, assuming that physics requires students with the highest abilities like problem solving in schools (Heilbronner, 2012; Lubinski & Benbow, 2006; Phillips, Barrow, & Chandrasekhar, 2002), representative samples with ability tests at the onset of college predict physics or engineering would at the lowest comprise 33 percent females (Hyde, Lindberg, Linn, Ellis, & Williams, 2006; Halpin, Feb 18 2018). But the proportion of female physics bachelor enrollment stagnates around 20 percent for the last decade (Hodapp & Hazari, 2015; Hyde et al., 2006). There is evidence, though, that enrollment patterns can be raised. For example, the cross-cultural variability in proportion of female participation in STEM is higher in Hong-Kong-China compared to most males throughout the world, and almost on par (or sometimes higher) with their male peers in Hong-Kong-China in mathematics and science abilities (OECD, 2015). This is further buttressed by research that demonstrates that skills like problem solving and spatial abilities are malleable with training (J. Feng, Spence, & Pratt, 2007; Uttal et al., 2013; Spelke, 2005; Kersey, Braham, Csumitta, Libertus, & Cantlon, 2018). On the societal level, scientific and technological knowledge as well as innovativeness of societies become hampered when young women do not engage in STEM to their full potential since young women’s capacities remain an ”untapped source for furthering scientific knowledge” (Ferreira, 2002; Kenway & Gough, 1998). The legitimacy and image of physics in particular suffers, since an equal participation of women in physics could contribute to reverse trends of public low interest in science and raise overall support (e.g., financial resources) for STEM (Hazari, Tai, & Sadler, 2007), such that scientific literacy in modern societies can also thrive (Hazari et al., 2007; United Nations Girls’ Education Initiative, 2017). Chemistry Nobel laureate Ben Faringa said: ”We should always encourage women to look at the sciences, the diversity is important for our culture and for our education” (Schulkes, Hong, & Versendaal, 2018).

Explanations for impaired engagement for girls and young women in STEM and physics in particular were sought in the complex interplay of individual factors with historical-cultural, structural, and social factors (Hyde, 2014; Osborne et al., 2003; Scantlebury, 2014; Ceci, Williams, & Barnett, 2009). In particular, schools as institutions and early upbringing in the family play an important role in determining the path of young women away from physics. With regards to Science Olympiads, anthropological (D. E. Brown, 1991), psychological (Eagly et al., 2004), and biological (Trivers, 1972) literatures point to the fact that males might be more inclined towards assertiveness and competitiveness, which resonates with enrichment programs such as Science Olympiads. These literatures can be taken as motivations to extend the Physics Olympiad towards the motivations and identities of young women (relational justice), such that a students who identify with historically underserved groups in STEM can be addressed and engaged for STEM, which would serve the outlined agendas of DPG and APS.

Studies that extend educational programs in physics in order to be more gender-inclusive gained knowledge on different strategies. In order to build upon these efforts and establish an understanding of factors for the underrepresentation of young women in physics, a literture review will be done in chapter 2. Chapter 2 will emphasize that large parts of the decisions of young women away from physics are deliberate and result from experiences in social learning contexts in physics (e.g., Ceci et al., 2009). The problem of young women's underrepresentation can be understood through a focus on the person-environment interaction. Consequently, a model for individual action and environment factors will be presented in chapter 2 that guides the empirical research in this dissertation.

# Chapter 2

# Theoretical background

> *Among the many methods which he may use [...] one method seems to me worth mentioning. It is a variant of the (at present unfashionable) historical method. It consists, simply, in trying to find out what other people have thought and said about the problem in hand: why they had to face it: how they formulated it: how they tried to solve it. This seems to me important because it is part of the general method of rational discussion. If we ignore what other people are thinking, or have thought in the past, then rational discussion must come to an end, though each of us may go on happily talking to himself.*
> — Karl Popper, *The Logic of Scientific Discovery.* 1959, p. XX.

Understanding gender inequity and promoting gender equitable practices in physics requires knowledge that has been advanced by different research disciplines. A research model and an evaluation model will be motivated in chapter 2. In order to develop a research model for the empirical studies in this dissertation, chapter 2 will start with outlining basic assumptions that will be made for factors and constraints to individual development. Individual development will be discussed in relation to identity development, agency, and individual engagement in academic domains. These constructs are discussed with regards to gender equity in STEM (Varelas, Tucker-Raymond, & Richards, 2015; Fredricks, Hofkens, Wang, Mortenson, & Scott, 2017; Hazari et al., 2010) and particularly relate individual behavior to social environmental factors. The interaction of individual behavior with social environmental factors for gender inequity will be unpacked to relate to macro, meso, and micro levels of constraints. On this basis, a research model for this dissertation, namely the situated agency model, will be developed that seeks to integrate the existing research. Alongside the situated agency model, an evaluation model for educational interventions will be motived that outlines the logic of the empirical intervention studies for this dissertation. At the end of chapter 2 the overarching research questions (RQ) for the empirical studies will be motivated.

## 2.1 Individual development

Individual development is the product of constant and complex interaction of an individual with social contexts (e.g., Mercier & Sperber, 2017; Mischel, 1996).

Csikszentmihalyi (2005) identifies three sources that influence individual development: evolution, social context, and the self. Biological potentialities (Bussey & Bandura, 1999; Roth, 2015), the social context, and the self either constrain or enable individual development, and the advancing symbolizing capacities of the individual frees her or him from social pressures from the immediate environment (Bandura, 2018). Other conceptualizations of individual development and individual differentiation such as basic needs theory (Maslow, 1968; Ryan & Deci, 2000) or moral developmental theories (Kohlberg, 1984) resonate with this proposal. These theories recognize the same three fundamental and hierarchical layers. First, evolutionary pressures shape human development. The general finding from behavioral genetics is that all individual differences (e.g., intelligence) are partly heritable (Rizzi & Posthuma, 2013; Rost, 2010; Pinker, 2018; J. J. Lee et al., 2018). For example, biological research suggests that interested activity has genetic foundations in all mammals (summarized in: Hidi & Renninger, 2006). Besides the biological roots of development and behavior, societal pressures (e.g., expectations) shape an individual's engagement in social contexts. E.g., humans are in constant interaction with their respective environments and form an identity through this interaction (Côte & Levine, 2002; Lave & Wenger, 1991). The self integrates expectations from the social environment and directs the interaction with the environment (Csikszentmihalyi, 2005). Self-fulfillment and generation of meaning range amongst the most complex goals in individual development. The capacity of the individual for self-direction and autonomy indicate a fulfilled development (Kohlberg, 1984; Loevinger, 1976; Maslow, 1968).

The processes that underlie individual development integrate biological potentialities, social contexts, and the self. Maturana and Varela (1987) postulate that individual development is the product of the interaction of the individual and the social context where neural correlates are activated and formed constantly. Individual behaviors are adaptations to social contexts. Piaget (1976) theorized that two mechanisms are fundamental in this interaction with social contexts: assimilation and accomodation. Assimilation is the biological adaptation of the individual to the social context or vice versa, whereas accomodation is the adaptation of cognitive schemata that the individual has acquired. As such, the human is an adaptable, open system with biological contraints. Through assimilation and accomodation the individual seeks an equilibrium with the surrounding environment, moderated through the cognitive process of equilibration where concepts are constantly formed and revised until a coherent interpretation of the social context is acquired (e.g., Chapman, 1988). The developmental process involves the formation of a self-concept. The formation of a self-concept is conceptualized as a process of differentiation and integration between an external world and an inner world (e.g., Marsh, 1984). Vygotsky (1978) emphasized the cultural dimension of development and learning where every higher cognitive functioning requires the immersion in a fostering social environment where repeated interactions with others are necessary conditions for development and learning in a so-called "zone of proximal development" (Lave & Wenger, 1991; Bransford, Brown, & Cocking, 2000; Rogoff, 1990). Rogoff (1990, p. 28) suggests that "the child and the social world are mutually involved to an extent that precludes regarding them as independently definable."

More specifically tied to social contexts in modern societies, Bussey and Bandura (1999) argue that individual development is a non-deterministic process that is shaped through reinforcement and punishment by social networks like parents, peers, institutions, and mass media (also: Bandura, 2001), where peers outperform parents in the upbringing of the individual (J. R. Harris & Pinker, 2014). A key mechanism for Bussey and Bandura (1999) is the process of modelling and predicting one's environment. Individuals model others in their environment, especially if those are conceived as powerful and admirable, so that their own conduct and self-formation is influenced by them. A reciprocal causation of internal personal factors, behavioral patterns, and environmental influences captures this process (Bandura, 2001).

### 2.1.1 Identity

Individual development in modern societies is neither linear and nor unidirectional. Development in modern societies is increasingly linked to individualization, such that building an identity is "one of the pivotal developmental tasks of adolescence" (S. J. Schwartz, Pantin, Prado, Sullivan, & Szapocznik, 2005). Identity is subjective sense of self-sameness and continuity over time (Erikson, 1968). Klimstra et al. (2010, p. 191) content: "The formation of a stable identity is the single most important developmental task of adolescence." Identity refers to the process of searching for and settling on a set of commitments to personal standards and life roles (Meeus, Iedema, Helsen, & Vollebergh, 1999), and researchers speak of a personal identity when an individual has adopted a clear and internally consistent set of goals, values, and beliefs (see: S. J. Schwartz et al., 2011). Identity development largely happens in the interaction between the self and the social context (Meeus, 2016; Burke & Stets, 1998), on micro and macro levels that the individual many not even have access to (Lichtwarck-Aschoff, van Geert, Bosma, & Kunnen, 2008). Identity development entails the negotiation of multiple identities that an individual holds, e.g., the social identity such as a gender group identity, the personal identity such as the association of personality traits with the self, and the domain-specific identity such as the affiliation with a school subject or a knowledge domain (Burke, Owens, Serpe, & Thoits, 2003). Other researchers identify other forms of identity such as social and personal identity (Burke et al., 2003), or, amongst others, A-identity (affinity with activities of certain groups) and D-identity (affinity with personality traits through discourse and interaction with others) (Gee, 2000). In any case, identity is not a monolithic construct, but multiple identities become salient and contested in different social contexts (Steele, 1997).

An individual typically acts in alignment with her or his identities in a given social context (Garcia & Cohen, 2012; Burke & Stets, 1998). In particular, the mechanisms of ingroup-outgroup, and identity standards provided by social roles can enhance or impair an individual's behavior in the situation. In fact, expressing an identity has been found to be a more pervasive feature in social contexts compared to expressing what one knows (identity-protective cognition: Tooby, 2017; Kahan, Jenkins-Smith, & Braman, 2010). For example, Eckert (1990) observed that students' participation in activities and classroom contexts functioned in important ways to express and maintain their affiliations in communities (e.g., peer groups). Persistent engagement in communities results in recognition by others as a certain "kind of person" in a context (Gee, 1999, p. 99). Identity is thus "coconstituted by the individual's relation to communities and by the relation of those communities to the individual" (as cited in: Greeno, 1998, p. 6, Mead, 1934).

Identity develops in a process of psycho-social differentiation and integration in sequential stages (Erikson, 1968). Identity development is a process that is achieved through exploration and commitment. Abstracting the model of Erikson (1968), Marcia (1966) proposed a conceptualization of identity development, where he postulated subsequential statuses for identity development. There is converging evidence that the primary status can be described as identity diffusion and the desired status as identity achievement. The status of identity diffusion refers to the state where the individual has no sense of choices and not made commitments. In the identity achievement status the individual identifies with a certain domain or community (i.e., commits to it). In between the statuses of identity diffusion and identity achievement, identity foreclosure and identity moratorium are located. These statuses are characterized by low explorations and forstalled commitment. The exact sequence of identity foreclosure and identity moratorium is not understood, and more research is needed to clarify the development (Meeus, 1996).

More recent works differentiate different dimensions for conceptualizing identity (Lichtwarck-Aschoff et al., 2008). Lichtwarck-Aschoff et al. (2008) differentiate a micro-macro dimension, and a static-dynamic dimension for identity research. This conceptualization is not contradictory to the former work, but it rather presents a finer-grained systematization for identity analyses. Both dimensions, micro-macro and static-dynamic, relate to developmental processes for identity. However, crucial differentiations are the notion of conscious versus unconscious access to identity, individual versus group level aggregates, and the time intervals for sampling (Lichtwarck-Aschoff et al., 2008).

Commitment to a certain domain (e.g., a school subject) is a crucial process in identity development. Several prerequisites seem necessary for an individual to commit to a domain. McClelland (1978) proposed a set of motives that individuals share in his achievement motivation model. According to his model, achievement motives (excel in relation to a set of standards), power motives (influence an organization and others), and affiliation motives (close personal relationships) are key to human engagement in social contexts. Later on, Deci and Ryan (1985) developed a theory of self-determination, in which the authors propose that the intrinsic motivation for a domain is key, and where competence, autonomy, and recognition moderate the development of self-determination (Deci & Ryan, 2000), and ultimately of an identity. Interest researchers pointed to the fact that the relation of the constructs of competence, interest, social-relatedness, and autonomy is reciprocal (Hidi, 2000) and found that interest is domain-specific (Hidi & Renninger, 2006). From a social justice perspective an influential conceptualization is given by Nussbaum (2007). Nussbaum (2007) proposes basic experiences of humans such as social affiliation, and cognitive capacities that enable an individual to feel as an individual in a domain. Therefore, they can be seen as *conditiones sine quibus none* for the striving towards identity achievement. Simon (1965) captured the idea of identity and basic motivations:

> Man is a problem-solving, skill-using, social animal. Once he has satisfied his hunger, two main kinds of experiences are significant to him. One of his deepest needs is to apply his skills, whatever they be, to challenging tasks—to feel the exhilaration of the well-

> struck ball or the well-solved problem. The other need is to find meaningful and warm relations with a few other human beings—to love and be loved, to share experiences, to respect, to work common tasks (Simon, 1965, p. 110).[1]

Following this quote, the individual's motivation through the expectation to be successful in a domain and the need to feel a sense of belonging to the domain are constitutive for identity development (see also: Goyer et al., 2017).

The process of domain identity development is intricately linked to motivations such as social affilitation and belonging, competence expectations, autonomy, power, and interest. For example, physics identity development can be conceptualized as the student's subjectively endorsing herself as a physics person that is informed by the recognition from others to see her as a physics person (Kane, 2012). The following constructs (or resources) were found to be integral to physics identity formation for students: interest, recognition, sense of belonging, competence beliefs, and performance (Cribbs, Hazari, Sonnert, & Sadler, 2015; Hazari et al., 2010; Carlone & Johnson, 2007).

- Interest is the enjoyment the student has in dealing with physics. Early interest in physics in middle and high school was found to be a strong predictor of later academic choices (Maltese & Tai, 2011; Tai, Qi Liu, Maltese, & Fan, 2006). For math interest it was shown that it was related to taking up of advanced courses in math (Köller, Baumert, & Schnabel, 2001). An explanatory link for the relationship between interest and persistence has been found to be a student's identity in a domain: as they become interested, they start to see themselves as that "kind of person," and ultimately choose to persist. Hidi and Renninger (2006) emphasize the intricate relation of situational interest and individual interest such that interest is constituted by the social environments that an indiviudal is engaging in.

- Recognition is the students' perception of how much others see her or him as a physics person and is therefore closely tied to the social environment. The recognition by meaningful others (parents, peers, teachers) as a "physics person" is strongly related to having a positive perception of the domain (Bleeker & Jacobs, 2004; S. L. Turner, Steward, & Lepan, 2004). Recognition by others as a "physics person" in high-school has been established to correlate with physics identity and intended physics career (Hazari et al., 2010). Furthermore, the lack of recognition can lead to disrupted identities (Carlone & Johnson, 2007). Sense of belonging refers to positive affilitation with the domain (C. Good, Rattan, & Dweck, 2012), and is positively related with other constructs such as self-efficacy (T. M. Freeman, Anderman, & Jensen, 2007). It is also linked to student retention and persistence in undergraduate education, and declines over the course of university education (Hausmann, Schofield, & Woods, 2007). Sense of belonging predicts also the intent to pursue math in the future (C. Good et al., 2012).

- Competence beliefs entails the students' belief in their ability to be good at the required tasks and understanding the domain (e.g., physics prob-

---

[1] The female pronouns (she/her) are clandestinely added to this quote.

lems). Competence beliefs have been established to be important at the outset of engagement in a domain (Bussey & Bandura, 1999). The belief of self-efficacy in a domain, which is similar to competence beliefs although more task specific, was found to be a variable that predicted students' performance and later educational outcomes (Pajares & Graham, 1999), and also student's commitment to science (Chemers, Zurbriggen, Syed, Goza, & Bearman, 2011). It was demonstrated that students on survey items do not distinguish between competence and performance so that these two are essentially one dimension in empirical studies (Cass, Hazari, Cribbs, Sadler, & Sonnert, 2011). In sum, these four constructs facilitate students' identity development in a domain. The exact structural relation and interdependence of these constructs has been quantitatively established, and it appears that self-efficacy undergirds the domain identity (Cribbs et al., 2015). However, interest and recognition were found to be mediating variables, where recognition has a stronger effect on mathematics identity (sense of belonging was not included in the model) (see Figure 5 in: Cribbs et al., 2015).

### 2.1.2 Agency

Individual development in general and identity development in particular are seemingly complex processes. A construct that links constraints for individual development in social contexts and the self is individual agency. Agency as a scientific construct received support for directing the research focus on factors that impair engagement for individuals that arise from the social context. Ryan and Deci (2000, p. 68) content: ”At their best, [humans] are agentic.” The concept of agency can help to escape circular argumentation where students' lacking identification is associated with a mismatch of the student with the domain. Agency can be attributed to an individual in a social context, rather than be construed as an individual cognition. Agency was called the lever in human development (Bandura, 2001). It is construed as the ”power to originate actions for given purposes” (Bandura, 2001; D. Schwartz, 1997, p. 6), irrespective of the outcome. Other authors further this understanding and configure agency ”as a capacity to institute new or unanticipated modes of behavior” (McNay, 2000; Varelas et al., 2015, p. 21). From within social justice theory, (Sen, 1984, p. 203) defines ”agency freedom” as ”what the person is free to do and achieve in pursuit of whatever goals or values he or she regards as important.” Such agency comes in three forms, as identified by Bandura (2018): personal agency (personally controlable agency), proxy agency (influencing others who have resources, means to act on their behalf towards desired outcomes), and collective agency (pooling knowledge, and act in concert with others).

On the one hand, individual cognitions play a key role for agency. Given that individuals seek to engage in domains, agency is made possible through intentionality, forethought, self-regulation, and self-reflectiveness (Bandura, 2001). Bandura notes that in fact ”efficacy believes constitute the key factor of human agency” (Bandura, 1997, 2000, p. 3). Furthermore, efficacy believes predict academic choices as outlined above. For example, self-efficacy was found to be more predictive than personality-based theories for vocational choices (Lent, Brown, & Larkin, 1987). Expectancy for success has been found to predict later engagement in a wide array of domains, and in particular with a focus on gender aspects of engagement (Eccles, 2011). On the other hand, agency is determined by the social structures that the student is embedded in. Consequently, social structures have been ascribed a key role for agency and agency is not a mere cognitive construct. Social structures have a ”dual” nature (Giddens, 1981). Giddens (1981, p. 27) configures structures as ”both the medium and the outcome of the practices which constitute social systems” (Bandura, 2008). Thus, through actions the individual both inscribes in social structures, but at the same time actions are the product of surrounding social structures (Giddens, 1979, 1984). Social structures and social identities (e.g., gender, class, or ethnicity) are intricately linked (Sewell, 1992). An individuals' actions are anticipated in reference to social categories such as gender, class, or ethnicity.

### 2.1.3 Engagement

Much of the development of adolescents in modern societies happens in mainstream institutions in formal or informal learning environments, where main features are interactions with peers, teachers, mentors, and engaging in cognitive tasks such as concept formation and problem solving. Thus, student development happens in constraining social contexts. It is a primary function of formal and informal learning institutions to maximize learning gains and literacy for all students. A key concept that captures the students' interaction with formal and informal learning contexts is engagement. Engagement in learning contexts refers to the quality of personal investment in an academic setting that is related to cognitive, affective, social, and behavioral dimensions (as in: Fredricks et al., 2017; Eccles & Wang, 2012). Cognitive engagement refers to learning strategies and self-regulated learning, emotional engagement focuses on positive and negative relations to teachers and peers, as well as interest in learning activities, behavioral engagement refers to participation, effort, attention, or positive conduct, and social engagement refers to the quality of social interactions in a learning setting (summarized in Fredricks et al., 2017). Student engagement is thus the product of facilitation of agency throughout education and a positive identity development. Context, self (relatedness, autonomy, and competence), action, and outcomes form the complex in which engagement can be facilitated (Skinner, Furrer, Marchand, & Kindermann, 2008). Engagement is a product of external dynamics (supportive environments that facilitates relatedness, autonomy, and competence) and internal dynamics that are part of engagement or disaffection. Engagement then leads to learning and achievement.

### 2.1.4 Identity, agency, engagement, and gender

Identity development, agency and engagement have been criticised to overemphasize male issues (e.g., autonomy) and fail to account for female issues. Major concerns were that women compared to men place different values upon certain aspects of identity development and that the foci of previous identity conceptualizations might be inadequate for the subgroup of women in particular (see: Josselson, 1996). For example, Josselson (1996) showed that women compared to men place more emphasis on interpersonal processes for identity formation. This implies that the traditional identity configurations do not capture the identity formation process for females adequately. Thus, diagnosing that female students lack an identification with physics might lead to reduced attention for that student and establish a circular argument where lacking identity leads to less attention and vice versa: to claim that female students lack an identification with physics, and that therefore physics is not for females. The risk is to pose that these differences are causal (for circularity reasoning regarding women in STEM see: Spelke, 2005; Ceci et al., 2009).

In order to reduce the risk of overemphasizing male issues in the theoretical framework and in order to derive a model that helps improving physics learning environments towards gender inclusiveness, a literature review of other theoretical frameworks with a gender focus is presented in Table 2.2. A model for situated agency that differentiates three levels that enable or constrain agency for young women in physics will be proposed. The differentiation between three levels: micro, meso, and macro for understanding individual engagement and development is elaborated in Bronfenbrenner (1979). These three levels are also important to understand agency (Table 2.2). The contents for the situated agency model stem from theorizations for gender differences that will be reviewed next (see Table 2.2).

**Macro level:** The macro-level considers theoretical frameworks that are concerned with societally shared notions about groups, domains, etc. that potentially affect an individual's agency. For example, social practice theory states that human identities shape social existence in the world and that humans act in reference to institutional structures and cultural norms (e.g., gender discourses) (Holland & Lave, 2001). Consequently, student engagement and agency will be constrained by their respective gender-group identity such as when a self-identified man will not enter a symbolically-marked female lavatory. In a similar line, social role theory posits that a society's division of labor shapes psychological gender differences of humans. In social role theory gender differences result from different adaptations to specific requirements and expectations for the respective gender group (Hyde, 2014). Historically, societies provide specific social role requirements for males and females (productive versus reproductive, respectively). An individual that self-identifies as male might learn that as a male he shall be assertive in social contexts, which is expected of him, whereas a female might learn that she shall be communal, altruistic, and emphatic. Expectations and cognitions in social contexts can be broadly characterized by these expectations. Fiske, Cuddy, Amy J. C., Glick, and Xu (2002) demonstrated that competence (assertiveness) and warmth (compassion, empathy) are of particular importance for social cognitions such as stereotypes. For example, on average, women are more associated with warmth, whereas men are more associated with competence (Kite, Deaux, & Haines, 2008).

Eagly and Wood (1999) propose the gender role theory where they state that, on average, social roles that are available for the respective genders shape also psychological gender differences. Adopting to social roles and socially held discourses prevent individuals from being stigmatized and socially ostracized (Goffman, 1963), where stigmatization results from non-conformity to mainstream expectations. It is always easier to act in accordance with broad stereotypes (mainstream expectations) (Kahneman, 2012) or in alliance with mainstream discourse, in spite that stereotypes cause much harm to societies through stigmatization processes and a climate of violence. Stigmatization might result in symbolic violence (i.e., the imposition of an ideology which legitimizes and essentializes the status quo). For example, Bourdieu (2005) recognizes the symbolic violence that is impinged upon marginalized groups in modern societies.

Table 2.1: Frameworks and theories that explain underrepresentation of females in STEM.

| Level | Definition | Example | Theory |
|---|---|---|---|
| Macro | Macro-level factors are societal structures such as discourses (broad assumptions of truth) that shape identities of students. Macro-level factors are rather unspecific with regards to individual cognitions, and the mechanisms that foster learning. | Gender stereotypes shape the social roles and identities of individuals in a society; domain curricula broadly represent the required thinking and knowledge that is necessary to engage in this domain. | • Social practice theory (e.g., Eisenhart & Finkel, 1998; Holland, Skinner, William, & Cain, 2001)<br>• Social/gender role theory (Eagly & Wood, 1999; Hyde, 2004) |
| Meso | Meso-level factors refer to the social contexts in which learning happens. These contexts incorporate their own discourses (often aligned with macro-level discourses), and can make social identities salient through situational cues. | Gender stereotypes, as socially shared notions, can be become salient to certain learners in classrooms and impair performance and agency for affected students. | • Situated learning (Lave & Wenger, 1991)<br>• Self-affirmation theory (Steele, 1988)<br>• Balanced identity theory (Greenwald et al., 2002)<br>• Stereotype content model (Fiske et al., 2002)<br>• Stereotype inoculation model (Stout et al., 2011)<br>• Self-to-prototype matching (Niedenthal et al., 1985)<br>• Social-identity theory (e.g., Burke & Stets, 1998) |
| Micro | Micro-level factors refer to individual attitudes, cognitions, values, motives, needs, and the like. Such individual cognitions enable (or hinder) students to exercise agency in a social context. | Individual cognitions (such as self-efficacy) towards domains and values (such as interest) form the basis for agency in this domain. | • Brain-type hypothesis (Baron-Cohen, 2012)<br>• Evolutionary psychology (Buss & Schmitt, 1993; Trivers, 1972)<br>• Expectancy-value theory (Eccles, 1994)<br>• Agency-communion theory (Bakan, 1976)<br>• Belongingness hypothesis (Baumeister & Leary, 1995)<br>• IQ theory (Wai, Lubinski & Benbow, 2009) |
| Integrated | Integrating macro, meso, and micro level | | • Expectancy-value theory (Eccles, 1994) |

With reference to the system theory of society by Luhmann (2017), Saltzmann Chafetz (1990, p. 90) registers the autopoietic dimension of gender systems "[that] are highly resistant to substantial change toward [in]equality. Gender systems are structured so as to automatically reproduce themselves."

In sum, the organization and structuredness of a society has much bearing on psychological gender differences in a society. In particular, societally shared notions such as gender stereotypes impact agency and engagement for an individual student. Such constraints can wield power on largely unrecognized, implicit levels, and constrain agency for individuals.

**Meso level:** The meso-level is more reflective of factors that are relevant in the proximal social context (e.g., situational cues) and constrain agency for young women in particular. These factors are oftentimes aligned with macro-level factors. In fact, the design of social contexts impacts individual cognitions. Social cognition research demonstrates that individuals automatically use categories such as gender in their attribution of social contexts. In the experimental paradigm called "Who said what?", statements of a fictional group discussion are presented to subjects alongside pictures of the discussants (3 males, 3 females) who said the statements. Being asked who said what afterwards (only showing the statements), the subjects misspecify statements being made by a female overproportionally to another female rather than male, and misspecify statements being made by a male overproportionally to another male rather than female (S. E. Taylor, Fiske, Etcoff, & Ruderman, 1978; Allport, 1954; Klauer & Wegener, 1998). This demonstrates that subjects experience the world in categories such as gender and behave accordingly. Maccoby (1999) accumulated evidence that gender typical behavior is an emergent feature from the social context rather than a matter of individual personality. Allport (1954) attributed such categorizations to be evolved features of the cognitive system of individuals in order to cope with the vast amount of information that is present in social contexts. In general, this leads to within-group differences to be minimized and between-group differences to be exaggerated, which then leads to discrimination of individuals in underrepresented groups (S. E. Taylor et al., 1978). Systems justification theory predicts that members of the dominant group use such inequalities to justify their status in the social hierarchy (in-group favoritism) and that even individuals who identify with the underpriviledged group come to see systemic inequalities as legitimate and favor the outgroup (Jost, Banaji, & Nosek, 2004).

Theoretical positions such as situated learning, self-affirmation theory, balanced identity theory, stereotype content model, stereotype inoculation model, self-to-prototype matching, and social-identity theory stress the individual-context interaction and account for gender group identity. Situated learning presents a broad framework for conceptualizing learning that is helpful here, because the interaction of the student with the social context is focused. Situated learning theory posits the importance of peripheral legitimate participation of a novice in a practice community as the mainstay for identity and agency (Lave & Wenger, 1991). The emphasis of identity development vis-à-vis the community gained much attention in the physics education community since it seems to be a reasonable conceptualization of what happens in physics learning that also distracts learners that identify with historically marginalized groups (Close, Conn, & Close, 2016).

The intricate relation of learning and the social context in which learning happens is similarly captured in self-affirmation theory. The basic tenet of self-affirmation theory is that "people are motivated to maintain self-integrity" (G. L. Cohen & Sherman, 2014, p. 336). Protecting self-integrity in a setting for students will empower the respective students (Steele, 1988). A closely linked theory is balanced-identity theory. Balanced-identity theory, in a nutshell, acknowledges the specifics of a person's group identity vis-à-vis the self concept in a domain vis-à-vis the domain stereotype (Greenwald et al., 2002). The three concepts (group identity, self concept, and domain stereotype) share propositional relations. For example, the propositional relations of the concept of the group (e.g., "I am male") with the self concept (e.g., "I am bad at physics"), and the relation "males are good at physics," creates an imbalance. This theory stresses the importance of the interaction of the person with the social learning setting and particular discourses (e.g., gender stereotypes) and the activation of self-related knowledge. Hannover (2000) identified situational cues in social learning contexts that are called activation sources that trigger gender-congruent and gender-incongruent self-knowledge (also: Hannover, 2008). These are: the sex-composition of groups (also: Sekaquaptewa & Thompson, 2003), gender stereotypes, and gender-typical activities. One's gender-group ("I belong to females/males") becomes an important self-category in many social contexts (Kessels & Hannover, 2002). Members of social groups particularly draw information from social settings "that hold relevance for the value and the status accorded to their group" (Purdie-Vaughns et al., 2008, p. 616). Students draw much of their motivation from social contexts, especially self-identification is an important mediator:

> [People] tend to become vigilant in environments where their identity is engaged ... They monitor such situations for cues related to whether their identity is relevant to their outcomes, for instance, whether it affects how they are treated by important figures in their social environment ... As in any hypothesis-testing process, people may be more sensitive to bias-confirming evidence than to bias-disconfirming evidence (Garcia & Cohen, 2012, p. 334).

Social learning contexts are characterized by norms, traditions, habits, or sanctions, varying between domains (e.g., Lave & Wenger, 1991). Learning environments in mainstream institutions often become identity-threatening to students who identify with historically marginalized groups (G. L. Cohen, Garcia, Purdie-Vaughns, Apfel, & Brzustoski, 2009; Goffman, 1963; Maalouf, 2001; Purdie-Vaughns et al., 2008; Steele, Spencer, & Aronson, 2002). Social settings can also have the capacity to be self-protective, self-verifying, and identity-safe (Deci & Ryan, 2000; Hannover, 1998; Purdie-Vaughns et al., 2008; Steele, 1988). For example, when the learning setting addresses the preferences and attitudes of students and when the students feel that they belong in that setting (e.g., through group-constellation, or in-group-experts, see Dasgupta, 2011; as also captured in the stereotype inoculation model by Stout, Dasgupta, Hunsinger, & McManus, 2011). Two complex mechanisms particularly constrain agency of students that identify with historically marginalized groups in social learning conexts: stereotypes and role-models.

Stereotypes play a crucial role in understanding identity, agency and engagement for students. G. L. Cohen et al. (2009) noted that the activation of negative stereotypes in a social setting will start negative recursive processes that threaten students that identify with contested group identities. This is similarly predicted by social-identity theory (Burke & Stets, 1998). Social-identity theory holds that a social learning context dehumanizes student's insofar as their social group identities become most important for the students' actions. Thus, a denigrated in-group identity can constrain the capacity for agency of a student in a learning context. Especially since ability stereotypes pervade social contexts in mainstream institutions. Particularly students that identify with groups that are historically marginalized often face difficulties to feel agentic in such environments due to psychological and physiological responses based on prejudice, stereotypes, stigmatization, ostracism, peer rejection, discrimination, or exclusion (Schmader, Johns, & Forbes, 2008; Steele, 1997; Smart Richman & Leary, 2009; T. D. Nelson, 2009). A pervading negative stereotype towards students from marginalized groups is the alleged lacking competence to perform well in certain (most often quantitative, mathematics-intensive) domains (Leslie, Cimpian, Meyer, & Freeland, 2015; Steele et al., 2002). Researchers identified negative recursive processes for marginalized students beginning with important school transitions like those from middle to high school (Adams & Gupta, 2015; G. L. Cohen & Sherman, 2014; T. D. Wilson & Linville, 1985). Low grades particularly for those students start cascades of questions like "Do I belong here," raise psychological vigilance for stereotype fulfillment and ultimately deter affected students from mainstream institutional settings. Mechanisms that affect students based on stereotypes are hard to challenge (Lepper, Ross, & Lau, 1986). In his hallmark study, Steele (1997) captures these mechanisms in what he called "stereotype threat." In line with balanced-identity theory, Schmader et al. (2008) identify three core concepts: one's in-group, the concept of the ability domain in question, and the self concept. The respective propositional relation between these three is important for the activation of stereotype threat (Inzlicht & Ben-Zeev, 2000; Murphy, Steele, & Gross, 2007; Nosek, Banaji, & Greenwald, 2002; Sekaquaptewa & Thompson, 2003). For example, a propositional relation where the individual self concept is low in a domain is unlikely to induce stereotype threat. Stereotype threat gets "under the skin" of students that identify with contested group identities in that it hampers performance and exacerbates sense of belonging (Ancis & Phillips, 1996; Deemer, Thoman, Chase, & Smith, 2014; Pinel, 1999; Schmader, Johns, & Barquissau, 2004; Schmader et al., 2008; Spencer, Logel, & Davies, 2016). The opposite direction–stereotype lift–is also possible when target students compare their social(group) identity with a denigrated out-group (e.g., Walton & Cohen, 2003). Nguyen and Ryan (2008) found in their meta-analytic review an effect size of $d = .26$ on performance difference from the mere situational activation of stereotypes in testing situations. Steele and Aronson (1995) show that domain-identified students of underrepresented groups that face negative stereotypes for their group in a social learning setting are likely to underperform in short and long term (Nosek et al., 2002; Steele, 1997, 1998). Researchers come to understand the mechanisms that stereotype threat induces. On first glance it is surprising that the awareness of stereotypes–stereotype threat–hampers rather than enhances performance. Schmader et al. (2008) present a process model on deleterious mechanisms of stereotype threat. The authors identify three powerful interrelated mechanisms of physiological stress response impairing prefrontal processing, actively monitoring performance, and suppression of negative thoughts and emotions. These mechanisms are empirically validated. For example, stereotypes were found to increase cognitive or emotional load that interfere with performance. Working memory tends to be reduced in stereotype threat situations (Croizet et al., 2004; Schmader & Johns, 2003). Students that identify with marginalized groups face additional situational burdens that curb their performance and sense of belonging. As part of the learner's social identity, gender identity can be made salient in social contexts (e.g., Kessels & Hannover, 2002). In general, identity salience is a function of the embeddedness of the individual in the social structure (commitment), the fit of the situational cues, and the characteristics of the identity such as its accessibility (Burke & Stets, 1998).

Role-models can be a source for identity development, agency, and engagement. The stereotype inoculation model predicts that role-models are particularly effective when they comprise in-group experts (Stout et al., 2011). A mechanism of self-protective conduct which is closely related to role-models and that intersects with gender-identity was called self-to-prototype matching (Niedenthal, Cantor, & Kihlstrom, 1985). In cognitive science, prototypes are central attributes of categories and ease reasoning about those categories (e.g., Lakoff, 1987; Rosch, 1975), such as the association of gender with a domain. Hannover and Kessels (2004) showed that in social contexts like school classrooms a student imagines a prototypical student who most likely pursues the subject and another student who most unlikely pursues the subject. The overlap between self-image and these two prototypes mediates the choices of the learner. If, for example, a domain is predominantly pursued by either females or males then gender identity is a constitutive feature of the prototypes for that domain. Self-protective engagement is particularly important in adolescence. Adolescence is a crucial stage in human development when gender identity largely impacts behavior and choices (see ”gender-intensification-hypothesis”: Galambos, Almeida, & Petersen, 1990; Hannover, 1991; Hyde, Fennema, Ryan, & Frost, 1990; Ruble, 1994). The contents of such prototypes are informed by the dimensions competence and warmth. Social cognition research identified the dimensions warmth and competence for assessing and judging the self and others (Bakan, 1966; Abele & Wojciszke, 2007; Fiske, Cuddy, Amy J. C., & Glick, 2007), and choosing domains that they engage in (Diekman & Eagly, 2008). For example, people that are perceived as warm also tend to express more communal goals and engage in such domains that foster this motivation. On average, females associate themselves more often, compared to males, with communal goals and interpersonal motivations, and make their academic choices accordingly.

In sum, the learning context influences the individual's identification with a domain. For example, stereotypes can be activated in learning contexts through imbalanced group-constellation (e.g., males outnumber females). Furthermore, in-group experts can be powerful resources for individuals to experience identity-match with the envisioned prototype in a domain and enable engagement for these students, e.g., through self-to-prototype matching.

**Micro level:** The micro-level is reflective of individual cognitive and non-cognitive states that are linked to identity, agency, and engagement. Aside from the constant interaction with various social contexts, students are characterized by a set of aspirations, interests, and traits that help them engage in certain domains. Psychologists observed that students basically seek environments that match to their personality traits that can be measured with personality inventories (Asendorpf, 2004). Brain-type hypothesis, evolutionary psychological stances, expectancy-value theory, agency-communion theory, belongingness hypothesis (attachment theory), and IQ theory capture important mechanisms that explain students' cognitive and non-cognitive reactions to social contexts and explain choices and behaviors on the micro-level.

Hannover (2000) emphasizes that self-relevant knowledge and schemata get acquired across the life-span (also: Piaget, 1976). The differentiation of the genders is, in fact, one of the earliest social categories that individuals acquire (at about 2 years of age) (Hannover, 2000), that later on guides identity, agency, and engagement. Baron-Cohen (2012) established the brain-type hypothesis and advanced an understanding of (average) female and male typical behaviors that result from average differences in brain-type. He postulates and empirically identifies two brain-types: empathizing, i.e., "the capacity to predict and to respond to the behavior of agents (usually people) by inferring their mental states and responding to these with an appropriate emotion" (average female brain), and systemizing, i.e., "the capacity to predict and to respond to the behavior of nonagentive deterministic systems by analyzing input-operation-output relations and inferring the rules that govern such systems" (average male brain) (Baron-Cohen, 2005, p. 819). This position is closely linked to evolutionary psychological accounts of gender differences that is posed, amongst others, by Buss and Schmitt (1993) and Trivers (1972). Evolutionary theories posit that gender-typical behavior is the result from differential parental investment and mate selection processes, and from different allocation of duties in hunter-gatherer-societies. The critics of evolutionary theories stress that the status of these theorizations is descriptive and post-hoc (summarized in: Bussey & Bandura, 1999).

It was furthermore shown that females and males expect different outcomes of their actions and place different values upon academic fields. For example, males show a higher expectancy for success in STEM (Eccles, 1983). In particular, agency-communion theory predicts two fundamental modalities of human existence: agency and communion (Helgeson & Fritz, 1999; Bakan, 1976). Agency is related to a motivational structure that emphasizes the self and separation, whereas communion was linked to a focus on others and connection (Helgeson & Fritz, 1999). Men, on average, were found from early on to gravitate more towards agentic goals of self-expression and self-assertion, whereas women, on average, gravitate towards communal goals such as helping others (Block, Gonzalez, Schmader, & Baron, 2018; Leaper, 1987).

A more generic motivation for individuals to engage in the world is the sense of belongingness to a domain for academic choices and the attachment to meaningful others (friends, peers, teachers, ...) in this domain. The belongingness hypothesis (and attachment theory) posits that individuals strive to connect with other people in a domain. In order to psychologically function, humans strive for social attachments to other people and form a basic need for such social interactions (Baumeister & Leary, 1995; Pickett, Gardner, & Knowles, 2004). Sense of belonging involves one's "personal belief that one is accepted as a member of an academic community whose presence and contributions are valued" (C. Good et al., 2012, p. 701). It was broadly replicated that, on average, females tend to score higher on communal goals, and in their developing identities the interaction and interpersonal connection with others plays a greater role

(Baumeister & Leary, 1995; Diekman, Brown, Johnston, & Clark, 2010; Josselson, 1996). The importance of attachment to meaningful others (though in a younger age) was furthermore established in the attachment theory (Bowlby, 1969), where the attachment to others is a critical feature for well-being.

Differences in cognitive abilities also explain average gender differential engagement and agency in physics. Research in cognitive abilities such as intelligence as conceptualized in the radex model with verbal, spatial, and numerical subdimensions (Wai, Lubinski, & Benbow, 2009), or cognitive abilities such as reasoning, or problem solving predicts that different scores in sub-dimensions of IQ relate to differences in vocational choices of individuals (Nisbett et al., 2012). While no gender differences appear for average IQ scores, differences appear for subscales. It is commonly found that females score higher in verbal skills such as fluency, while males outperform females in visuospatial skills such as object rotation (Nisbett et al., 2012; Kimura, 1999)–a cognitive ability that is relevant in physics: "STEM disciplines place a premium on nonverbal ideation indicative of quantitative and spatial reasoning" (Lubinski, 2010). However, all cognitive abilities are shaped by individual experiences made in the interaction with social contexts throughout the development. For example, certain expectations arise from interactions with social contexts about what kinds of thinking activities an individual should engage in and what of these activities are appropriate for girls and boys, respectively. It was hunched that especially the rough-and-tumble play of boys has a bearing on the later development of spatial skills, since this kind of play requires boys to roam around, predict movements of animate objects such as fellow players, and require eye-hand coordination such as when playing football (Bjorklund & Brown, 1998; Hines, 2011). Evidence for the relation between physical play and performance in spatial cognition later in life comes from studies with adults, and preschoolers (summarized in: Bjorklund & Brown, 1998). Evolutionary accounts for these differences suggest that male activities in evolutionary adaptation comprise navigation and hunting, whereas female activities, on average, involved fine-motor coordination necessary for gathering food (Silverman & Eals, 1992). Recent meta-analyses buttress the idea that cognitive abilities (spatial in particular) are malleable with training (Uttal et al., 2013).

In sum, individual gender differences (that are produced by societal and biological factors) affect individuals and are responsible for differential academic choices amongst the genders. However, abilities such as IQ or spatial abilities are malleable on the individual level.

**Integrated level:** A theoretical framework that integrates macro, meso, and micro theorizations for gendered agency and engagement is given with Eccles' expectancy-value model for academic choices (Wigfield & Eccles, 1992; Eccles, 1983). Based on achievement motivation models (Atkinson, 1957) and attribution theory (Weiner, 1985), the key mechanisms in the expectancy-value model are expectancies towards tasks (expectancy of success), and values that the students hold towards tasks. The focus on tasks and values relates the model to domains. Values comprise attainment (how much does solving a task suits one), cost (how much effort does success require in this domain), utility (how useful is this task), and interest (how interesting is the task). The expectation to be able to solve a task was found to be one of the most pervading cognitions related to academic choices and engagement. This can be explained by the close resemblance with self-efficacy. Bandura (1977) demonstrates that self-efficacy (the expectation to be able to solve a given problem) is predictive for educational outcomes. In the expectancy-value model individual choices are intricately linked to tasks. Individual expectations towards these tasks and the domain at large, and the values attached toward these tasks guide academic choices towards or away from these domains. Eccles (2009, p. 81) emphasizes the agentic experiences that a student makes: "[T]oday's choices become part of tomorrow's history of experience. This [...] includes the agentic effects of individual's choices on subsequent behaviors of socializers and the larger cultural milieu." Expectancy-value models have been empirically tested in different contexts and samples–especially with regards to gender differences (Eccles & Wigfield, 1995; Updegraff, Eccles, Barber, & O'Brien, 1996).

Drawing from the expectancy-value model and social-cognitive theory, Figure 2.1 depicts a model that integrates the aforementioned theoretical frameworks. The impact of the societal context, the social context, and individual cognitive and non-cognitive factors were motivated based on macro, meso, and micro level factors that constrain agency and engagement. Social contexts (like classrooms) and learner's self interact through situational cues. The self comprises cognitive and non-cognitive factors related to the personality, motives, goals, values, attitudes, etc. Interactions of self and social context facilitate (or hinder) identity development, agency and engagement. There is also an effect of the interaction back on social context and societal structures such that a student's engagement in social structures has the potential to change these very structures. The student leverages much of her agency from the self and from the social context that she acts in. All three levels in this conceptualization can be sources for constraining or facilitating the student's agency (Figure 2.1).

## 2.2 Modelling agency and engagement

### 2.2.1 Towards a model for situated agency

The model in Figure 2.1 will be called the situated agency model. The situated agency model integrates the three levels of determination for agency. Agency in this model is understood as the capacity to act purposefully in social contexts. The backbone of the model for situated agency is the interaction of the individual's self with the social context (individual-context-model). The model for situated agency can be envisioned in the tradition of adaptive theories. Adaptive theories refrain from fixed human traits that determine individual action. Researchers argued that adaptive theories adequately capture the changeability of human personality in reference with social contexts (e.g., Gigerenzer, 2008). The situated agency model is analogous to models in gifted education and behavioral model. Models in gifted education stress the interrelatedness of environment and person that is crucial for high achievement, and stress contextual thinking in general (Ziegler & Stoeger, 2009). An elaborated model for the development of giftedness arose from the systemic perspective and was called the Actiotope model Ziegler and Stoeger (2009). The situated agency model shares the emphasis of the environment and the interaction of person-variables with the environment with the Actiotope model, and the reciprocal capacities of actions that have the potential to change the individuals and the environment (Ziegler, 2005). Behavioral models such as the theory of planned

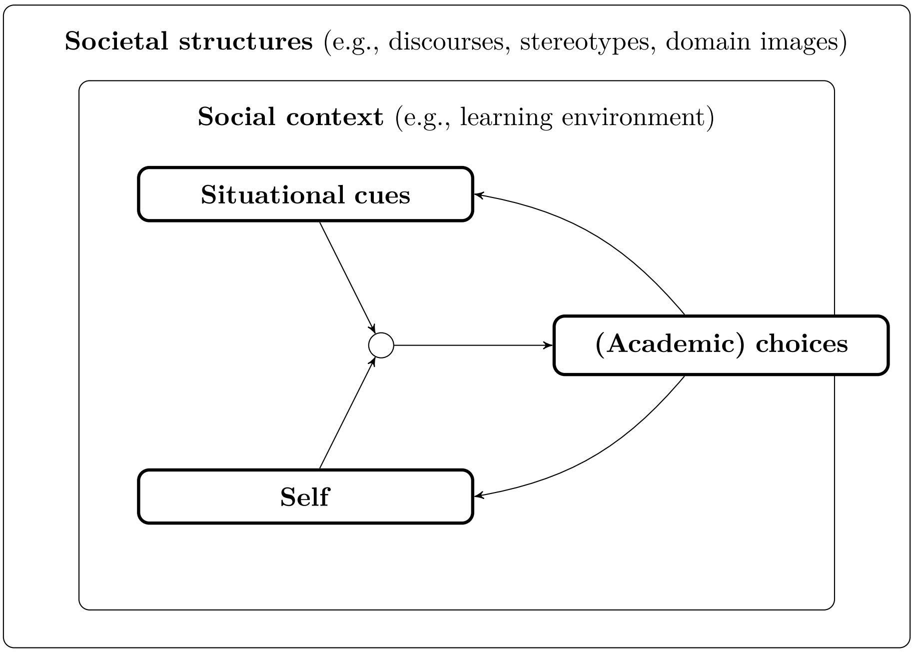


Figure 2.1: Modelling the interaction of social context, self, and (academic) choices (adapted from Bandura, 1997, p. 6; Côte & Levine, 2002, p. 137).

behavior (Ajzen, 1991) share the assumption with the situated agency model that attitudes or self-efficacy believes are necessary conditions for subsequent individual actions such as academic choices. The situational agency model furthermore aligns with models for domain identity development (see Figure 4 in: Hazari, Cass, & Beattie, 2015) insofar as it focuses on the interaction of the individual with situational cues. The situated agency model aligns with vocational choice theories (Lent, Brown, & Hackett, 1994; Lubinski, Benbow, & Morelock, 2000) since it acknowledges the role of expectancies of success in the domain. Lubinski et al. (2000) outlined correspondences between an individual's abilities and interests that lead to satisfaction in a domain and direct choices. This process of matching is established in the situated agency model within the individual-context interaction. Considering the history of learning theorization, this position reflects the integration of the cognitive perspective (i.e., learning as changing cognitive structures such as concept formation), and the situated perspective for learning (i.e., learning as a socially embedded process concerning the initiation of a novice in a community), as is done in social cognitive learning theory (Bussey & Bandura, 1999). Societal constrains are represented in the outer circle in the situated agency model. The meso level is captured in the inner circle (social context), in particular with the individual-context interaction at the heart of the model for situated agency. For the micro level, the conceptualization by (Eccles, 1983) of expectancies and values that are brought to social situations and determine agency are key.

Figure 2.2 is a parsimonious version of the complex expectancy-value model by Eccles (1983), focusing the particular aspects that relate to gender differential agency in formal and informal learning contexts. However, the model

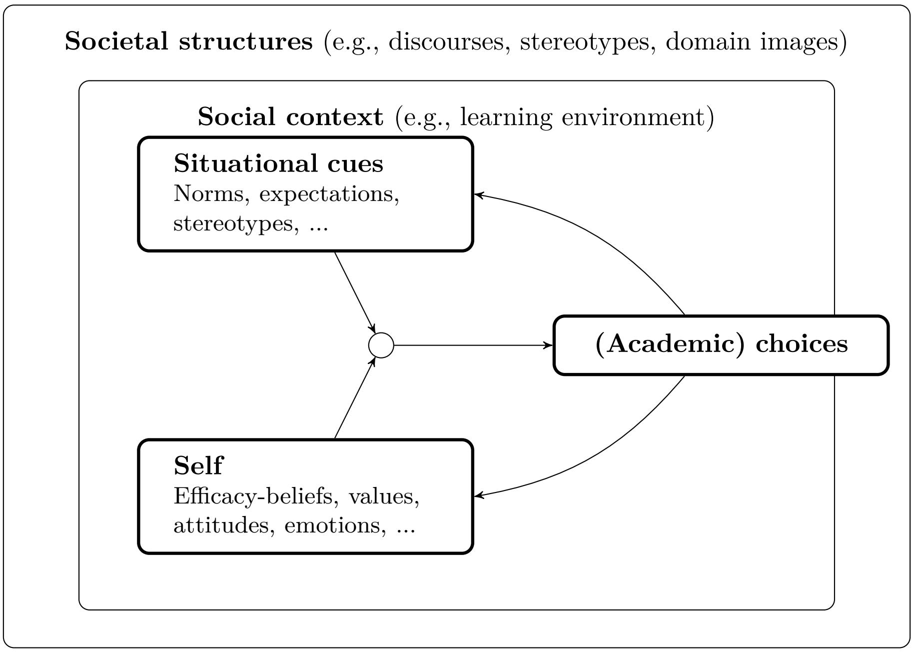


Figure 2.2: Outline of a model for situated agency.

for situated agency emphasizes the interaction with the actual social context of the individual, which comes from the agency focus that was outlined above (see also: Lent et al., 1994). This pinpoints the opportunities to supporting students' agency that arise for educators. The macro constraints (e.g., stereotypes) are captured through placing the individual-context interaction within societal contexts, stressing the idea that these settings are structured in alignment with societal contexts. McNay (2000, p. 133) argues that individual-context models, such as the model for situated agency, circumvent deterministic notions of agency, providing an account of the "ontological grounds of the creative dimension of agency."

### 2.2.2 Empirical support

Empirical support for the situated agency can be gleaned from research related to the theoretical position outlined in Table 2.2. The three levels of understanding in the model are characterized by increasing order of malleability. For example, social role requirements and discourses (e.g., gender stereotypes) are summarized at the macro level. Stereotypes, as socially shared notions, are harder to challenge than micro level cognitions like ability self-concept or self-theories. Also, changing macro-level constraints will likely impact micro-level constraints, whereas micro-level changes will not necessarily impact the macro level. In the following, empirical research with regards to macro, meso, and micro-level constraints for situated agency of young women in STEM and physics will be reviewed in order to flesh out Figure 2.2 with key mechanisms for gender differential agency and engagement in physics.

**Macro-level:** On a macro-level, at least two discourses pervade STEM and physics in particular. First, physics is perceived as a ”masculine domain” (Adamuti-Trache & Andres, 2008; Archer et al., 2012a; Carlone, 2003; Farenga & Joyce, 1999; A. J. Gonsalves & Seiler, 2012; Kelly, 1985). Greenwald, McGhee, and Schwartz (1998, p. 1464) utilized the implicit associations test (IAT) in order to track people’s implicit ”judgements that are under the control of automatically activated automation.” Drawing from research in science in general, meta-analyses of the gender-science IAT with some $30,000$ respondents found effect-sizes in the magnitude of $d = 1.00$ in order to associate males with science and females with liberal arts. Mass media and journals like *Science* portray the masculine scientist prototype (Barbercheck, 2001; Flicker, 2003). As early as second grade stereotypical perceptions of scientists can be seen for girls (Chambers, 1983). Such stereotypical notion become increasingly ingrained in students over time (Baker & Leary, 1995; Chambers, 1983). Girls and boys are unlikely to draw female scientists. Only 0.6 percent of $5,000$ participants did in 1983 (Chambers, 1983; Parsons, 1997). Though this number has increased today, still the majority of students depict scientists as males (Farland-Smith, 2009). In schools, prototypical physics students are envisioned as males either (Hannover & Kessels, 2004). While some evidence indicates that countries with a high enrollment of females in tertiary education have weaker explicit and implicit gender-science stereotypes (D. I. Miller, Eagly, & Linn, 2015), yet, a higher gender-equity index of a country correspnds to a lower representation of females in STEM (Gender-Equity Paradox: Stoet & Geary, 2018). Also, missions to change the representation of females that are not research-based, are unlikely to be effective. The EU commission issued a campaign to ”make physics pink” and alter traditional stereotypes with a video showing girls in high-heels examining atomic models. The campaign triggered a backfiring that demonstrates how deeply entrenched expectations about what kinds of people ought to do science are (Khazan, June 22, 2012).

Broad notions of gender appropriate behavior in society constrain the possible identities that students can endorse. Archer et al. (2012a) analyzed girls’ patterns of engagement in science. She and her colleagues proposed ”identity repertoires.” These are gendered patterns of engagement that are influenced by historical notions of engagement, labor division and social roles. ”Feminine scientist identity” and ”Bluestocking scientist identity” are two contingent identity repertoires for girls to pick up in physics. An important feature of these two identities for the girls was that forging such an identity brought along a negotiation with their feminine identity and ”balancing acts” of maintaining intact relationships with their peer-group. Since peer relations and sense of belonging are basic needs for individuals in order to engage in a domain, physics identity development, agency, and engagement are impaired (Carlone & Johnson, 2007; A. J. Gonsalves & Seiler, 2012; Hazari et al., 2010). For example, high achieving girls needed to ”balance out” their cleverness with popular heterofemininity (e.g., interested in fashion and relationships) (Skelton, Francis, & Read, 2010; Archer et al., 2012a). In fact, not all the girls had the capacities to ”level out” their cleverness (Renold & Allen, 2006; Skelton et al., 2010). Josselson (1996, p. 178) reported that for the studied female subjects during adult identity crisis ”most often [...] the struggle to keep experiences of competence and connection in balance” appeared as a barrier. Furthermore, students engaging in physics are threatened to be stigmatized as ”geeky,” ”boffin,” or ”nerds” (Hannover & Kessels, 2004; Skelton et al., 2010). Yet, overt intellectual assertiveness of high-achieving young women is rather sanctioned by their peer groups and thus concealed (Renold & Allen, 2006; Silvermann & Miller, 2009). Ultimately, the "girly girl"-identity that is associated with irrational behavior presents a specifically contested identity in physics settings. Rather, the doctoral students in a study by (A. Gonsalves, 2014) seemed to gain recognition by reproducing discourses around traditional gender norms that despise overt femininity.

Carlone and Johnson (2007) underlined the crucial role of recognition by others for identity development for successful female doctoral science students (see: Hazari et al., 2010; Lock, Hazari, & Potvin, 2012). Even though the women in this sample were all high achieving and stayed in the "physics pipeline," some developed a "disrupted science identity" due to a lack of recognition by meaningful others. More generally, Nespor (1994) observed physics university courses and identified a narrow physics curriculum and narrow meanings of physics persons. Students that did not develop appropriate physicist identities were either marginalized in the community or dropped out of physics. Engagement in this domain of physics for girls and young women is potentially precarious vis-à-vis their social identity. Aikenhead (1996) coined the phrase of "cultural bordercrossing into the subculture of science." Tan and Calabrese Barton (2012) suggested from their studies with underprivileged youth the notion of a "cycle of reproduction." This expression captures the tendency that norms and traditions get reified such that the status quo within mainstream institutions is maintained (Apple, 1992; Beyer & Liston, 1996). As Francis, Read, and Skelton (2010) noted, school contexts largely define the acceptable and normal femininity and masculinity, e.g., that physics is pursued by boys. Thus, societal discourses constrain classroom practices in terms of gender-linked engagement. The masculine classroom culture has some ramifications that will be expanded upon more broadly in the following section. Social contexts that activate traditional gender discourses hamper agency for the students. Both, girls and boys are constrained in their ability to exercise agency since they adopt their behavior in certain ways, particularly when their gender identity is salient (Kessels & Hannover, 2002).

**Meso-level:** The study of interactions of social identities like gender with stereotypes in concrete learning contexts sheds light in the detrimental effects of stereotype activation. Researchers compare the situation of young women in physics with the situation of students that identify with historically marginalized groups in mainstream institutional settings in general: Negative discourses (e.g., stereotypes) get activated in social settings and eventually comprise personal motivations (like efficacy beliefs and sense of social belonging) (Aguilar, Walton, & Wieman, 2014; Cheryan, Plaut, Davies, & Steele, 2009; Lock et al., 2012). Research on stereotype threat yielded insights on how young women were affected. Stereotype threat is pervasive for women in "quantitative fields" like mathematics and science (Deemer et al., 2014; C. Good, Aronson, & Harder, 2008; Huguet & Régner, 2007; Marchand & Taasoobshirazi, 2013; Steele, 1997). Steele (1997) argued that "domain-identified" students from underrepresented groups perform on par with students from majority groups if not stereotype threat hampers their performance. Guzzetti and Williams (1996) found that U.S. students were wary of gender-based bias in science learning settings even without triggering such stereotypes. C. Good et al. (2012) showed that stereotype threat in mathematics eroded women's sense of belonging to the mathematics community. In particular for domain identified young women stereotype threat impugns performance and sense of belonging (C. Good et al., 2008; Schuster & Martiny, 2016). In the long run the young women turned away from mathematics more likely than their male counterparts. Similar evidence is given by Brickhouse and Potter (2001, p. 973), who write that their girls' performance was hampered by the "stereotype threat [...] [of] being at risk of confirming, as a self-characteristic, a negative stereotype about one's group." Stereotype threat might arise from situational cues like learning materials. J. J. Good, Woodzicka, and Wingfield (2010) demonstrated that through pictures in learning materials stereotypes can be transported and affect performance. Also more innocuous cues like number of male and female toilets in a building, Star-Trek posters in the test room, television commercials, brochure about a university department with photos of predominantly male students, or videos of scientific conferences that were attended predominantely by men subtly trigger safety or threat and start a cascade of physiological stress and coping reactions such that choice making is affected (Murphy et al., 2007; Walton & Carr, 2012). Stereotypes are also activated through group-constellations where women are underrepresented (Dasgupta, Scircle, & Hunsinger, 2015; Schuster & Martiny, 2016; Sekaquaptewa & Thompson, 2003). This conditions caused young women to underperform in tests (Inzlicht & Ben-Zeev, 2000) and lower their STEM career aspirations (Schuster & Martiny, 2016). For example, simply mentioning ones gender accounted for much of the performance difference in a mathematics test (Danaher & Crandall, 2008). With the extent of female underrepresentation these effects rise, peaking in quantitative domains like physics because female-to-male ratios are most concerning in physics (Inzlicht & Ben-Zeev, 2000; D. I. Miller et al., 2015). Also, telling that a test was diagnostic of abilities hampered young women's performance in a mathematics test (Martens, Johns, Greenberg, & Schimel, 2006). In general, physics social contexts seemed to be characterized by a subtle gender bias against girls and young women. On average, females received less attention than their male peers from teachers and had less time to manipulate the experimental equipment in physics (Faulstich-Wieland, Weber, & Willems, 2004; Reiss, 7. - 10. September 2000; Warrington & Younger, 2000). Boys were more encouraged in physics classes (Guzzetti & Williams, 1996) and teachers unconsciously imposed detrimental self-thoughts in mathematics and physics on young women (K. A. Heller & Ziegler, 2010; Kerr, 2000; Siegle & Reis, 1998). Particularly high-achieving young women in the high-school competitions mentioned a lack of appropriate role-models for their engagement (O'Connor, 2002). Especially those role-models that shared personality traits in a physics environment were important in order for young women to engage with physics (V. S. Taylor, Erwin, Ghose, & Perry-Thornton, 2001).

**Mirco-level:** Educational researchers engaged in the question for differences in cognitive abilities for a long time. The debate was started with a *Science* article that reported large differences in mathematics abilities between the genders in the United States (Benbow & Stanley, 1980). Benbow and Stanley (1980) reported differences of 13 to 1 males to females in the extreme quantiles of the mathematics ability distribution (SAT$\geq$ 700). Generally, males tend to be overrepresented at the extremes of the ability distributions in mathematics and physics, while equal representation is found around the mean of the ability distribution (Hyde, 2005; Benbow & Stanley, 1980). To illustrate this finding, Figure 2.3 depicts a simulated distribution for males and females in STEM skills

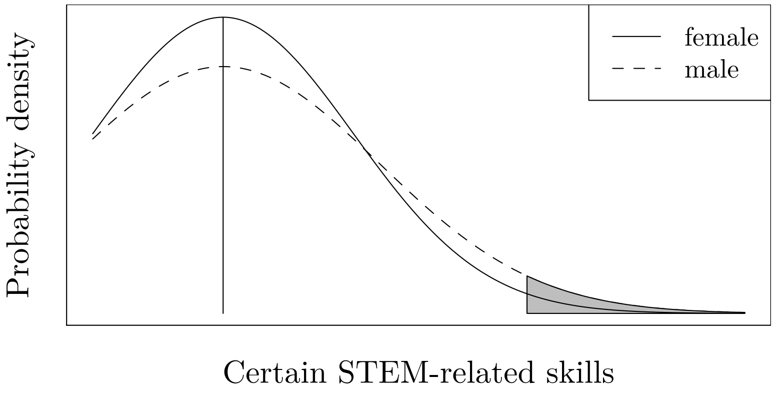


Figure 2.3: Idealized depiction of male and female distribution of abilities in STEM and math. Since the distributions are symmetrical, only the upper tail is depicted.

or mathematics abilities. The variance for males is greater than the variance for females, while the means are similar. While differences in male-to-female representation in quantiles around to median (50 percent quantile of the distributions) are small to non-existent, the extreme ends of the distribution favor males. When considering the extreme tails (e.g., the top 1 percent as in Figure 2.3), a consistent male advantage can be found for scientific reasoning over the last decades of approximately 4 : 1 (Wai et al., 2010). In mathematics the male advantage declined from the extreme 13 : 1 in the early 1980s to about 3.8 : 1 in the time from 2006 to 2010.

Halpern et al. (2007) reviews the gender research of the last 40 years and comes to the conclusion that females tend to outperform males in ”verbal abilities,” while males, on average, tend to outperform females in ”visuo-spatial” abilities. Furthermore, the authors document the observation that males are overrepresented in the higher and lower quantiles of the distribution, and that this overproportional representation increases with age. Such differences have been tracked down to physiological gender differences, where girls use some cortical areas more for verbal functions, while boys use these areas more for abstract and physical-spatial functions (Gurian & Stevens, 2004).

Large-scale assessments in the education sector such as PISA document gender differences for average STEM performance of, for example, 7 points in Germany favoring boys (OECD-average: 2 points). This difference is stronger in the PISA-subtests ”physical systems” and ”earth- and universe” (Quaiser-Pohl, 2012; OECD, 2015). Performance differences are also found in high school physics in general (Reilly, Neumann, & Andrews, 2015) and in physics concept inventories in high school and university (Madsen, McKagan, & Sayre, 2013). Another longstanding topic of discussion are differences in cognitive abilities like spatial skills. Girls and boys do differ in some spatial abilities and strategies on how to approach spatial problems (for an overview see: Spelke, 2005), and in other cognitions (Kimura, 2004). The water-jar test (placing a water-jar on a steep hill and require students to draw the water surface, that should be horizontal) is a test item were males, on average, outperform females. Deeper analyses went beyond reporting the differences. For example, mediation analyses reveal that variance in gender differential performance can be explained by different degrees of interest in the domain (Köller, Daniels, Schnabel, & Baumert, 2000; Stanat & Kunter, 2002), which points to the fact that these differences are likely acquired during socialization.

On average, women and men act upon different values, and value physics differently (Eccles, 2007, 1983). For example, women engage more in careers that are related to humans. Girls and young women rate contents that relate to the human body or to socio-scientific issues particularly high (Hoffmann, Krapp, Renninger, & Baumert, 1998; Sjøberg & Schreiner, 2010). Since physics teaching in high school is dominated by technical contents, boys place a higher value in school on physics (Eccles, 1994; Sjøberg & Schreiner, 2005). In a review, Boucher, Fuesting, Diekman, and Murphy (2017) document the communal goal incongruity of subjects such as computing or engineering (closely related to physics) impair engagement of young women in these fields. Consequently, girls and young women tend to rank physics at the bottom of all subjects (Zwick & Renn, n.d.). Manifest differences of male and female preferences arises in mathematics-intensive domains such as physics. In a study comparing gender differential occupational choices all subjects were born during the second wave in feminism in the 1970s and were fully aware of their talents, and the parents encouraged all of them to pursue their careers and develop their talents (Pinker, 2003, p. 356). The authors found that while the girls acted upon diverse interests that are mostly aligned with ”social values” such as humanitarian and altruistic goals, the boys adhered to ”theoretical values” such as abstract intellectual inquiry. The women pursued careers in law, biology, or medicine, while the boys more often stuck to mathematics and science (Lubinski & Benbow, 1992). Expertise research with representative samples of mathematically precocious youth over four decades revealed that boys and young men are more likely to allocate to their career and specialization, compared to girls and young women that tended to allocate their time more to domestic pursuits and family (Lubinski, Benbow, & Kell, 2014). Thus, boys and young men specialized in a certain domain, while girls and young women distributed their resources and interests more to multiple domains.

Amongst the sources for self-efficacy in physics, females, compared to males, tend to rate helping others among their most important sources (G. Jones, Howe, & Rua, 2000). Further evidence can be found in interest studies that document that females gravitate more towards people oriented subjects for their vocation (e.g., working with others), with a large effect size ($d = 0.93$) (Su, Rounds, & Armstrong, 2009). Men also show more realistic and investigative interests, compared to women, which were predictors for interest in STEM subjects (Su et al., 2009). Thus, interest was claimed to be a significant factor for differential STEM engagement of women and men (Su et al., 2009; Osborne et al., 2003). Ultimately, researchers started to recognize that females in STEM domains report lower feelings of belongingness (C. Good et al., 2012). C. Good et al. (2012) showed that factors in a mathematics environment (entity theory of math ability) negatively influenced the sense of belongingness of women to mathematics.

A central aspect to agency on the micro level are cognitions that relate to competence. C. Good et al. (2012) found that young women who viewed mathematics ability as fixed were particularly susceptible to negative stereotypes and drop-out (Dweck, 2006). This happened to be detrimental for their academic choices since they did not believe that they could personally grow in domains like physics. Research regarding epistemological aspects of physics indicated that young women in high school construed physics knowledge as ”stable for all the time”, ”authoritative”, ”incontestable”, ”uncreative”, ”objective”, ”inaccessible” and ”abstract” (Hannover & Kessels, 2002). These attributes likely put young women at risk to devalue physics as unimportant and shy away from it. Young women tended to construe physics as ”not for me” (Nosek et al., 2002), which could partly be associated with a more ”emphatic” brain-type (Zeyer, 2017). Physics was broadly construed as a domain which is for brilliant people and geniuses (Leslie et al., 2015). This narrative of brilliancy was generally more endorsed by young men. For example, girls’ and boys’ differential assignments of smartness to their own gender group started as early as 6 years of age (Bian, Leslie, & Cimpian, 2017). Young women that endorsed their gender identity were negatively affected (Schmader, 2002). From the detrimental interaction with physics learning contexts the young women tended to develop unrealistic self-conceptions of their own competences. For example, many high-achieving young women showed an impostor-syndrome. Test-performance and self-conceptions for these young women were dissociated. They did not believe in their abilities and skills to the degree that their competence would predict (McGregor, Gee, & Posey, 2008).

The situated agency model is now utilized to outline mechanisms for constraining agency for young women in physics (Figure 2.4). Social learning contexts in physics are embedded in larger societal structures such as discourses (physics is for geniuses) and stereotypes (females cannot do physics). The proximal social context is characterized through situational cues (persons, things, ..., see: Purdie-Vaughns et al., 2008) that relate to identity resources, such as competence, recognition, and interest. For example, a teacher can recognize a student through encouraging feedback that relates to competence. Also, female in-group peers might contest heterofeminine identity for young women in reference to physics such that the young women have to eventually balance their identities in physics learning environments. Or, the group constellation can make the gender group identity salient such that agency is constrained for young women in physics. The negative interaction of situational cues with the self leads to experiences of mismatch and identity threat. Finally, prior knowledge, self-conceptualizations, interests, attitudes, values, and motives can get activated in proximal social learning contexts in physics such that competent performance is enabled. In this complex of influences, academic choices are formed.

## 2.3 Fostering engagement

In a genre of household physics curricula that appeared in the early 19th century particularly female students were meant to be engaged with physics through understanding vacuum cleaners and ironing devices in the household (Behrman, 2018). From today’s perspective such strategies sound inappropriate and prone to reinforce traditional role understandings and perpetuate the female under-representation in physics. The reason why such approaches are unlikely to work is that they address the surface level of physics engagement, rather than the deep level of physics engagement such as basic motivations and physics iden-

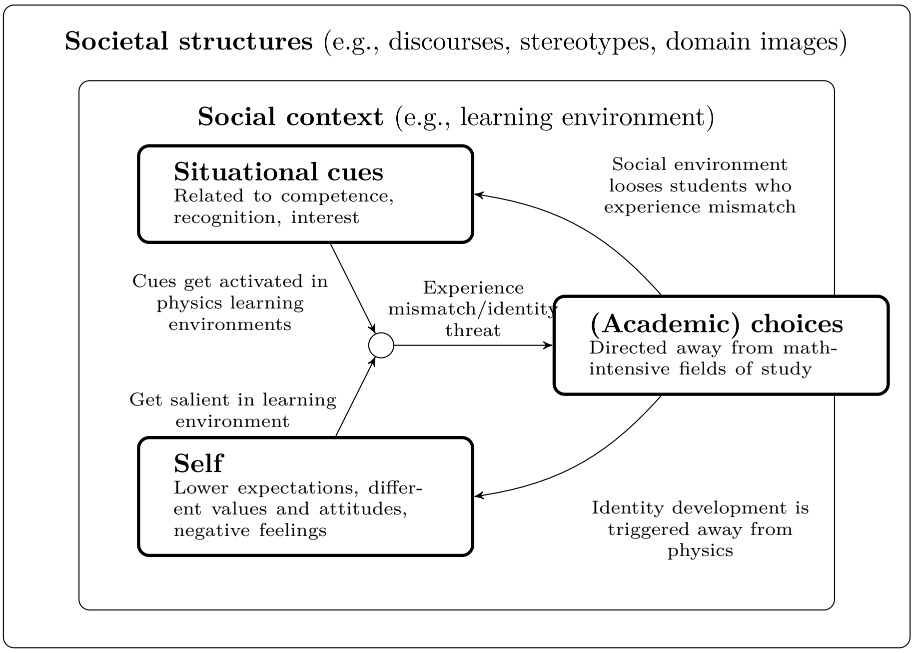


Figure 2.4: Mechanisms that impact gender differential agency and engagement through the lens of the situated agency model.

tity resources. Empirical research is necessary in order to develop considerate interventions that target relevant mechanisms that are pertinent to physics engagement.

In the following, specific interventions will be reviewed that had the goal to engage young women in STEM. Walton, Logel, Peach, Spencer, and Zanna (2015) argue that both, interventions that support young women to navigate a difficult, male-dominated environment, and interventions that improve STEM settings (e.g., reduce implicit biases) are necessary to increase the representation of women in STEM (also: Logel et al., 2009). Framed through the situational agency model, three intervention strategies are possible that are linked to the macro, meso, and micro level of agency. The interventions address the individual young women's physics engagement (i.e., "second-choice" interventions, Walton et al., 2015), and the global physics contexts.

**Macro-level:** With regards to the competence dimension of social cognition (i.e., physics is difficult and for geniuses), motivating and presenting an alternative, more accurate image of physics is important in order to promote a reconstrual of physics in society. The fact that physics is often conceived as uncommunicative is disadvantageous since physics (such as science in general) is dialogic by nature: "dispute lies at the very heart of science" (Driver, Newton, & Osborne, 2000; Merton, 1973, p. 301). Merton (1973) engaged in the question of what science looks like from a moral standpoint. He identified four principles of which communism, the idea that knowledge in science and scientific progress is communicative in nature (Merton, 1973), is one. Consequently, the communicative nature of science is an aspect that was emphasized in physics interventions since students' perception is that science is merely the accumulation of facts without dispute (Driver et al., 2000). Studies showed that cooperative complex problem solving is a mainstay of engineers work (Jonassen & Strobel, 2005). One concrete way of intervention was shown to be the presentation of a text to students that emphasizes the dialogic nature of science. Researchers implemented such an intervention and found that utilizing an appropriate text by theoretical physicist Thomas Kuhn was effective in challenging the notion that physics is unsocial (Kessels, Rau, & Hannover, 2006). The implementation of peer instruction and collaborative classrooms lends to the goal of portraying physics as more communicative and interpersonal (e.g., Mazur, 1997).

Furthermore, the fact of male overrepresentation in physics and the alleged higher competence of males compared to females in physics is an important facet of broad discourses about physics. Presenting historical records of participation numbers in physics would emphasize that female participation was increasing from the beginning of the 19th century up to around 2010. Gender stereotypes with regards to competence and assertiveness also changed (e.g., Eagly et al., 2004). Researchers stressed the fact that some countries in large-scale assessments like PISA have different gender-ratios in performance and enrollment (e.g., Hong-Kong-China, see OECD, 2015), outruling biological, deterministic explanations of gender differential performance in physics. This reasoning should be included in strategies regarding the promotion of identity development, agency, and engagement for young women in physics. Hazari et al. (2010) found that the discussion of the underrepresentation of young women in physics in their respective physics classes was an important aspect for young women to identify with physics, eventually because young women developed adequate reactions to threatening social contexts regarding their competence and group identity. Even though the conditions for successfully discussing these aspects need to be established in depth, it should be stressed that a discussion of female underrepresentation might be implemented in curricula and will likely benefit the young women, since they might worry whether they will be the only females in their later vocation in physics, which can be debunked based on recent enrollment numbers.

Finally, physics pedagogy is oftentimes not in line with recent developments in educational research. The idea in educational research for an active and engaging pedagogy can be summarized as: ”People understand concepts only when they are forced to think them through, to discuss them with others, and to use them to solve problems” (Pinker, 2018, p. 378). Hestenes (1987) pointed to the pitfalls of much of physics pedagogy and instruction. His contention with traditional instruction was that it even was not instruction. He wonders ”how such knowledge ever gets transmitted to students under traditional instruction” (Hestenes, 1987, p. 18). And with traditional instruction he is referring to content-centered, teacher-centered instruction. Only few students who ”rediscover” the knowledge really learn the concepts. In order to make physics more inclusive for more students, this instructional approach needs to be altered through adequate adaptations to instructional design and curriculum. For example, students have to explicitly be shown how to model physical phenomena in order to erase the idea that many students hold that physics is the accumulation of static facts. It has been shown in an intervention that an adaptation of the physics curriculum benefits either the girls and the boys (Hoffmann et al., 1998). Modern, engaging pedagogies have been proposed such as Active-leanring in physics instruction, spearheaded by the American Association of Physics Teachers (AAPT), and the American Institute of Physics (AIP) (see: Carlone, 2004; Meltzer & Thornton, 2012, also: van Heuvelen, 1991). In Active-learning in physics instruction real-world problems, inquiry-based learning, and students' interests and social issues are part of the currculum–aspects that tend to be neglected in traditional physics instruction. "Active learning engages students in the process of learning through activities and discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work" (S. Freeman et al., 2014). There is evidence that active learning is beneficial to many outcomes (such as failure rate) for students compared to traditional teaching approaches (S. Freeman et al., 2014). Students are emphasized to be producers of knowledge (rather than receivers) in this approach. Changes in the physics curriculum on a deeper level compared to changing the contexts of problems (surface level) can help to raise gender equity, because this pedagogy can reduce the influence of prior knowledge and help all learners to develop a basic understanding of physics. This is particularly important since physics knowledge accumulates and a lack of conceptual knowledge at earlier stages can severely impair understanding of more advanced concepts.

**Meso-level:** Further research sought to alter the social contexts and instructional approaches in physics learning environments through intervention, and thus engaged in meso level facilitation for situational agency. Supporting young women's physics engagement can be achieved through adapting the physics social learning contexts (Spencer et al., 2016; Walton et al., 2015). Aguilar et al. (2014) stressed the effectiveness of social psychological interventions to leverage the perceived social belonging of young women towards physics and challenge the negative impact of stereotypes. "[Social psychological] interventions do not teach students academic content but instead target students' psychology, such as their beliefs that they have the potential to improve their intelligence or that they belong and are valued in school" (Yeager & Walton, 2011, p. 267). The term social psychological intervention was coined to encompass a certain type of intervention that is usually a brief exercise that reinforces important thoughts and experiences of stigmatized learners (Yeager & Walton, 2011). Such interventions can have long-term effects as assessed through follow-up questionnaires after three years (G. L. Cohen et al., 2009; Walton & Cohen, 2011; Cook, Purdie-Vaughns, Garcia, & Cohen, 2012). One way to create identity-safe social learning settings was accomplished by engaging successful female role-models (Drury, Siy, & Cheryan, 2011; McIntyre, Paulson, & Lord, 2003). This finding is buttressed in the stereotype inoculation model by Stout et al. (2011). Female in-group experts can "inoculate" females in physics contexts and raise their identification with the domain. In fact, it was found to be important that these role-models showed expertise (Bigler & Liben, 2006). Introducing female in-group expert scientists, e.g., Marie Curie, has to be done with care, because otherwise these role-models can even demotivate female students because they might construe for themselves that these achievements of the double Nobel laureate are so extraordinary that they will never achieve them (Eckes, 1994). Also positive contact with majority group members and insights in their personal struggles proved as a successful intervention that raised young women's participation in STEM (Walton et al., 2015). Finally, a "forewarning" intervention explained to students that endorsed contextually threatened identities the mechanisms of stereotype threat and test anxiety such that the students did perform on par with students exposed to non-evaluative test situations (Aronson & McGlone, 2009).

Another meso-level intervention strategy was the integration of appropriate conceptualizations of their the self for young women in physics. Hannover and Kessels (2004) adopt the strategy of self-to-prototype matching in mathematics and physics as a means to support young women's agency in these domains. Here, the perceived distance of the self to the imagined prototype that typically pursues the domain is important. In an intervention the authors were able to positively influence perceptions of prototypical students (Hannover & Kessels, 2002; Kessels et al., 2006). A study by Marx and Roman (2002) found that exposing young women to female experimenters that were introduced as expert mathematicians improved the performance of the young women in the test. The authors confirmed that it was the mathematics expertise as compared to the physical appearance that protected the performance of the female test takers. Furthermore, stories about scientists are important vehicles for designing appropriate social learning contexts. Physicists were sometimes portrayed as geniuses who work out their brilliant theories on their own without a doubt on their abilities. Portraying successful scientists with their struggles in their scientific engagement was one way to challenge this misconception. Intervention measures on the struggles of famous scientists (e.g., Einstein) "helped students to create perceptions of scientists as hardworking individuals who struggled to make scientific progress," which increased students' interest in science (Lin-Siegler, Ahn, Chen, Fang, & Luna-Lucero, 2016; Hong & Lin-Siegler, 2012). This had benefits to the young women compared to young men since they were more affected by prototypical portrayals of scientists as geniuses (Lin-Siegler et al., 2016). The giftedness and genius discourse attributed to students proved also to constrain agency. Labelling students as gifted in their classrooms can cause psychological distress and cause "social isolation, development of egocentric attitudes and behaviors, endangering or disturbing the personality development and self-concept through extreme achievement pressures or too much responsibility" (K. A. Heller, 2004, p. 308).

Regarding changes in instructional design and learning materials, the adaptations of curriculum materials to address specific motivations for girls and young women were able to support young women's physics agency and engagement. For example, a study by Häußler and Hoffmann (2002) found that a revised curriculum that addressed many contexts that included aspects and practices that girls, compared to boys, are particularly interested in (e.g., medicine contexts, hands-on materials) raised interest and achievement for the girls. Other interventions improved selected measures that are tied to engagement. For example, Berger (2002) showed that utilizing a radiation physics unit enhanced interest for young women in physics (see also: Colicchia, 2002). Medicine contexts appear to raise real-life relevance of physics knowledge. Real-life relevance was a significant predictor for later STEM interest, regardless of gender (Kitchen, Sonnert, & Sadler, 2018). In general, medical physics is a "rapidly growing specialty" of physics (Podgorsak, 2010). Medical contexts and life relevant applications receive increasing interest in the physics community. Addressing life relevant applications and contexts in which physics appears is considerate of vocational motives and motivations of young women (Morgan, Isaac, & Sansone, 2001).

**Micro-level:** Target constructs that individual-centered interventions focused on were: attitudes, sense of belonging, epistemological beliefs, competence beliefs, performance, performance perceptions, expectancies, and values. For example, students learned to navigate through difficult contexts with appropriate coping strategies (e.g., Aronson & McGlone, 2009). Coping interventions particularly focused on sense of belonging. Identity threatened students that prior to being exposed to the threatening environment wrote about their core values (family, friends, music), significantly improved desired outcomes as their self-integrity was ensured (G. L. Cohen & Sherman, 2014; Cook et al., 2012)– a mechanism called ”values affirmation” (Aronson & McGlone, 2009). Miyake et al. (2010) showed that female college students in physics who wrote about their most important values prior to the courses significantly improved their performance as compared to the control group (”value affirmation”-strategy). A similar self-affirmation effect is described by Martens et al. (2006). After receiving a self-affirmation treatment, their young women were not affected by stereotype threat in a testing situation.

Knowledge about psychological states can bolster young women’s performance. For example, reconstrual interventions (Spencer et al., 2016) provided the students an external explanation for induced arousal in stereotype threat situations that is experienced in the social learning contexts (Ben-Zeev, Fein, & Inzlicht, 2005). Presenting performance tests with an introductory text that emphasizes that the present test does not show gender differences yielded beneficial results (C. Good et al., 2008; Martens et al., 2006). Such knowledge particularly reduces anxiety. Dweck (2006) pointed to the fact that researchers ”get a handle on the psychology” that deters high talented females from mathematics and science through interventions of epistemological beliefs and competence beliefs. ”Growth-Mind-Set”-interventions construe intelligence and domain-linked talent as something that is malleable and grows with experience, like the brain as a muscle that grows with challenges. Effects of such interventions in mathematics and physics for young women include proactive learning and increased motivation (Blackwell, Trzesniewski, & Dweck, 2007; Dar-Nimrod & Heine, 2006; C. Good, Aronson, & Inzlicht, 2003). Research on causal attributions (i.e., the construal of causes of own success or failure) showed that talented young women saw their own success in physics as rather external happenstances than caused by their own efforts and hard work. Attributions were retrained towards an attribution on internal locus of control and yielded positive results on performance in physics (though not in follow-up measures) (Ziegler & Heller, 2000). A growth-mindset mentality can also be fostered through targeted instruction (Nickerson, 1994). For example, cognitive scientists motivated the explicit instruction of problem solving and meta-cognitive abilities (Flavell, 1979) such as self-regulation. Interventions that explicitly teach problem solving and meta-cognitive abilities can be effective (Perels, Gürtler, & Schmitz, 2005). Furthermore, arranging classrooms around personally relevant problems can be a motivational strategy for improving physics instruction (Raine & Symons, 2012; Strobel & van Barneveld, 2009). Students that identify with historically underrepresented groups in particular benefit from making explicit the ways of thinking that are practiced in science and contrasting them with everyday ways of thinking, e.g., explaining things (Roseberry, Warren, & Conant, 1992). For example, Huffman (1997) found that particularly the girls were positively affected by explicit instruction of physics problem solving (see also: Cooper, Cox, Nammouz, Case, & Stevens, 2008). An adaptation of problems and tasks also

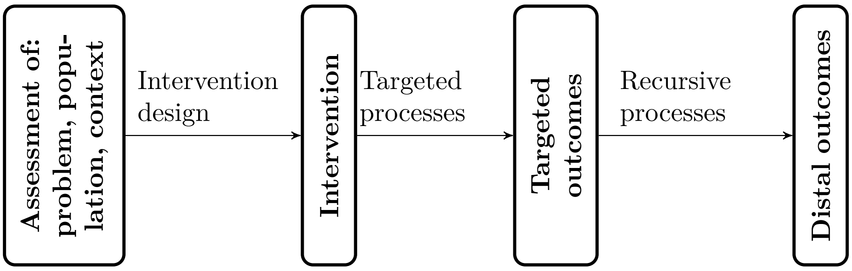


Figure 2.5: Conceptual model for targeted interventions.

lent to competence beliefs. For example, the average superiority for females in verbal abilities is well documented. The performance advantage also includes object discrimination, and that females are more persistent facing complexity in problem instruction (Mcbride, 2009). Furthermore, physics problems that include vertical and two-dimensional motion seem to put young women at a disadvantage (e.g., Docktor & Heller, 2008; K. Wilson, Low, Verdon, & Verdon, 2016). This suggests that the considerate design of physics problems and learning materials can facilitate enageement for young women in physics. Finally, utility-value interventions taught students' parents about the usefulness of STEM courses (Harackiewicz, Rozek, Hulleman, & Hyde, 2012). Students of those parents took significantly more STEM courses in high school than the students in a control group (Harackiewicz et al., 2012). Since it is well established that young women are particularly interested in people-oriented careers (Su et al., 2009), ultility-value interventions capitalized on people-oriented aspects in physics (Häußler & Hoffmann, 2002). An intervention that seems particularly tied to young womens values and challenge the attribution of science with agentic values, is the communal values intervention (E. R. Brown, Smith, Thoman, Allen, & Muragishi, 2015). The authors showed that stressing the communal values of biomedical research enhanced students' (both young women and men's) momentary motivation and motivation over time.

## 2.4 Implementing interventions

The logic of educational interventions was captured in a sequential model (Figure 2.5). Harackiewicz and Priniski (2018) presents this conceptual model for intervention studies in education in order to outline essential features that need due consideration when designing interventions. The problem assessment in the present dissertation for interventions linked to gender-inclusive physics is the fact of female underrepresentation in physics to degrees that remains below expectatopms based on ability distributions in STEM. The main idea for interventions to solve this problem is changing the social learnign context presented to students. On this basis, interventions can be designed that target potential mechanisms that facilitate different facets of agency and engagement for young women in physics. The target outcomes refer to attitudinal changes, further engagement, and future participation in the physics community (distal outcomes), or to changing the perception of learning environments.

*Assessment of problem and context:* Interventions that strive for gender-inclusive physics share the goal of achieving equity. As such, challenging existing practices in order to raise equity, i.e., overcoming existing macro, meso, and micro level constraints for agency is a goal of these interventions. The basic assumption is that the macro, meso, and micro level constraints for agency contribute to an unequal distribution of resources, life-chances, and procedural biases amongst individuals. In order to design and implement interventions, some specific considerations regarding the intervention design, population, and target outcomes can texture the conceptual model for targeted interventions. Ramifications for intervention design, population, and targeted outcomes can be gleaned from the reviewed research on situated agency and from the empirical evidence on effective interventions that raise gender-equity in physics.

*Intervention design:* Identity development happens in time, such that longitudinal research is the preferred choice. Research on human development (Bronfenbrenner, 1979), formation of implicit social cognitions (Kiefer & Sekaquaptewa, 2007; Nosek, Hawkins, & Frazier, 2012), stereotype threat and social belonging interventions (Cook et al., 2012), choice-making processes in STEM (Lykkegaard & Ulriksen, 2016; Fredricks & Eccles, 2002), science identity research (Johnson, 2012; Rahm & Moore, 2016), identity research (Lichtwarck-Aschoff et al., 2008; S. J. Schwartz et al., 2011), and dynamics system analyses (Bertenthal, 2007) propose that studying variables over time is necessary for obtaining a good understanding of underlying processes of identity development, agency, and engagement. Longitudinal research is the preferred choice in order to establish causality, which is a goal of empirical research (Bijleveld, Catrien C. J. H. et al., 1998). Varelas et al. (2015, p. 442) motivated the importance that studies of agency need to follow students for an extended period of time in order to "explore the intricate ways in which institutional, organizational, ideological, and interpersonal structures influence students' agency" (see also: Carlone, Webb, Archer, & Taylor, 2015). Care should be taken that interventions to support young women do not remain isolated efforts (Mokhonko, Nickolaus, & Windaus, 2014; Sharp, Carey, Frechtling, & Burgdorf, n.d.; Stout et al., 2011), and design has to address the learning environment rather than change the individual students, because otherwise the complexity of the problem of female underrepresentation in physics as outlined in the situated agency model is not addressed.

*Population:* Williams and Ceci (2015) argued that gender discrimination in tertiary education is not the main problem when solving the issue of female underrepresentation in physics. Rather, interventions have to start earlier. Early adolescence is likely to be a reasonable starting point (Hazari et al., 2010). Students develop an interest in physics at around 14 years of age (Lindahl, 2007; Maltese & Tai, 2010; Schoon, 2001; Tai et al., 2006). 14 was also found to be the critical age for developing and differentiating vocational orientations (Gottfredson, 1981). Early adolescence is the critical phase identity crises are faced and decisions regarding what to do in life are made. Furthermore, the gendered aspects of identities are discovered (Breger, 1974; Erikson, 1963; Hannover, 1997). Feedback from peers is especially salient in early adolescence. As Erikson (1968, p. 255f.) put it:

> Die heranwachsenden, sich entwickelnden Jugendlichen sind angesichts dieser psychologischen Revolution [Pubertät, Geschlechtsreife] in sich selber vor allem daran interessiert, wie sie in den Augen anderer

> erscheinen, verglichen mit ihrem eigenen Gefühl, das sie von sich haben, und wie sie ihre früher geübten Rollen und Geschicklichkeiten mit den augenblicklich vorherrschenden Idealtypen in Verbindung setzen können.

In this developmental stage, adolescents consolidate their commitments to life plans and projects (Erikson, 1963; Marcia, 1980). Early adolescents identity is "most likely to be unstable, and most apt to change, because early adolescents have only just begun to consider identity issues" (S. J. Schwartz et al., 2011, p. 374). Gender research suggests that the development of a gender identity and behaving according to it is particularly relevant in this transitional period (Galambos et al., 1990). Successful young women in physics have been found to decide and opt for physics in high school (Hazari, Brewe, Goertzen, & Hodapp, 2017; Ivie, Cuzjko, & Stowe, 2001; Ivie & Guo, 2006; Lindahl, 2007). In this transitional stage of adolescence, mainstream institutions hold great relevance for young women in physics (Maltese & Tai, 2010). Particularly physics teachers are of fundamental importance in this stage (Hazari et al., 2017; Mujtaba & Reiss, 2014). Interventions that target to support young women's physics identity development, agency, and engagement can address a population of students in middle and high school. In a similar line, M.-T. Wang and Degol (2017, p. 130) conclude that "[t]he optimal time for intervention would be during middle childhood and adolescence, before youth lose the opportunity to enroll in the advanced math and science courses that will best prepare them for a major in STEM."

Considerations regarding the population can be extended with regards to the expert-novice paradigm. In line with Steele (1997), domain-identified young women and those who lack an initial interest in physics can be differentiated. Durik and Harackiewicz (2007) found that the coloring and font variation in mathematics problems affected students with a low individual interest in mathematics positively, but had a negative effect for students with a high individual math interest. A differentiation between students with a high individual interest (i.e., domain-identified experts) and students with a low individual interest (i.e., novices) is useful for research with young women in physics (e.g., Drury et al., 2011). Both these populations have different issues of concern. On the one hand, it can be motivated that for domain-identified young women (i.e., those who construe themselves as physics persons) particularly the social context is important. Their individual motivation and prior knowledge in physics is high. Stoet and Geary (2018, p. 12) concluded: "In particular, high-achieving girls whose personal academic strength is science or mathematics might be especially responsive to STEM-related interventions." Identity threat might prevent domain-identified young women to meaningfully engage in physics (C. Good et al., 2008; Steele, 1997). On the other hand, for students who do not identify with physics the setting and individual motivations are at stake in order to experience agency and identify with physics. Young women who dislike physics have more fundamental issues relating to knowledge and motivations. Their knowledge and motivation for physics is low.

*Targeted outcomes:* The reviewed research utilized various target outcome variables and covariates in order to evaluate the effectiveness of interventions (see Figure 2.5 for an overview). These constructs include mirco level constructs such as self-concept and constructs related to the environmental. Different conceptualizations of identity will also address different aspects of identity (Lichtwarck-Aschoff et al., 2008). For example, long-term identity can be studied with interviews and questionnaires that probe ”students’ long-term aspirations,” because of its relative stability over time (Cobb & Hodge, 2011, p. 189), and its accessibility. However, micro level instantiations of identity (identity as performance in social contexts) are not necessarily accessible to the student, and perforance measures such classroom observations can be utilized (Lichtwarck-Aschoff et al., 2008). These methods can gain information on difference facets of physics identity that are beyond self-report. Considering quantitative approaches for identity measurement in the context of supporting young women’s physics identity development, agency, and engagement, a host of constructs has been proposed (Table 2.2). In terms of the three levels of agency the scales can be linked to macro, meso, and micro-level constraints for agency. Table 2.2 summarizes (quantitative) measures that are validated and found reliable in the context of female underrepresentation in physics. The overarching construct is agency in physics. Agency is informed by variables that reflect characteristics of the social context (e.g., salience of stereotypes, perceived environmental entitiy theory), and variables that relate to personal values and competence beliefs (e.g., self-efficacy, cost of physics engagement).

Table 2.2: Important measurement scales for understanding and assessing the underrepresentation of females in physics.

| Level | Definition | Scale<br>*Short description of scale* |
|---|---|---|
| Macro | Measures about traditional discourses (e.g., gender stereotypes, ability beliefs) | • Explicit and implicit gender-science stereotypes (Greenwald, Nosek, & Banaji, 2003)<br>*Measures the amount a student agrees to gender-science stereotypes*<br>• Domain-specific Ability Beliefs (Leslie et al., 2015)<br>*Belief, if abilities required in a domain need a special talent that can't be taught*<br>• Systemizing and empathizing for domain (Leslie et al., 2015)<br>*Students experience for whether a domain is more dominated by sytemizing versus empathizing features* |
| Meso | Measures that are linked to the particular learning setting | • Perception of environmental stereotyping (Good et al., 2012)<br>*Measures the extent to which gender stereotypes were salient in the setting*<br>• Perception of environmental theory of talent (Good et al., 2012)<br>*Measures the extent a students' feeling that a growth mind-set rather than an entity theory dominated in the setting* |
| Micro | Measures that relate to the learners personal construal of her self and identity in physics | • Sense of belonging to the physics community (Good et al., 2012)<br>*This variable monitors the feeling of acceptance by the community that is also fundamental to invest personal resources in the domain*<br>• Physics identity (Hazari et al., 2010)<br>*Measures the students' narrated physics identity with respect to competence/performance, recognition, and interest in physics*<br>• Theory of talent (Dweck, 2000)<br>*Measures the students' growth mind-set in physics*<br>• Expectancies of success and values towards physics (Eccles & Wigfield, 2002)<br>*Measures expectancy to be successful and values (utility, cost, interest, and attainment) in physics*<br>• Possible self in physics (Markus & Nurius, 1986; Stake & Nickens, 2005)<br>*Measure of how much friends will endorse the career and how much fulfillment a career in physics might offer*<br>• Science peer relations (Oyserman, Bybee, & Terry, 2006; Stake & Nickens, 2005)<br>*Issues with arranging a demanding science career with family and peer-group effects*<br>• Endorsement of gender group (Bieg, Goetz, Wolter, & Hall, 2015; Schmader et al., 2004)<br>*Perceived importance of group belongingness* |

# Chapter 3

# Research questions

Identity development, agency, and engagement have been found to be constrained for young women in physics. Such constraints manifest in macro, meso, and micro levels. Identity development, agency, and engagement are facets of individual development, while the underlying mechanism for individual development was captured in the reciprocal causation where individual, social context, and behavior interact (Bandura, 1986). In this causation, cognitive schemata are formed through assimilation and accomodation (Piaget, 1976). Assimilation and accomodation are informed by the social context where different situational cues activate different knowledge elements that the individual endorses. As a consequence, social contexts activate different knowledge. In order to organize this knowledge, an individual develops a self-conceptualization in a process of differentiation and integration of an internal and external world (e.g., Marsh, 1984). In line with this differentiation, identity researchers proposed a conceptualization where identity comprises different knowledge about oneself also in reference to social contexts and others, such that identity has been proposed to be the ”missing link” between individual development and the socio-cultural context (e.g., Sfard & Prusak, 2005). Identity development for individuals in modern societies is constituted through the development of multiple identifications that eventually result in an achieved personal identity (Erikson, 1968). The identities that an individual endorses guide the behavior of the individual in social contexts. Especially adolescence is regarded as a critical period in the development, because identities are fluid in this phase and life-plans are formed.

Affiliations with certain subjects such as physics are an essential feature towards achieving a personal identity (through exploration and commitment), because these subjects can provide goals and values for the individual. In order to achieve an identity, the capability for exercising agency in a domain is key, and agency is seen as the lever in individual development (Bandura, 2001). A positive interaction with the environment, captured in the agency construct, raises students' ability to cognitively, affectively, socially, and behaviorally commit to a domain. Students' ability to cognitively, affectively, socially, and behaviorally commit to a domain is called engagement (e.g., Varelas et al., 2015; Fredricks et al., 2017). A student's engagement and agency can be constrained on multiple levels, such as societal stereotypes (e.g., gender ability stereotypes), situational identity threat (e.g., group constellation), or individual cognitions (e.g., interests and values). Such constraints for agency are moderated through situational cues from the environment. Situational cues can make social identities salient and exacerbate identity development, agency and engagement (Kessels et al., 2006; Steele, 1997). Amongst the social identities the feminine gender identity can become particularly contested in physics learning settings (Francis, Archer, Moote, de Witt, & Yeomans, 2016). The social context can also be considerate of facets of a student's identity such that agency and engagement are fostered. On the micro-level, individual cognitions are recognized that might constrain agency. For example, females and males, on average, differ in their career goals, motivations, and interests. Females, on average, express more communal and interpersonal goals such as helping others (Lubinski & Benbow, 1992). At the same time, males rather express instrumental values for their career choices such as assertiveness, money, and prestige (G. Jones et al., 2000). Physics, as it historically developed as a male-dominated field, resonates more with masculine values and interests and likely presents a chilly climate for females. This line of argument implies that engaging students with physics is partly about training cognitive skills (e.g., content knowledge and problem-solving abilities). Yet, motivational aspects have to be factored in in order to engage students in physics, because engagement can be impaired by environmental influences such as negative stereotypes.

The reasons for young women's dearth in physics are due to free and constrained choices about their life courses (Ceci & Williams, 2011). As for the constrained choices, intervention efforts proved effective in facilitating engagement for young women in physics with regards to specific target outcomes. Interventions with regards to identity studies provided insights in patterns of engagement for diverse learners in physics, social-psychological interventions indicated that considerate intervention measures can have lingering effects and support engagement for young women in physics, And interventions from science education demonstrated what kinds of learning materials were effective in order to address specific motivations for young women. However, a model that integrates these findings is missing in order to solve the complex problem of female underrepresentation in physics.

Consequently, a situated agency model was outlined on the basis of empirical research that captures constraints for agency for young women in physics learning contexts. The situated agency model deduces guidelines for implementing and evaluating interventions. Macro, meso, and micro level constraints for agency for young women in physics were identified. E.g., situational cues (arising from the social context) in physics can make the female gender identity salient such that agency is impaired. Macro level (stereotypes, prototypes), meso level (situational cues, environmental entity theory), and micro level (competence beliefs, goal-congruity) constraints for agency can be differentiated. A three level understanding of agency (macro, meso, and micro) eventually enables a more comprehensive understanding of agency, of interventions, and of potential shortcomings in interventions. Furthermore, the situated agency model is meant to part from a deficit model where young women are seen to lack motivations or competence. It is emphasized that young women oftentimes experience a mismatch with physics learning environments, and that, in order to support young women's physics agency and engagement, the physics environments should be adapted.

Raising gender equity through targeted interventions is a complex problem and many intervention measures in physics that strive to raise gender equity can make suggestions as to how to improve the "culture of physics" towards gender-inclusiveness. However, few theoretically driven policies are implemented in educational programs to raise female participation in physics learning contexts. In order to potentially inform stakeholders and policy makers, this dissertation seeks to probe effects of an integrated intervention that faciliates physics engagement for young women. It was argued that quantitative and qualitative research should be applied to a problem in order to gain a more comprehensive understanding (e.g., Creswell, 2003). Thus, a twofold research strategy is employed in order to approach the research goal of probing effects in order to raise gender equity in physics and support young women's identity development, agency, and engagement in physics. First, the situated agency model's assumptions will be explored in a physics context in order to assess the validity of the situated agency model. Second, integrated interventions that are theoretically grounded in the situated agency model will be implemented and evaluated in physics learning contexts in order to inform strategies that potentially raise gender equity in physics.

Out of the interest to motivate more high-achieving students to STEM, and following the suggestion to learn from female students who have experienced male-dominated physics environments for a long time (a similar rationale is presented in: Carlone & Johnson, 2007), physics enrichment programs were chosen as the context for addressing the research goals of identifying, implementing, and evaluating effective strategies for raising gender equity in physics. A physics enrichment program where adolescent students participate is the Physics Olympiad. The Physics Olympiad comprises high-achieving students in physics such that participants can be assumed to have a personal interest in physics. Consequently, participants in these learning environments are likely to be more sensitive to changes in physics and they are the experts to judge whether changes are appropriate, coherent, and helpful for them. Raising gender equity in the Physics Olympiad might attract talented students to STEM who will likely be successful candidates that enrich the physics community with their skills (Stake & Mares, 2001). Even amongst the most talented students, many report a lack of motivation to pursue STEM subjects, and young women, in particular, drop out disproportionally from the Physics Olympiad. Approaching these young women might facilitate their career aspirations for physics so that potentially capable students for enriching the physics community are won.

Aligned with the twofold research effort, four empirical studies explored facets of identity development, agency and engagement in physics for young women in the Physics Olympiad and probed interventions that potentially raise gender equity in the Physics Olympiad. In particular, study 1 explored facets for young women's physics engagement in the context of the Physics Olympiad. Assumptions from the situational agency model can be tested for the high-achieving young women in the context of the Physics Olympiad. The following research question guides study 1:

RQ 1: What are facets of physics engagement for high-achieving young women that participated in the Physics Olympiad?

Study 1 is accompanied by three intervention studies that are designed on the basis of the situational agency model and the evaluation model for educational interventions. Thus, studies 2, 3, and 4 sought to implement and evaluate effective interventions that adopted specifically designed learning materials and social context adaptations that were gleaned from the prior research. Study 2 explored an integrated intervention strategy to challenge the physics image for university students through learning materials in the form of a historical case study. The following research question guided study 2:

RQ 2: To what extent can specifically designed learning materials challenge the perceived physics image for university students who participated in the intervention?

More specific to the Physics Olympiad, study 3 pilots an intervention which implemented the learning materials from study 2 in addition to an adaptation of the social context. As such, study 3 particularly tested the effectiveness of adopted learning materials and social context for the physics identity development of students in the Physics Olympiad. The following research question guides study 3:

RQ 3: To what extend can a specifically designed intervention enhance physics identity resources for participating young women?

On the basis of the findings from study 3, study 4 implemented a longitudinal intervention in order to evaluate long-term effects of a targeted intervention in the context of the Physics Olympiad. Study 4 adopted the learning materials and social context adaptations from study 3 and particularly sought to affect target outcomes that could not be influenced in study 3. The following research question guided study 4:

RQ 4: To what extend can a specifically designed long-term intervention facilitate physics identity development for participating young women?

The four empirical studies were meant to inform the overall research goal, namely identifying effective strategies for raising gender equity in physics. In the chapters to come, each of the four empirical studies will be presented in its respective context. An introduction will provide the context and goals of the respective study in detail. After each study the evidence that the study can provide for altering the Physics Olympiad environment towards gender equity will be discussed. On the basis of the empirical work, the findings will be evaluated in reference to prior research on gender differences in physics that has been laid out in chapter 2. Chapter 8 will give an overarching discussion on the findings and outline efforts in physics on how ”policies and procedures that give the same opportunities and encouragement to the study of physics by girls and boys” (DPG, 2002) might look like.

# Chapter 4

# Exploring physics engagement for young women in the Physics Olympiad (Study 1)

## 4.1 Introduction

As outlined in chapter 3, study 1 seeks to develop an understanding of the physics enagement of young women in the context of the Physics Olympiad in order to explore the validity of the assumptions based on the sitated agency model for the context of the Physics Olympiad. Gender related research in the Physics Olympiad is scarce, and the initial understanding of the physics engagement of high-achieving young women in the context of the Physics Olympiad comes mainly from research related to gender-issues in STEM education research. For example, it has been reported that young women, on average, experience feelings of isolation (chilly climate) when engaging in physics learning environments (Brickhouse & Potter, 2001) and many young women perceive physics in school as unpleasant, difficult, and masculine (Archer, Moote, Francis, DeWitt, & Yeomans, 2017; Adamuti-Trache & Andres, 2008; Carlone, 2003, 2004; Duit, Niedderer, & Schecker, 2007; Farenga & Joyce, 1999; Kessels et al., 2006; Baker & Leary, 1995; Scantlebury & Baker, 2007). Researchers documented a clash of the so called feminine identity (e.g., endorsing belongingness to female group) and the perceived "narrow culture" of physics (Eisenhart & Finkel, 1998; Archer et al., 2012a; Skelton et al., 2010; Archer et al., 2017; Carlone, 2004). For example, from their engagement in physics learning environments, even physics-interested girls adopted an image of physics as being brainy and non-feminine (Fiebig, 2008). Mechanisms that make physics classrooms identity-threatening for young women relate, amongst others, to the salience of negative stereotypes that affect the engagement of (even STEM interested) female students (e.g., Marchand & Taasoobshirazi, 2013; Archer et al., 2012a). Young women have to tread a precarious line between fitting in with stereotypes about endorsing femininity and enacting all the behaviors required to succeed academically (Renold & Allen, 2006; Skelton et al., 2010). Societal expectations and gender stereotypes sometimes led young women to camouflage their talents in order to be recogniced by their peers as normal young women (A. X. Feng, Campbell, & Verna, 2005; Kerr, 2000; Simpkins, Price, & Garcia, 2015).

Consequently, physics environments should be considerate of such research finding. Importantly, Hazari et al. (2010) found that the influence of social networks (e.g., parental and teacher support) was a physics identity resource for young women and young women valued teacher encouragement and relied more than young men on institutional appraisal to engage in physics (Baker & Leary, 1995; Fredricks et al., 2017; Garvin, 1996; Hazari et al., 2010; Maltese & Tai, 2010; Reis & Park, 2001; Lind, 2001; Tirri, 2002). However, empirical evidence suggests that parents, peers, and teachers tend to hold constraining expectations towards young women's physics engagement (Mujtaba & Reiss, 2013; Crowley, Callanan, Tenenbaum, & Allen, 2001). Even young women who were high-achieving in STEM were sometimes barely supported by their parents in their STEM engagement (Aschbacher, Li, & Roth, 2010; Cho & Lee, 2002; Lengfelder & Heller, 2002; Nokelainen, Tirri, & Campbell, 2004). Also, teachers were found to hold stereotypical expectations towards girls' and women's abilities in physics (K. A. Heller & Ziegler, 2010) and neglect young women in the physics classroom (Faulstich-Wieland et al., 2004; Guzzetti & Williams, 1996; Reiss, 7. - 10. September 2000; Warrington & Younger, 2000). Yet, high-achieving young women particularly relied on the confidence that meaningful scientific others (e.g. teachers) expressed about their abilities (Zeldin & Pajares, 2000). Baker and Leary (2003) found that young women particularly endorsed learning experiences that required cooperation with peers. Having a close friend engaged in science improved views about science for young women (Baker & Leary, 1995). But girls, on average, perceived less support from their peers for science activities compared to boys and have fewer science activities with peers outside the classroom (Jovanovic & Steinbach King, 1998; Kelly, 1988).

In order to explore the assumptions of the situated agency model in the context of the Physics Olympiad, it is required to examine to what extent such factors as explicit gender stereotypes or discouraging meaningful others were also experiences by high-achieving young women in the context of the Physics Olympiad.

## 4.2 Research Question(s)

The aim of study 1 was to explore facets of physics engagement for high-achieving young women in the Physics Olympiad context that explore the assumptions of the situated agency model. Understanding facets of physics engagement for these high-achieving young women can help refine the situated agency model and form the starting point for subsequent studies that seek to support engagement for young women who participate in the Physics Olympiad.

RQ 1.1 What are facets of physics engagement for high-achieving young women who participated in the Physics Olympiad?

## 4.3 Method

In order to explore facets of physics engagement of young women in the Physics Olympiad context, personal accounts of young women's engagement in the Physics Olympiad context would be valuable sources. This is because individual experiences of engaging in social settings such as the Physics Olympiad through learning and interacting with peers and mentors likely become important aspects of the self-construal such that they are valuable sources about the person and the environment the person acted in. Individual experiences can be narrated and on the basis of these narratives factors that affect young women's engagement can eventually be reconstructed (e.g., Clandinin, 2006; de Fina, 2009). For example, it has been observed that experiences of positive engagement and control over the happenings in the environment (i.e., purposeful actions, or agency) constitute a recurring theme in personal narratives (Habermas & Bluck, 2000; McAdams, 2001; McAdams & McLean, 2013).

In particular in the context of gender research, prioritizing personal narratives approaches was encouraged as a means to emphasize the young women's voices in studies. Personal narratives approaches enable young women to explain their own experiences in a more contextualized and personal manner, as compared to closed form questionnaires (Baker & Leary, 1995). Self-efficacy theorists argued that deeper insights are likely to come from narrative research, relying on personal accounts (e.g., Zeldin & Pajares, 2000; McAdams, 2001; Riessman, 2002).

### Design

In order to tap a rich source of experiences in physics environments, young women who successfully participated in the Physics Olympiad were solicited for participation. These are young women who persisted in physics for a long time and engaged in it above average. In a similar line, Baker and Leary (1995) and McNay (2000) argued that learning from young women who persisted in STEM and deeply engaged in STEM was a means to find evidence-based strategies to make physics learning environments more gender inclusive and more supportive for girls (Johnson, 2012). Also, Brickhouse, Lowery, and Schultz (2000) proposed to take a closer look at girls and young women who persisted in physics so as to understand the experiences and motivations of these successful young women and the ways in which they overcame barriers to their engagement in physics classrooms and in informal physics settings such as competitions (also: Carlone, 2003).

The highest-achieving young women in the Physics Olympiad were found in the pre-final stage of the Physics Olympiad. Participating in the pre-final stage assured that these young women engaged in two stages of the competition and eventually in the pre-final stage. The pre-final stage is the most advanced round in the competition where female students participate. The pre-final stage of the competition is a week-long seminar where contestants come together at a research facility in Germany (see chapter 1.5). The young women who participated in the pre-final stage of the Physics Olympiad in 2015 (further referenced as study A) and 2016 (further referenced as study B) were contacted via e-mail to voluntarily participate in this study that was introducted to the young women to comprise an interview and a questionnaire. In both years overall 50 participants advanced to the pre-final stage. In 2015 $N = 4$ of them were females, and 2016 $N = 5$ were females. All of the young women agreed to participate, so that the entire sample (studies A and B combined) comprised $N = 9$ students. In study A the interviews were conducted in person right at the beginning of the pre-final stage of the competition where the participants got together to compete on theoretical and practical exams. Prior to the interviews the participants filled in a background questionnaire at the beginning of the pre-final round. In the following year (study B) phone interviews were conducted before and after the pre-final stage of the competition, since this was more practical. Based on prior studies (Vogl, 2013), it was not expected that phone interviews and in-person interviews made a substantial difference in content of responses.

### Sample

When studying participants in competitive programs such as the Physics Olympia, prior research pointed to the above average educational background of the participants' parents (P. B. Campbell & Steinbrueck, 1996; Lind, 2001). In order to characterize the participants in this study with regards to these prior findings and in order to assess the variability that the young women differentiates from each other, some background characteristics will be reported in the following. In study A the young women ($N = 4$) were enrolled in the final grade of secondary education (i.e., grade 12, German gymnasium, except for one who attended grade 11). This means that the young women had potentially 4 years of physics classroom experience. The mean (SD) age was 17.3 a (0.5 a). Participants' background variables are listed in Table 4.1. The young women have above average grades (mean overall GPA: 90.3 %, mean STEM GPA: 93.3 %) which was consistent with previous findings on girls who succeeded in this type of selective competitions (Lengfelder & Heller, 2002). The participating young womens' advanced courses comprised mainly STEM-related subjects, including at least one advanced mathematics course. This further validates the extent of experience in physics classrooms that the young women brought to the interviews. Consistent with prior research, the participants' parents had an above average educational background (Table 4.1). Finally, all participants of study A reported aspirations to perform jobs within the domain of STEM (medicine included) in the future.

The participating young women in study B ($N = 5$) were also enrolled in the final grades of secondary education in German Gymnasium (Table 4.2). The mean (SD) age was 17.3a (1.0a). Only three of the five participants in study B provided background information in an additional questionnaire. From the three available responses, the young women had outstanding grades in school (mean overall GPA: 92 %, mean STEM GPA: 95 %), as expected from study A. The parents of the participating young women in study B had varying educational degrees and occupations. All the young women aspired a STEM-related job and were involved in other science competitions, which is consistent with other research findings (Urhahne, Ho, Parchmann, & Nick, 2012).

Overall, all young women in both studies were well immersed in STEM environments through advanced courses and STEM competitions. They can be considered high-achieving students in STEM, as judged by their respective science and mathematics GPA, and by their achievement in the Physics Olympiad. The participating young women all had a rich base of personal experiences in physics learning environments as evidenced through their advanced courses and their competition engagement. Furthermore, the young women were also representative of the Physics Olympiad population as assessed through alignment with prior research. The participating young women thus comprise a suitable sample for the aim (understand physics engagement of high-achieving young women in the Physics Olympiad) of this study.

### Instruments

In order to yield a contextualized understanding of the young women's facets of physics engagement, semi-structured interviews were utilized. Semi-structured interviews enable interviewees to construct personal narratives (King & Horroks, 2010). The interview protocol aimed to enable the young women to share their experiences in the context of the Physics Olympiad and their physics classes. The interview topics were gleaned from the literature review and comprised support by meaningful others (teachers, parents, peers), gender stereotypes in physics, physics learning, and general experiences in physics engagement. For outline of topics and examples of wording of questions see appendix A. The outline of the interview protocol in study A can be found in Table A.1. In study B a similar interview protocol was used. See Table A.2 for an overview of the interview protocol for study B. Some topics in study A were identified to be leading for the young women and introduce uncomfortable situations. Consequently, the topic of gender differences was omitted in study B and rather when talking about meaningful others and physics learning, potential gender differences were asked for. In both interviews, the interviewer was introduced first and the purpose of the study (improve the design of the Physics Olympiad to the needs of the participants) was outlined in order to create rapport. At the end of the interviews the young women were given the opportunity to suggest improvements for the competition in order to avoid ending the interviews with a controversial topic.

In addition to the interviews, background data was gathered via a supplementary paper-pencil-questionnaire. In this questionnaire demographics (e.g., school track), school grades, and motivational variables related to inclination towards physics and the Physics Olympiad were measured (for an overview of employed scales see appendix A Table A.3). The questionnaire data enabled the triangulation of some of the responses from the interview data and collect background information on the participants.

### Data collection and analysis

The interviews in study A lasted 15 to 25 minutes and were digitally audio-recorded. They took place during the pre-final stage of the Physics Olympiad. The competition venue was a large research facility in Germany and the students were invited in a seminar room at one evening to be interviewed. The interviews were conducted by the first author in German. The interviews were transcribed and translated into English by a professional translator. In study B the interviews lasted about 30 minutes and were also digitally audio-recorded and held via telephone after the pre-final stage of the Physics Olympiad took place. A female graduate research assistant with a physics and mathematics background conducted the interviews. Interviews in both studies were coded in English by two independent coders using the software package MaxQDA 11.2. The questionnaire was administered to all students at the competition site and took approximately 30 minutes to complete.

For data analysis, constant comparative analysis was used (Corbin & Strauss, 1990). Constant comparative analysis enables to identify common themes among

Table 4.1: Sample overview in study A.

| Category | Student A | Student B | Student C | Student D |
|---|---|---|---|---|
| Age | 17 | 17 | 17 | 18 |
| School type | Gymnasium | Gymnasium | Gymnasium | Gymnasium |
| Advanced courses | Math/English | Math/Physics/Biology | Math/Chemistry/English | Math/Physics |
| GPA | 100%; 0.7 | 88%; 1.2 | 82%; 1.8 | 91% 0.9 |
| Science and math GPA | 100%; 0.7 | 95%; 1.0 | 82%; 1.8 | 92%; 0.8 |
| Degree/Occupation Mother | PhD/Medical Doctor | University degree/Not answered | University degree/Salesperson | Apprenticeship/Secretary |
| Degree/Occupation Father | PhD/Medical doctor | University of applied science degree/ Engineer | Apprenticeship/ Factory worker | University of applied science degree/Mechanical Engineer |
| Occupational aspiration | Medical doctor | Electrical engineer | Medical doctor | Physics (doing research and develop products) |
| Former experiences in competitions | STEM competitions | STEM competitions | STEM science fair | Missing info |

[a] GPA refers to German grading system that ranges from 0.7 (best, 100%) to 6.0 (worst, 0%).

Table 4.2: Sample overview in study B.

| Category | Student 1 | Student 2 | Student 3 | Student 4 | Student 5 |
|---|---|---|---|---|---|
| Age | 18 | 16 | 18 | - | 17 |
| School type | Gymnasium | Gymnasium | Gymnasium | Gymnasium | Gymnasium |
| Advanced courses | Math/English | -/- | Physics/Chemistry | -/- | Math/Physics |
| GPA | 89%; 1.3 | - | 95%; 0.97 | - | 92%; 1.12 |
| Science and math GPA | 89%; 1.3 | - | 99%; 0.77 | - | 97%; 0.85 |
| Degree/Occupation Mother | University of applied sciences degree/Butcher | -/- | Apprenticeship/Physiotherapist | -/- | University degree/Architect |
| Degree/Occupation Father | University of applied sciences degree/Factory worker | -/- | University degree/Civil servant | -/- | PhD/Engineer |
| Study aspiration | Medicine/Chemistry | - | No specific answer; but STEM related | - | No specific answer; but STEM related |
| Former experiences in competitions | 3 STEM competitions | - | 2 STEM competitions | - | 5 STEM competitions |

interview transcripts. Two independent coders, the author and another researcher with expertise in gender research (study A) and the author and a graduate student, who received instruction on the comparative method (study B), went through two of the interview transcripts independently and used open coding in an iterative and generative reading process to identify topics that inform the research question (facets for physics engagement for the interviewed young women). The structure of the interview protocol was accordingly designed to elicit relevant personal accounts. For example, in the interview gender-related aspects to physics engagement were addressed and the young women articulated on gender patterns in the Physics Olympiad. The responses of the young women were coded into the category gender when they were pertinent to the transcripts of all young women. Similarly, when all students talked about their physics attitudes, a new theme, attitudes, was generated that was also relevant to the research question of facets of physics engagement for high-achieving young women in physics. Coding disagreements were discussed and resolved until a final code system was developed that captured the data. This coding system was used to analyze the remaining transcripts. When new patterns were identified the process was reiterated.

## 4.4 Results

### Study A

The overarching research question for this study was to identify facets of physics engagment for high-achieving young women in the Physics Olympiad. The interview protocol in study A provided the young women an opportunity to elaborate on their first involved with the Physics Olympiad. Throughout the narratives of the young women, a theme called reasons to participate in the Physics Olympiad emerged.

#### Theme 1: Reasons to participate in the Physics Olympiad

Theme 1 subsumes reasons for young women to participate in the Physics Olympiad. This also included instances when the interviewees hypothesized about obstacles or incentives for other participants. Two subthemes emerged that constitute reasons for the participating young women. Physics Olympiad's tasks were considered to be one relevant factor and encouragement by teachers and peers as another factor.

Regarding the physics tasks, all adolescent girls in different ways reflected the beauty and challenge of the physics tasks in the Physics Olympiad. The young women construed the tasks as motivating for them, but at the same time considered (or implied) the tasks as factors that potentially discouraged their female peers:

> Interviewer: How did you hear about the IPhO [i.e., Physics Olympiad].
>
> Student C: Well, I heard about it in school because the physics student association has hung up posters and then I've just looked at the posters and then I found it to be quite interesting tasks. And then I've participated in it. [...] I found the tasks quite interesting.

---

> Interviewer: What do you think is the reason for such a low participation of girls?
>
> Student B: So there certainly have been girls as well that came forward and also wanted to join in, but then they looked at the exams, so like during the first stage, and then they found it to be a bit too difficult or so. Although I wouldn't necessarily make it easier on this level, in order to get more girls into it. That doesn't necessarily make it more fun, I think.

The second reported reason for participation was the encouragement by teachers and peers. In this subtheme interviewees emphasized encouragement or support by meaningful persons in their surroundings:

> Interviewer: Describe to me how you became aware of the IPhO and how did you experience the first round?
>
> Student B: Yes, so my physics teacher approached me and then told me: 'Just give it a try'. Yes I haven't known about that before, I only knew the IChO [i.e., international Chemistry Olympiad]. Well, and then I participated in it and that has been fun. He said: 'Calculate this' [...].

---

> Interviewer: How did you heard of the international Physics Olympiad and who were your most important persons to talk to?
>
> Student A: I got to know some people [...]–if you are older, you can participate, we were told. And the other two years I did the other Olympiads, but I knew people who were involved with the international Physics Olympiad. They told me that the Physics Olympiad is fun, and then I thought that this year it is worthwhile and my teacher asked me, whether I'd like to take part, and then I took the chance this year.

In the supplementary questionnaire the young women were asked in an open question who encouraged the young women's participation were examined as well (see Table 4.4). In fact, all young women wrote influential persons that affected their participation in the Physics Olympiad. Either peers, parents, and teachers were reported.

Besides the initial reasons for participation, another important facet of physics engagement and engagement in the Physics Olympiad context was the personal accounts of experiences that the young women made in the course of their participation in the Physics Olympiad and how they construed that these experiences were important for their persistence. Again, similar reasons were expected as for theme 1 based on the literature. The interaction with peers might be well recognized by the young women because in regular physics classes they may have conflicts with their peers who mostly are not engaged in physics. Some studies found that high-achieving young women expressed feelings of social ostracisms in physics environments (Brickhouse & Potter, 2001). Also, young women who persisted in STEM reported interactions with others as their primary sources for self-efficacy development (Zeldin & Pajares, 2000). This provides evidence that the social environment and social interaction plays a central role for the young women in their engagement in the Physics Olympiad.

Besides reasons for participating in the Physics Olympiad, experiences when engaging in physics were of interest. A theme emerged that captured such experiences that the young women made during their engagement in the Physics Olympiad and that eventually led them to persist in the Physics Olympiad.

### Theme 2: Experiences that led the young women to persist in the Physics Olympiad

The experiences that the young women made during their participation in the Physics Olympiad were classified into two subthemes. The young women narrated about engaging with physics tasks and the young women narrated about social interactions and the social environment of the Physics Olympiad. In the first subtheme interviewees referred to their working on the physics problems in the Physics Olympiad. They expressed positive attitudes towards working on physics content in the physics Olympiad:

> Interviewer: What are the things which you like about the physics Olympiad?
>
> Student A: [...] and then I like it when you got confronted with the tasks. That you have tasks which are hard, and you cannot solve all the problems, but you face them and you learn to handle them a little after a while and you try your best and when you solved a problem then you feel good about it and this is always very nice – a sort of challenge.
>
> ---
>
> Interviewer: What are the most important things that change that [i.e., talent or skills]?
>
> Student D: Take a look at new problems where you might know the principles but then do not know how you have to do it and the more difficult it will be, the better it will be. And I think that for this stage I haven't had enough yet.

The second subtheme focused on social interactions and the social environment within the Physics Olympiad. The interviewees described what they particularly liked about this advanced round in the physics Olympiad. Interactions they had with other olympians or with the people involved in the competition (e.g., mentors, organizers) became a recurring topic. This included attitudes about meeting other students in the Physics Olympiad:

> Interviewer: Why do you find the competition to be exciting and attractive?
>
> Student D: Well I think the best thing is actually that you meet so many other people here that also love to do math [and] physics and where you aren't the absolute outsider.
>
> ---

> Interviewer: What incentives are of importance for you in the federal round?
>
> Student C: So what I find very exciting is to exchange ideas with like-minded people, to see what experiences they have made.

These findings resonate with the feedback that the young women provided in the supplementary questionnaire. In this questionnaire the young women were asked to indicate their top motivations for participating in the Physics Olympiad amongst challenging tasks, meeting others, material reward, authentic environment of how scientists work, and compete with others. Meeting others ranged for all young women amongst the top two choices.

Finally, besides the reasons to participate and the experiences that the young women made during their engagement in the Physics Olympiad, another topic emerged in the interviews, namely gender. Evidence suggests that even high-achieving young women depict gender stereotypes, portray physics as masculine (Nosek et al., 2002; Kessels et al., 2006), and might conceal their cleverness in academic settings such as competitions (e.g., A. X. Feng et al., 2005) in order to maintain a feminine gender identity in stereotypically male domains (Renold & Allen, 2006; Skelton et al., 2010). Endorsing a nerd identity was found to be particularly contested for young women in schools (Skelton et al., 2010). Furthermore, gender stereotypes might refer to greater confidence of males in their physics ability (or lack of female students in their physics ability) (e.g., Fiske et al., 2002) or with regards to stereotypically male subject preferences (mathematics or physics) and female subject preferences (arts and languages) (Kessels et al., 2006; Hannover & Kessels, 2004).

### Theme 3: Gender

Gender as a category captured parts in the narratives where gender appeared as a potentially relevant category. Stereotypic notions appeared in all narratives of the young women. Several subthemes could be identified in this theme: the lacking confidence of girls, the disreputable physics identity for girls, and 'language=female-vs-science=male' preference:

> Interviewer: What is your guess of why there are so few girls in the international physics Olympiad?
>
> Student A: [...] naturally, girls are mostly interested in biology or in languages, but I think there are also – so there are girls who are interested in physics. I could imagine that girls lack courage. In my experience, that girls are rather hesitant and believe, 'oh god I am not qualified to do that well and the others are much better', whereas in fact they might not be less talented. I could think of that boys rather have the mentality: 'I beat all, I show them that I am the best', while girls perform without anybody noticing. And maybe this is why they back off from the competition in the first place. Whereas this should count in all subjects equally.
>
> ---
>
> Interviewer: Are there any explanations as to why the participation of girls in the IPhO is so low?

> Student D: I also believe that it is extremely disreputable among girls at school already to choose something like math or physics or computer science because somehow it's also partially different, especially cause it's frowned upon among girls somehow.

---

> Interviewer: Do you have any guesses as to why the girls' participation in IPhO is so low?
>
> Student C: [...] and I think for girls on the other hand, if you delve into natural sciences or such then you're already a little nerd, so that's not something what most girls prefer, and I think if you don't receive encouragement from the teachers that it is something that you should take part in it, then the probability that the girls there have the confidence to do that is quite low.

An overview of the themes can be found in Table 4.3. Overall, the identified themes resonated well with prior research. All themes point to facets of physics engagement for young women. Enabling instances for the young women's physics engagement appeared to be an intrinsic motivation for physics, such as when the young women sought challenging problems and endorsed learning new physical principles and content. This contrasts with regular female high school students who rarely hold such positive attitudes towards subjects like physics (e.g., Kessels et al., 2006). Furthermore, peers and teachers played a crucial role for the young women to engage in the physics Olympiad. Peers and teachers encouraged the young women to participate in the Physics Olympiad. The findings are reminiscent of the physics-identified girls in the study by Archer et al. (2017), insofar that the young women in the current study were similarly enthusiastic about physics (some of the girls' quotes in Archer's study are almost literal translations from the responses in this study).

However, the young women also construed the underrepresentation of girls in physics as normal and sometimes even natural. Gender stereotypes (e.g., girls are naturally more interested in biology and reading, and lack the confidence in physics) indicated to barriers to the physics engagement for the young women. Some of the interviewees were aware of their outsider status relating to their physics identity. The young women's statements were reminiscent of an observation by Steele (1997) that stereotypes are a primary concern that parts students that identify with historically marginalized groups from those identifying with the dominant group. Again with regards to the study by Archer et al. (2017) the feminine identity in physics settings appeared to be contested and the pervading gender stereotypes remained an issue.

## Study B

Further evidence for facets of high-achieving young women's engagement in the Physics Olympiad was gathered in study B. Similar in structure to study A, study B extended the interview protocol for more questions such that topics could be explored in more depth such as the young women's engagement in physics. In study A, the young women reported that their female peers might lack confidence for tackling the problem in the Physics Olympiad–a topic well supported by the literature (Else-Quest, Hyde, & Linn, 2010). Furthermore, the

Table 4.3: Codes with definitions and examples for study A.

| Code | Definition | Example |
|---|---|---|
| 1) Reasons to participate at the IPhO | Reasons or events (for the interviewees or for women in general) that led participants to enroll in the Physics Olympiad. These are events prior to participation in Physics Olympiad that potentially led to the decision to participate. | I got to know some people and there were adverts for the big science competitions - if you are older, you can participate, we were told. And the other two years I did the other Olympiads, but I knew people who were involved with the international Physics Olympiad. They told me that the Physics Olympiad is fun, and then I thought that this year it is worthwhile and my teacher asked me, whether I'd like to take part, and then I took the chance this year. |
| 2) Experiences at Physics Olympiad that lead the adolescent girls to persist | Experiences (events, stories) participants have during the competition. | Well, on the one hand I like it that we come together with other students, which all are interested in science. And you can exchange ideas this way. And then I like it when you got confronted with the tasks. That you have tasks which are hard, and you cannot solve all the problems, but you face them and you learn to handle them a little after a while and you try your best and when you solved a problem then you feel good about it and this is always very nice - a sort of challenge. And, well, I find a week like that always very nice, so a little bit of a program and - that is always very nice. |
| 3) Gender | Ideas and beliefs that are related to gender | And I think for girls on the other hand, if you delve into natural sciences or such then you're already a little nerd, so that's not something what most girls prefer |

Table 4.4: Influential person for participants' participation in competition reported in the questionnaire in study A.

| Item | Student A | Student B | Student C | Student D |
|---|---|---|---|---|
| Which person was the most important and influential person(s) for your participation in the Physics Olympiad? Please indicate how this person(s) influenced you. | Other participants (told stories) | Physics teacher (told her about the competition) | Parents (encouraged her) | Physics teacher (gave her the tasks) |

young women portrayed females as more into languages and biology, compared to physics. Study B followed up on this topic and theme 1 emerged that related to the personal attitudes of the young women towards physics.

### Theme 1: Attitudes towards physics

The participating young women in study B expressed their personal affiliation with physics, which were very positive. At several instances in the interviews the young women, when asked, expressed positive attitudes towards physics:

> Interviewer: Do you like physics?
>
> Student 4: He yes. Very much so [i.e., she likes physics], otherwise I'd not be taking part in the competition. And well, for me physics means always a new challenge, to think through new content areas and I find that physics is universal, I'd say, also from the fields of study in physics one has many opportunities to specialize.
>
> ---
>
> Interviewer: Do you like physics?
>
> Student 5: Yes I do like physics, in school, physics is one of my favorite subjects. [...] I like that, so that it is like in the other sciences. [...] In the humanities it always is so much talk and there is, so to say, no definitive solution and so with physics you can describe the world and – like math – there is a definitive solution.

In fact, such positive attitudes towards physics were also found for high-achieving female students in physics in general (Mujtaba & Reiss, 2013). Even though the young women suspected that their female peers might be rather into languages, these young women expressed very positive attitudes towards physics. The interview followed up on this and probed the young women about their physics learning. Theme 2 emerged where young women expressed their personal approaches of physics problem solving and their felt competence in solving problems.

### Theme 2: Physics tasks and competence

The participants referred to physics problems at different occasions. For example, when they first engaged in the competition all young women had to face the tasks and found ways to deal with them. The following quotes particularly addressed the young women's construal of their interaction with physics problems. The young women expressed their affinity to dealing with physics and endorsed the challenging tasks in the Olympiad:

> Interviewer: ok, then, when you learn for physics, is there something that you normally do? A certain place, or certain people or something?
>
> Student 3: I can't help it, but I liked this problem instantly and had, I don't know, I think, I had an ansatz, I took me the whole day off to calculate it through and on the second day I pursued another ansatz and, well, I concentrated on the problem with all my capacities and that is a thing which is easy to me or which I really like. [...] I like physics and physics problems are fascinating to me and if you read a problem on a poster that you start thinking about it and then you are excited to work on it. Yes, and we have an engaged physics teacher in school. He also supports my 'Jugend forscht' [i.e., German science fair] project and he spread the competition problems in the first place.

> Interviewer: Now I would like to talk to you about the personal value of the IPhO for you and also about physics learning. The first question, ahm, so, what is the most interesting thing that you learned in your participation in the IPhO?
>
> Student 2: Well ... I found it fascinating how you can solve the problems, those strategies with simplifying and assuming things and so on. The problems sound, when you first look at them, relatively complex and, most often you can simplify it to certain core problems and I found that very interesting.

Interviewees' responses from the supplementary questionnaire supported these findings. A prime motivator for the young women was the challenging nature of the physics competition. Given a list of items[1] all three young women listed "learn something new" as their primary motivation, followed by "feel intellectually thrilled," and "meet like-minded students," which resonated with study A where the young women expressed social interactions as a prime motivator for their participation.

As in study A, the accounts of the young women also entailed instances where gender became a relevant topic. Though, in study A the young women provided explanations for the underrepresentation of young women in the Physics Olympiad and provided stereotypical explanations for the underrepresentations. In study B the gender topic was introduced when the young women were provided

---

[1] The items were: "learn something new," "feel intellectually thrilled," "meet like-minded students," "can travel," "work on challenging tasks," "decide when I work on which tasks," "get to know the job of real scientists."

an opportunity to share their experiences in the Physics Olympiad. Descriptive statistics and research suggests that the young women had less experience with same-sex peers (Petersen & Wulff, 2017; Lengfelder & Heller, 2002). Thus, issues of missing same-sex peers might have emerged as a topic in the interviews.

### Theme 3: Gender

Similar to study A, gender appeared as an analytical category in study B as well. Particularly, this theme emerged with regards to the lacking female peers that were present in the Physics Olympiad environment:

> Interviewer: So, and the students that you met, so the other participants: Were they of the same sex as you, or different sex?
>
> Student 3: So I'd say that merely statistics says, I think you know that as well, that there are [in the Physics Olympiad] mainly boys, so, I mean, if you are at a place, where there are on average equal shares of girls and boys, than the probability is somewhat higher that participants from the physics Olympiad are boys. [...] I rather participated for the physics than for social motives.
>
> ---
>
> Interviewer: And does it influence your participation that there are only boys?
>
> Student 5: If you are more into science then you are used to, so to say, that the girls are in minority and I don't find it so unsettling, because I get along with the others equally well and yes. Though I am excited what other girls will be at the competition in Göttingen, but as I said that wouldn't influence me insofar that I say: "I don't know any other girl so I wouldn't go there."

In the personal accounts of the young women it appeared that they expected to be in the minority in this learning environment. Student 5 said that she was not affected by the fact that she was in the minority. It was further probed what other experiences the young women made in their engagement in the Physics Olympiad. From study A it was expected that peers and mentors played an important role in the accounts of the young women.

### Theme 4: Experiences in the Physics Olympiad

When the interviewees talked about their experiences in the physics Olympiad (theme 4) they mentioned interactions they had with other participants and also made clear that they drew on their peers in their decision to participate in the Physics Olympiad.

> Interviewer: So you spoke of other participants. So I conclude that you got in contact with other participants?
>
> Student 3: Yes, that is the really interesting thing [to meet others], because I knew some participants from another circumstance where also participants of the competitions are involved. So I knew other participants of the pre-final stage, before I came here, although they are not at my school.

---

> Interviewer: Did you–during or before your participation in the IPhO–thought about the other participants? Who they are?
>
> Student 2: Oh yes, the best was when we arrived at the youth hostel with two friends. There still were some other students there and they all talked about physics and that was ... so, when we came there we thought: ”Yes! This is where we want to be!”

These accounts resembled the accounts in study A insofar that it became apparent that the young women endorsed the social interactions they had in the Physics Olympiad. However, the literature review made also clear that oftentimes young women receive less support from their peers and teachers regarding their physics engagement. In study A it was seen that this was quiet different for the participating young women because they well received support from their peers and teachers. Theme 5 emerged that captured the support of the social environment (e.g., teachers and peers) of the young women.

### Theme 5: Support from meaningful others

In theme 5 the young women's accounts of support they received from meaningful others was summarized. Supportive (or unsupportive) meaningful others were found to be former participants of competitions, parents, teachers and mentors.

> Interviewer: Mhm, and when you learn physics, do you have any habits, or places you go to? Or are there certain people that you contact?
>
> Student 5: So my father did physics, so he studied physics, and, well, if I hadn't understood something then I simply asked my father and besides that I didn't learn so much for physics because it came easy to me. And if I learn I do it for utility purposes, but more in the train with which I drive to school.

---

> Interviewer: How did you got in contact with the IPhO for the first time?
>
> Student 2: So mainly in third grade I did only math competitions and in my new school, at the Gymnasium, there was a person sidelined for a team-competition in physics just a day before the competition and my math teacher asked me whether I'd like to join in, because I can at least calculate, because I raised attention there and [...] he said 'try it out. Physics is not much different [than math].' And then I joined in and then he said I should join the physics club at our school.

Overall, the young women in study B expressed positive attitudes towards physics and excitement with physics problems. All young women expressed that they liked physics as one of their most favorite subjects in high school. The young women liked the challenge that came along with new sorts of physics problems. These thoughts and attitudes provided an important source for the

Table 4.5: Codes with definitions and examples for study B.

| Code | Definition | Example |
|---|---|---|
| 1) Attitudes towards physics | Attitudes, ideas, values towards physics, math and sciences in general are expressed | Yes I do like physics, in school physics is one of my favorite subjects |
| 2) Physics tasks and competence | Participants describe physics tasks in the competition. They might distinguish them from school tasks. Participants further describe their strategies to approach them or their feelings when confronted with them. | OK, well I found that this first task something similar we had done in school, because this was exactly our content in the 11th grade and - yes that is why such problems were quiet easy to me and I found it really nice that there was a cross-word included, because that was a little like a riddle, so something different than just the regular tasks. |
| 3) Gender | Experiences and opinions that relate to gender. For example, when participants talk about their female friends and the relation to physics | ,If you are more into science then you are used to - so to say, that the girls are in minority and I don't find it so unsettling, because I get along with the others equally well and yes. Though I am excited what other girls will be at the - competition in Goettingen, but as I said that wouldn't influence me insofar that I say: I don't know any other girl so I wouldn't go there. |
| 4) Experiences in the Physics Olympiad | Feelings and experiences during the competition (e.g., in dealing with the tasks or in training seminars) are considered here | ,Well I'd say that I, ehm, prior to the competition I learned a lot of different content areas in physics, and, well, I don't know, which do not come up in school normally, and that I haven't had yet in school and that was in fact a very interesting experience. |
| 5) Support from others | Participants describe sources from their social surroundings that helped them to deal with physics or get involved with the competition | ,So my father did physics, so he studied physics, and, well, if I hadn't understood something then I simply asked my father and besides that I didn't learn so much for physics because it was easy to me. |

young women's physics engagement. Furthermore, the young women expressed that they received support from their teachers, peers, and parents. However, for one of the students the teacher encouragement was a hindering factor to engage with physics. This was a serious limitation for her physics engagement. The young women in study B showed an awareness of gender issues in physics: They expected girls to be in the minority in science settings, while they also expressed the opinion that this did not necessarily affect their physics engagement for worse.

## 4.5 Discussion

This study sought to explore facets of physics engagement of high-achieving young women in the context of the Physics Olympiad. In two studies, young women were interviewed about their experiences in their engagement in physics and the Physics Olympiad. The emerging themes accounted for the complex set of factors that are related to physics engagement for young women. Study A provided evidence that young women chose to participate in the Physics Olympiad with the help of their teachers and through appeal of the Olympiads' problems. Furthermore, social interactions were important for the young women during their participation in the Physics Olympiad. Finally, the young women provided explanations for the underrepresentation of young women in the Physics Olympiad that are based on traditional gender stereotypes. The young women reported that they themselves experienced instances of social exclusion on the basis of their physics engagement. Study B followed up on these topics and many accounts of the young women in study A were replicated. The young women in study B similarly valued social interactions during the Physics Olympiad and reported their teachers and peers as important sources for their physics engagement. Furthermore, these young women accounted for their positive attitudes towards physics and physics problem solving. However, also instances of lacking support by the teachers, gender stereotypes, and female underrepresentation appeared as hindering factors for their physics engagement.

The accounts of the young women were shown to be largely in line with prior research findings and can be characterized as enablers and barriers to young women's physics engagement in the Physics Olympiad. Enablers facilitate the engagement for the young women, whereas barriers represent hindering factors that exacerbate physics engagement for young women:

### Enablers to physics engagement

The expressed positive attitudes with physics were important enablers of engagement (see also: Fredricks et al., 2017). The young women found the competition problems in the Physics Olympiad challenging and appealing. Such positive attitudes for physics were found in many successful physicists (e.g., Parsons, 1997). The high-achieving young women developed strategies to approach the problems. Such strategies ranged from breaking down the problems or management of personal resources (e.g., time) to solve them. Such learning attitudes and self-regulatory instances are powerful enablers for engagement in physics (e.g., Flavell, 1979). The women in the study by Zeldin and Pajares (2000) expressed a similar sense of self-efficacy for what they did as the young women in this study expressed an excitement about intellectual challenges.

Most of the interviewees received support from their respective environment: The physics teacher approached them, handed out problems for the physics competition, supported them in dealing with the problems, and encouraged them in their physics engagement. Teacher support was an important enabler for physics engagement (Hazari et al., 2017). Also parental support and support by peers was important. All the young women were socially immersed in STEM competition environments (e.g., they personally knew other participating olympians) and STEM after-school programs. This was found to be a strong predictor for success in competitions (e.g., Urhahne et al., 2012). The immersion in different environments (school physics, competitions) might have been able to compensate for social adversities that some of the young women faced in school and enabled physics engagement.

### Barriers to physics engagement

However, the interviewees internalized stereotypic notions and explanations of gender-differential participation in physics. Even these high-achieving young women portray reality in a way where physics seems rather not for girls. This has been documented also with other successful adolescent girls in the UK (Archer et al., 2017), and with successful female doctoral students in physics in the US (A. Gonsalves, 2014). Many of the young women in this study reported essentialist arguments for gender-differential engagement ("because girls are rather interested in languages"). None of the interviewees provided an explanation for the underrepresentation focusing on sociohistorical inequities that are prevalent in modern societies, in particular in physics. Put another way, neither of the young women reflected upon their own stereotypical interpretations or the fact that their view on women's underrepresentation was also based on traditional gender stereotypes (this was also not asked in the interview). The fact that even these successful female students internalized stereotypical arguments illustrates that physics learning environments are still entrenched with barriers to female engagement in physics. The young women also narrated about a lack of social support from their environment. For example, one young women explicitly mentioned that she was ostracized by her classmates due to her mathematics and physics interests. Another interviewee described a lack of support by her teachers for her physics engagement. And, again, other students mentioned that engagement in physics is unusual for girls. This causes psychological distress in social environments (Cvencek, Greenwald, & Meltzoff, 2012) and is attributed to constitute a barrier for the young women's physics engagement.

Generalizations of these findings need to be considered with reference to the selective group and the special environment. Also, the social context of the study (Physics Olympiad) and the interview questions potentially constrained the young women's opportunities to narrate about their physics engagement. The questions aimed to illuminate facets of physics engagement of the young women, but the interview setting and the constraints exposed through the interview protocol might have omitted certain personal views of the young women. Simply the fact that the young women were interviewed in the context of their participation in the Physics Olympiad might restrict them to appraise their physics engagement for otherwise a conflict between the situational expectation ("participant in Physics Olympiad are enthusiastic about physics") and the identity (i.e., feeling as a physics person) might arise.

Enablers and barriers for physics engagement relate to internal and external factors. Some constraints may be located within the young women that were internalized during socialization (e.g., gender stereotypes). More important seem the external enablers and barriers such as teachers and the social environment. The personal accounts of facets of engagement in the Physics Olympiad for the participating young women in this study emphasize the importance of the social learning environment for physics engagement. Barriers for the young women resulted from the social environment that the young women acted in. In particular, gender stereotypes, the lack of support from meaningful others in the environment, or detrimental expectations from meaningful others constrained the physics engagement of these high-achieving young women.

### Conclusions

Several implications from this study will be discussed that inform strategies that support agency and engagement for young women in the context of the Physics Olympiad. First, changing the design of the physics problems is unlikely to be effective, because the young women endorse these problems. It seems more important to consider strategies for improving the social circumstances in which physics learning happens (Osborne et al., 2003). Johnson, Ong, Ko, Smith, and Hodari (2017) suggest that physics instructors and faculty have the crucial role in being aware that feelings of isolation exist, and to create shared spaces that are shaped by respectful interaction in order to foster the feeling of belongingness for female students. Also, addressing stereotypes in physics environments seems important. Ability stereotypes are formed around at the beginning of school (Bian et al., 2017). Challenging broad socially held notions like stereotypes in classroom settings is possible (Kessels et al., 2006). For example, addressing aspects of physics that are usually omitted, such as the dialogic nature of science and physics (Driver et al., 2000; Merton, 1973), are demonstrably effective in order to ameliorate the image of physics for young women and include more communal motivations and interpersonal values in physics (Kessels et al., 2006). Also portraying female in-group experts as role-models is likely to reassure the young women's motivation for physics in the context of their possible future self with respect to physics (Stake & Mares, 2001).

Support from meaningful others is likely to be a central enabler for physics engagement. Thus, teachers need to encourage girls and adolescent girls to engage in physics. Teachers are agents of change (Hazari et al., 2017; Mujtaba & Reiss, 2013). They are so important since they represent the physics community and construe in their classrooms what identities and outcomes are conceivable. Science enrichment programs like the Physics Olympiad can foster physics engagement for high-achieving young women through female in-group experts as mentors. These programs ideally positively resonate with the young women's motivations and needs. In these programs the young women can be reaffirmed in their aspiration for cognitive challenge (e.g., through challenging tasks) and meet other young women and mentors that also engage in physics. It is important for actors in enrichment programs to make these encounters identity-safe for the young women, e.g., through safe spaces (Johnson et al., 2017) or the reduction of stereotype saliency (Hannover, 2000). The current study suggests the importance of peer interactions in the context of the Physics Olympiad. It seems advantageous if the Physics Olympiad enabled the participating students to come together at an early point in their engagement and have positive (and meaningful) interactions with their peers.

It is also important for teachers to acknowledge and encourage more young women for their thinking skills, meta-cognitive strategies, and higher order thinking, rather than ”tidiness” (quality of their work) as done so often in the past (Siegle & Reis, 1998). In order to facilitate agentic thoughts in physics, researchers proposed particular interventions targeting a specific approach to learning and problem-solving. Young women benefitted, compared to males, from explicitly teaching physics problem solving strategies (P. Heller & Hollabaugh, 1992; Huffman, 1997). In order to better support young women, skills and strategies like problem solving need to be made explicit. Similar proposals have been made some time ago (Hestenes, 1987).

# Chapter 5

# Challenging the physics image of university students (Study 2)

## 5.1 Introduction

In study 1, barriers for young women's physics engagment were identified to be gender stereotypes and, at times, a lack of social support. In particular, the physics identity resource of recognition was motivated to be important for young women's physics related choices. A most pertinent feature that is linked to students' physics identity resource of recognition is the physics image. A subject's image is a cognitive representation similar to a stereotype that informs interest and academic choices (Kessels & Hannover, 2006). Images are socially shared and relatively stable as a part of a student's self (see Figure 5.1). Kessels et al. (2006) theorized that the physics image comprised, amongst others, the facets: difficulty and heteronomy. The notion that physics was difficult affected young women and men in a negative way (Watson, Dawson, & McEwen, 1994). Research by Leslie et al. (2015) suggested that physics was more associated with innate abillity (see also: Kessels et al., 2006), a mind-set that disengaged students from learning (see chapter 2). Considering heteronomy, the association of physics with attributes such as objective and unsocial was particularly disadvantageous for young women (e.g., Kessels & Hannover, 2006). Students believed that personal conflicts had no bearing on engagement in science because science was seen as objective rather than subjective (e.g., Leslie et al., 2015). Students' image of school science converged around ideas of science as the collation of facts, where science knowledge was fixed for all time (Driver et al., 2000). This seemed to be the consequence of a science teaching in school that was described as concurrence seeking with lacks of opportunity to discuss ideas with other students (Driver et al., 2000). Further research by Leslie et al. (2015) distinguished systemizing (thinking about mechanism and systems) and empathizing (thinking about others persons state of mind) features for the physics image. This research suggested that the physics image was associated less with empathizing (see also: Hannover & Kessels, 2002) and more with systemizing Baron-Cohen (2005). This also places barriers on young women's physics engagement, because young women, on average, endorse empathizing more than systemizing (Baron-Cohen, 2012). In summary, aspects of the physics image that relate to abilities and thinking styles (see Figure 5.1) are features that potentially constrain young women's physics engagement, because

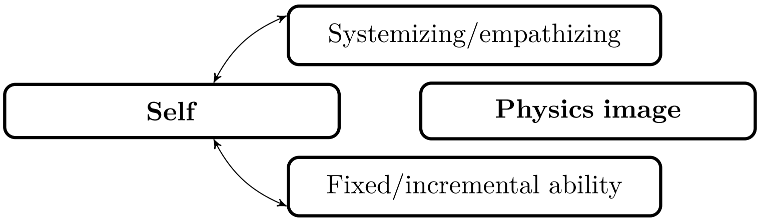


Figure 5.1: Dimensions of the image of physics (Kessels, 2014).

young women prioritize humanistic, communal goals for engaging in a subject (Diekman, Clark, Johnston, Brown, & Steinberg, 2011) and particularly value cooperative learning methods. In order to facilitate young women's physics engagement, means to challenge the traditional image of physics might be a promising strategy.

## Challenging the traditional physics image

As a cognitive representation the image of a subject is malleable in principle. Challenging the traditional physics image is thus one way for addressing barriers to young women's physics engagement. Challenging these notions pays also respect to scientists' view of science as more creative, self-expressive, communicative, social, and gender-neutral. For example, researchers debunk the idea that physics is unsocial. On the contrary, it was emphasized that social aspects are a constituting feature of science (Driver et al., 2000; Lederman, 1992). (Merton, 1973) emphasized that communality was one of four key principles for science. Interventions have probed to challenge the traditional physics image of students towards ideas that emphasize incremental abilities and empathizing features of science and mathematics. These studies were able to alter traditional notions of physics with positive effects for young women (and men):

*Emphasis of incremental abilities:*

- Interventions portrayed the struggles of famous scientists (e.g., Einstein) and thus ”helped students to create perceptions of scientists as hardworking individuals who struggled to make scientific progress,” and ultimately increased students' interest in science Lin-Siegler et al. (2016); Hong and Lin-Siegler (2012).
- Interventions (in mathematics classrooms) explicitly taught students the idea that intelligence was malleable and thus incepted positive trajectories in grades and classroom motivation for students (Blackwell et al., 2007)–eventually promoting a more positive and realistic image of mathematics, which was less aligned with notions of innate talent, intuition, and brilliance, that affected young women in particular (Leslie et al., 2015).
- Interventions that emphasized the creative and dialogic nature of physics (how theories in optics evolved over time) reduced students' associations of physics with heteronomy (the opposite of self-expression) (Kessels & Hannover, 2006).

*Emphasis of empathizing features:*

- Interventions fostered females' communal goal orientation through showcasing how STEM fields can fulfill people's communal goals of collaboration and helping others and thus particularly motivated young women to engage in STEM (Diekman et al., 2011).
- Interventions adopted socially relevant topics (e.g., medicine) in the physics curriculum and thus positively affected young women's interest (particular young women who had a low initial interest) in physics (Berger, 2002; Häußler & Hoffmann, 2002).

What remains unclear is how different intervention strategies can be integrated and how a more integrated intervention affects the perceived physics image of students. This study integrated intervention strategies with regards to the empathizing features and incremental ability of the physics image in order explore effects on students' perception of the physics image in an intervention.

## 5.2 Research question(s)

Study 2 sought to probe effects of an intervention in university-level physics that was meant to alter the students physics image towards empathizing features and incremental ability with the overarching RQ 2.1: "To what extent can specifically designed learning materials challenge the perceived physics image for university students who participated in the intervention?" (see chapter 3) In particular, it was expected that students improve their physics image through a specifically designed intervention towards more empathizing features and more incremental ability for physics:

RQ 2.1: To what extent did students that participated in the intervention altered their perception of empathizing and systemizing in physics and, as a control condition, biology?

RQ 2.2: To what extent did students that participated in the intervention altered their perception of fixed ability in physics and biology?

## 5.3 Method

Intervention strategies for challenging the traditional physics imgage were related to empathizing features and fixed ability in physic. For exmaple, these studies motivated that physics is rich in social elements (empathizing) and depictioned personal biographies of scientists with an emphasis on struggles these scientists experienced (fixed ability). These approaches were combined in the present study in order to challenge the traditional physics image of students. A historical case study was chosen as an integrated intervention strategy that combined the aforementioned strategies. This case study depicted an experiment from the history of science, namely the X-ray diffraction of the human DNA that paved that path towards discovering the double helix structure of the human DNA. This context related to the human body, because DNA is a central unit for functioning of living organisms. This context also related to empathizing and communal goals because this discovery enabled therapies for cancer treatment. Unfortunately, regular school and univeristy textbooks and popular science books report about the discovery context in a gender biased manner, such as the following example demonstrates: ”Scientific discoveries continue to astound, to delight, to answer the formerly unanswerable. When Watson and Crick discovered the structure of DNA, they could not have dreamed of a day when the genome of a $38,000$-year-old Neanderthal fossil would be sequenced.” (Pinker, 2018, p. 386). However, only Rosalind Franklin and her groundbreaking experiments with X-ray diffraction made possible the structural analysis of human DNA. The intervention in this study reconstructed the discovery context and emphasized aspects of Rosalind Franklin’s personal history and her academic career as they related to the DNA-discovery.

## Design

Special learning materials were designed in order to both emphasize the personal history of Rosalind Frankling and engage especially the young women in the physics contents. The learning materials included a hands-on experiments that mimicked the original experiment of DNA structural analysis. Students learned about the life and work of Rosalind Franklin through a text (Braun, Tierney, & Schmitzer, 2011; Elkin, 2003). Furthermore, the students created a concept map with the famous picture ”Photo 51” in the center and with relevant persons and interrelations between them in the context of the DNA structural analysis arranged around this photo. Central to the learning materials were the key ideas that Rosalind Franklin was a hardworking research scientist (challenging fixed ability) who took the pivotal picture that enabled DNA structural analysis. Students learned that her work was used without her consent and that she suffered from interpersonal conflicts with, amongst others, Gosling. It was further emphasized that Watson and Crick critisized Rosalind Franklin for her aversion of ”speculative thinking” and ”intuition.” These learning materials related to the physics image because through the case study of Rosalind Franklin it was motivated that also physics is intricately related to human affairs and personality conflicts (empathizing features).

The intervention was integrated in an undergraduate course on science history. Overall, the intervention lasted 150 minutes, split into two sessions. In the first session the students were instructed about the physics contents (introduction to wave theory and diffration experiment). Then they performed the experiment in small groups. Afterwards, the students took a picture of their diffraction pattern (model of ”Photo 51”). In the diffraction experiment, laser light was used to simulate the X-ray diffraction used in the original experiment. In a homework assignment the students read about Rosalind Franklin’s life, work, and relations with her co-workers. In the second session these information on the life and work were integrated in concept maps that then were used for further plenary discussions that emphasized the information related to the physics image.

## Instruments

*Dependent variables:* The physics image was measured on the basis of the dimensions of systematizing/empathizing and fixed ability, which were utilized as dependent variables (see: Leslie et al., 2015), because the change in these measures was of interest. Table 5.1 list the dependent variables that were measured

Table 5.1: Overview of measured variables.

| Scale | Resp. | # | $N_{t_1}$ | $\alpha_{t_1}$ | $N_{t_2}$ | $\alpha_{t_2}$ |
|---|---|---|---|---|---|---|
| Systematizing physics | 1:6 | 2 | 22 | .98 | 26 | .79 |
| Systematizing biology | 1:6 | 2 | 22 | .67 | 28 | .9 |
| Empathizing physics | 1:6 | 2 | 26 | .75 | 26 | .95 |
| Empathizing biology | 1:6 | 2 | 24 | .99 | 27 | .92 |
| Fixed ability physics | 1:6 | 4 | 30 | .66 | 30 | .27 |
| Fixed ability biology | 1:6 | 4 | 29 | .67 | 30 | .61 |
| Physics identity recognition | 1:5 | 4 | 29 | .97 | 31 | .96 |
| Physics identity competence | 1:5 | 5 | 29 | .92 | 31 | .94 |
| Physics identity interest | 1:5 | 3 | 29 | .97 | 30 | .96 |
| Biology identity recognition | 1:5 | 4 | 29 | .98 | 31 | .98 |
| Biology identity competence | 1:5 | 5 | 29 | .95 | 31 | .94 |
| Biology identity interest | 1:5 | 3 | 29 | .94 | 31 | .97 |

pre and post the intervention. In order to assess the reliability of these scales in the current sample, Cronbach's $\alpha$ as a measure for internal consistency was used. Systematizing and empathizing through items such as "Identifying the abstract principles, structures, or rules that underlie the relevant subject matter" (systematizing) and "Having a refined understanding of human thoughts and feelings" (empathizing) on a 6-point response scale ("never involved" to "highly involved") with 2 items for each scale. Internal consistencies were acceptable for both scales either pre and post (see Table 5.1). Fixed ability was measured with 4 items such as "Being a top scholar of physics requires a special aptitude that just can't be taught," on a 6-point response scale ("strongly disagree" to "strongly agree"). Internal consistency was acceptable, except for post in physics, $\alpha = .27$. It cannot be explained why the fixed ability scale had such a low internal consistency only at time 2. All other scales were aggregated and used for further analyses.

*Background variables:* The identity resources (recognition, competence beliefs, and interest) were included as background variables for physics and biology. Sample items were "I see myself as a physics person," "I am confident that I can understand physics," and "I am interested in learning more about physics," for recognition, competence beliefs, and interest respectively. The identity resources were measures on a 5-point Likert scale ("Not at all" to "very much so"). The respective change of means for physics identity resources over time was, recognition: $M(SD)_{t1} = 1.92\ (1.26) \rightarrow M(SD)_{t2} = 2.36\ (1.42)$, competence beliefs: $M(SD)_{t1} = 2.68\ (1.11) \rightarrow M(SD)_{t2} = 2.94\ (1.2)$, and interest: $M(SD)_{t1} = 2.93\ (1.42) \rightarrow M(SD)_{t2} = 3.1\ (1.43)$. For biology identity resources the change of means was, recognition: $M(SD)_{t1} = 3.17\ (1.64) \rightarrow M(SD)_{t2} = 3.03\ (1.67)$, competence beliefs: $M(SD)_{t1} = 3.86\ (1.17) \rightarrow M(SD)_{t2} = 3.65\ (1.21)$, and interest: $M(SD)_{t1} = 3.63\ (1.37) \rightarrow M(SD)_{t2} = 3.63\ (1.4)$. While some changes in physics appear for recognition and competence beliefs, no such changes (except some slight negative changes) were found for the biology identity resources. GPA , ethnicity, age, and self-reported gender were available for the students.

Background variables furthermore included GPA and age, because GPA accounts for students' school performance that should be related to their perception of physics and age might as well relate to different experiences, because younger students could be less reflected and more affected by gender issues in science–especially in the age of adolecence (e.g., Tenenbaum & Leaper, 2003). Proportion of majors was assessed as a background variable, because majors affect interest and perception towards a domain (e.g., students with more STEM-related majors might endorse more positive attitudes towards physics). Students from different departments attended the class. Finally, self-reported ethnicity was included, because students who identified with underrepresented groups in science (e.g., African Americans, Hispanics) might hold more negative attitudes towards STEM subjects (e.g., Greenfield, 1996; Varelas et al., 2012). Ethnicity included African Americans, Asian, Hispanic/Latino, and White.

## Sample

The intervention took place at a large university in the southern United States and was integrated in a history of science class. 27 students (female = 17, male = 10) took part in this study at both time points. 14 more students were dropped from the sample because they either missed the pre and/or post questionnaire because they were absent from class. Mean (SD) age (in years) was 21.9 (3.1). The mean (SD) GPA of the students was 2.9 (0.5). Since potential gender differences in the effects of the intervention were of interest, it was assessed to what extent both females and males were comparable with regards to the background variables that potentially related to students' perception of the intervention (Häußler & Hoffmann, 2002). Significant differences between the gender groups were found in GPA, $W = 128, p < .05, r = -0.41$, and age, $W = 35, p < .05, r = -0.49$ (see also: Table 5.2). Majors of female students were Biology (general)=11, Chemistry=3, Mathematics, General=2, Physics=1. The majors of the males were Biology (general)=3, Business Marketing Management=1, Chemistry=1, Geology=1, Mathematics (general)=3, Physics=1. Overall, only few students had non-STEM majors. Thus, it was concluded that differences in majors need not be included in the analyses that relate to gender differences. No differences in representation of ethnicity groups for the gender groups appeared as assessed through $\chi^2$-test, $\chi^2(3) = 2.9, p = .41$. Therefore, ethnicity was not included in further analyses. With regards to physics and biology identity resources, no significant gender differences appeared for physics identity resources, recognition: $M(female) = 1.75, sd = 1.21; M(male) = 2.23, sd = 1.36; t(14.79) = -0.89, p = .388, r = 0.23$, competence beliefs: $M(female) = 2.64, sd = 1.13; M(male) = 2.78, sd = 1.14; t(16.34) = -0.3, p = .765, r = 0.08$, and interest: $M(female) = 3.07, sd = 1.45; M(male) = 2.67, sd = 1.4; t(16.93) = 0.69, p = .502, r = 0.16$. No significant gender differences appeared for biology identity resources, recognition: $M(female) = 3.37, sd = 1.57; M(male) = 2.81, sd = 1.81; t(14.48) = 0.79, p = .443, r = 0.2$, competence beliefs: $M(female) = 4.09, sd = 1.06; M(male) = 3.42, sd = 1.32; t(13.61) = 1.31, p = .212, r = 0.33$, and interest: $M(female) = 3.88, sd = 1.36; M(male) = 3.15, sd = 1.34; t(16.56) = 1.32, p = .205, r = 0.31$. Therefore, gender groups were comparable with regards to physics and biology identity resources which was an important prerequisite, because physics and biology identity resources relate to intervention experiences and are potentially confounding variables. However, gender comparisons have to be done with caution due to differences in the other background variables.

Table 5.2: Gender differences in sample.

| | Female | | | Male | | | | |
|---|---|---|---|---|---|---|---|---|
| ind | $N$ | $M$ | $SD$ | $N$ | $M$ | $SD$ | $W$ | $p$ |
| GPA | 17 | 20.88 | 2.32 | 10 | 23.50 | 3.75 | 35 | $< .05$ |
| Age | 17 | 24.00 | 2.92 | 10 | 25.33 | 4.04 | 6 | .76 |
| ACT | 17 | 1580.91 | 189.23 | 10 | 1765.00 | 136.75 | 8 | .08 |
| SAT | 17 | 3.12 | 0.34 | 10 | 2.64 | 0.52 | 128 | $< .05$ |

An interesting pattern emerged when physics and biology identity resources for the whole sample were compared. For either recognition and competence beliefs biology identity resources were significantly higher compared to physics identity resources, as assessed through a $t$-test, recognition: $M(phy) = 1.92, sd = 1.26; M(bio) = 3.17, sd = 1.64; t(46.87) = -3.09, p = .003, r = 0.41$, $M(phy) = 2.68, sd = 1.11; M(bio) = 3.86, sd = 1.17; t(49.86) = -3.7, p = .001, r = 0.46$, and $M(phy) = 2.93, sd = 1.42; M(bio) = 3.63, sd = 1.37; t(49.94) = -1.8, p = .078, r = 0.25$.

## 5.4 Results

From the literature, it was expected that the students initially perceive physics as low in emphatizing features and high in fixed ability, compared to, for example, biology. In order to assess the initial image of the subjects physics and biology prior to the intervention, an ANOVA was fitted with gender, group, and the interaction of gender and group (group means physics versus biology) as predictors and the respective dependent variables (i.e., dimensions for the subject image, see Table 5.1). See Table B.2 (appendix B) for differences in the images. As expected from the literature, the students rate physics as significantly lower in empathizing compared to biology, $F(1, 47) = 8.87, p < .01, \eta_p^2 = 0.16$, with a medium effect size. Quiet unexpectedly, all other effects were not significant. Especially no significant differences for fixed ability were found between physics and biology, $F(1, 50) = 0.75, p = .39, \eta_p^2 = 0.01$.

Further analyses related to time effects are presented in Table 5.3 where a descriptive overview of the measured variables with means, standard deviations, and paired $t$-tests can be found (the correlation matrix can be found in appendix B in Table B.3). While no dependent variables significantly changed with respect to time as evidenced through the $t$-tests, a large effect was found for empathizing in physics. A more rigorous analysis based on a repeated measures ANOVA was fit to cross-validate this effect. ANOVAs were fit for all six outcome variables. In order to account for multiple testing, emerging effects were also tested with bonferroni correction of the alpha level ($p_{\text{bonf}} = \alpha/6 = 0.008$). The models included gender, and time as predictor variables: `outcome ~ gender + time + gender × time`.

With regards to RQ 2.1 (To what extent do systemizing and emphatizing change), a significant time effect was found for emphatizing in physics, $F(1, 20) = 16.41, p < .001, \eta^2 = 0.15$ (the complete ANOVA tables can be found in appendix B). This was a medium size effect. No such effect was found

Table 5.3: Descriptive statistics of variables over time.

| | 1 | | | | 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Female | | Male | | Female | | Male | | | |
| Variable | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *t* | *p* |
| Systematizing physics | 4.75 | 1.49 | 4.45 | 1.12 | 5.03 | 1.26 | 5.11 | 1.14 | 1.74 | .10 |
| Systematizing biology | 5.38 | 0.62 | 4.75 | 1.44 | 5.19 | 1.00 | 5.12 | 1.22 | 0.26 | .80 |
| Empathizing physics | 2.13 | 0.61 | 2.90 | 1.37 | 3.64 | 1.69 | 3.56 | 1.53 | 3.91 | <.001 |
| Empathizing biology | 3.50 | 1.44 | 3.45 | 1.52 | 4.10 | 1.40 | 3.17 | 1.73 | 1.49 | .15 |
| Fixed ability physics | 2.59 | 0.95 | 2.52 | 0.68 | 2.76 | 1.07 | 2.68 | 0.87 | 1.73 | .10 |
| Fixed ability biology | 2.12 | 0.75 | 2.80 | 0.86 | 2.41 | 1.04 | 2.55 | 0.81 | 0.60 | .55 |

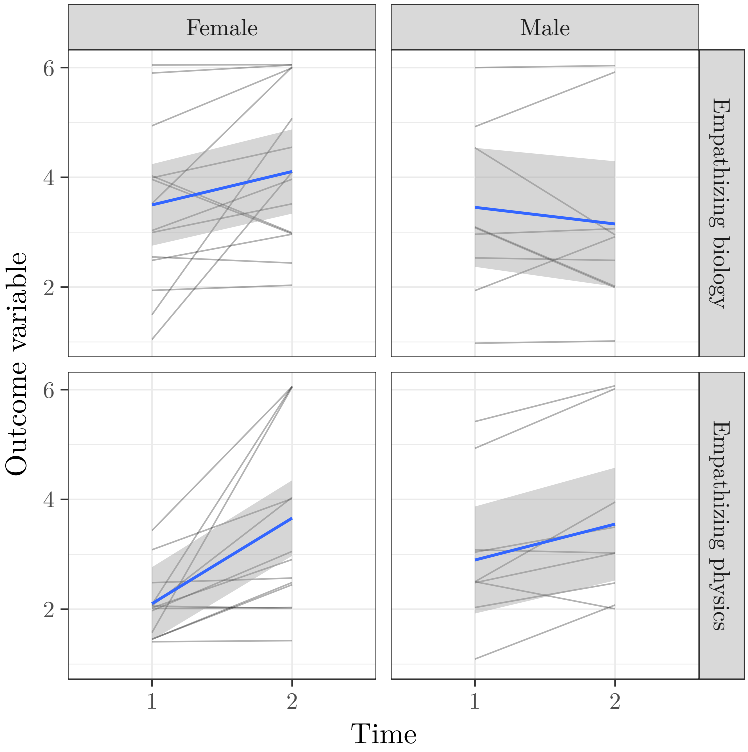


Figure 5.2: Development for empathizing physics in pre and post measurements for females and males with regression lines (and confidence intervals).

for emphatizing in biology, $F(1,21) = 2.43, p = .13, \eta^2 = 0.02$. No interaction effects with gender and time were significant. For systemizing no time effects were found for physics, $F(1,21) = 2.89, p = .10, \eta^2 = 0.04$, and biology, $F(1,21) = 0.07, p = .80, \eta^2 = 0$. With regards to RQ 2.2 (To what extent do ability theory change), a similar analysis was performed for physics and biology. Overall, no time effects were found for fixed ability theory in physics, $F(1,24) = 2.88, p = .10, \eta^2 = 0.02$, or fixed ability theory in biology, $F(1,24) = 0.4, p = .54, \eta^2 = 0$.

## 5.5 Discussion

In this study an intervention was evaluated that sought to challenge students' perceptions of the physics image with regards empathizing features and fixed ability. The overarching RQ was: To what extent can specifically designed learning materials challenge the perceived physics image for university students who participated in the intervention? The physics image was measured with regards to the systematizing/empathizing features and fixed ability. Accordingly, the specific RQ for this study assessed to what extent the perception of the image was challenged with regards to these two dimensions. In order to challenge the physics image with regards to these two dimensions the students in this study participated in an intervention that utilized integrated learning materials designed on the basis of formerly found effective intervention strategies. Namely, a historical case study with protagonist Rosalind Franklin and her role as a major contributor to the structural analysis of DNA and her personal struggles within the scientific community were portrayed and discussed. Preliminarly data analyses confirmed that the students in the sample perceived physics as lower in empathizing compared to biology. Regarding ability theory, no differences for physics and biology were found.

Regarding RQ 2.1 (To what extent do students that participate in the intervention alter their perception of systemizing/empathizing in physics and biology (control condition)?) no effects for the systemizing dimension in physics and biology were found. However, a time effect of medium effect size appeared for empathizing in physics. Students rated empathizing features in physics higher after the intervention than they did before. No gender differential effects were found, and no gender effects were observed for biology either (control condition) were the students started off with higher values. This suggests that the students in this intervention raised their perception of empathizing features in physics. For RQ 2.2 (To what extent do students that participate in an intervention do alter their perception of ability theory (fixed ability) in physics and biology (control condition)?) no effects were found. The students did not lower their perception of fixed ability that they think is required to excel in physics.

Limitations for interpreting the results arise from the selected sample (a substantial amount of students had to be dropped from analyses because they did not completed the assessments). This suggests that the effects have to be considered as exploratory hypotheses that need to be substantiated in more controlled designs (e.g., through utilizing a control group). The absent effects for ability theory likely come from the initially low believe in innate abilities for physics. For example, in the study by Leslie et al. (2015) the values of fixed ability believes for physics were $M(\text{female}) = 4.23$, and $M(\text{male}) = 4.44$. In this study these values are $M(\text{female,pre}) = 2.78$, and $M(\text{male,pre}) = 2.93$. Effects for such low values in ability beliefs are certainly more challenging compared to stronger beliefs. Further limitations for interpreting the effects arose from the gender differences in background variables such as GPA and age. Therefore, gender differences should not be considered, but rather global effects that appeared throughout the intervention such as improving perception of empathizing features.

## Conclusions

It can be emphasized on the basis of the results of this study that a careful consideration on what kind of image will be presented for physics in schools and universities can alter the students' perception of physics and raise their awareness for empathizing features in physics. It seems worth the while to reflect upon the struggles that are related to success stories such as the discovery of DNA where in particular women did not receive full credit for their work. Raising awareness amongst students for the conflicting history of gender and science might enhance the students sensitivity for biasing mechanisms that should be challenged in school physics and beyond.

Given the exploratory nature of this study, some possible effects for these integrated learning materials are worth considering for further research. The historical case study seems to be a viable method to reach out to students and affect their perception of empathizing features in physics. The historical case study might be particularly effective since it reflects important aspects of the physics image (difficulty, heteronomy, masculinity) and barriers that young women, on average, face in their physics engagement such as marginalization in scientific communities. The discussion of Rosalind Franklin's historical case could affect young women's and men's awareness for social issues that relate to physics. The learning materials utilized in this intervention seemed to be effective for transmitting an image of physics (or science) that is high in empathizing. Future interventions that seek to challenge the physics image should focus more on the fixed ability discourse in physics. This is a particularly influential belief (Leslie et al., 2015) and from this study it is not clear how to promote incremental ability perception for physics.

# Chapter 6

# A Short-term intervention to facilitate physics engagement for young women in the context of the Physics Olympiad (Study 3)

## 6.1 Introduction

Study 1 (see chapter 4) suggested that the physics engagement of high-achieving young women in the context of the Physics Olympiad is constrained. The interviewed young women in study 1 attributed female students to normally not pursue physics. They also reflected their minority position that they confront as young women in the Physics Olympiad context. However, the young women in study 1 also reported that they were influenced by meaningful others in their social environment, such as teachers: Teachers motivated the young women to participate in the Physics Olympiad. Lave and Wenger (1991), amongst others, stressed the importance of environmental support such as supportive teachers for students' formation of self and identity development. In particular, as discussed in chapter 2, multiple identity resources that students glean from physics-related environments enable students to form a physics identity in order to make physics-related academic choices (see Figure 6.1).

Drawing from study 1 and identity research, it has to be noticed that even high-achieving young women in physics lacked facilitation for their physics identity resources (interest, recognition, and competence beliefs) in their respective physics environments. A misalignment of physics curricula with the specific interests, values, and goals of young women lead young women to rank physics amongst their least liked school subjects and thus compromise interest development (Kessels et al., 2006; Hoffmann et al., 1998). Carlone and Johnson (2007) noted a lack of support for some successful young women in science environments that would lend to feelings of recognition. Furthermore, social situational cues (e.g., gender stereotypes) in physics environments potentially threaten the young women's gender identity and exacerbate competence beliefs for the young women (Kessels & Hannover, 2002; Hannover & Kessels, 2004; Steele, 1997).

Studies 2, 3, and 4 are set to probe effects of identity-responsive physics environments that seek to foster young women's engagement in physics. As a

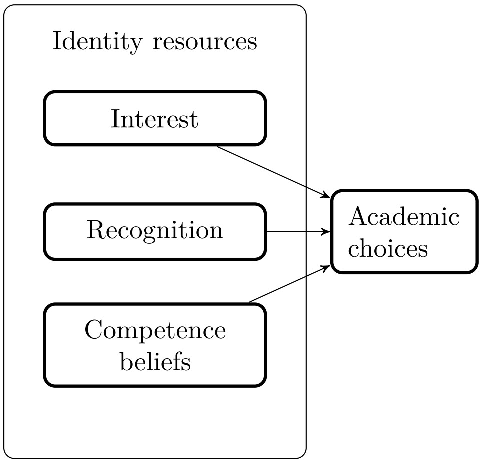


Figure 6.1: Physics identity resources and academic choices in phyics.

first step, study 2 (see chapter 5) was set to probe the effects of challenging the traditional image of physics that students tend to endorse, namely that physics is seen as low in empathizing and high in fixed ability (see chapter 2). An intervention that presented the students a historical case study on the structural analysis of DNA with Rosalind Franklin as protagonist altered the perception of the students' physics image with regards to the empathizing dimension. The students eventually recognized that the history of science and physics is entangled with social conflict, particularly for female scientists. Further evidence for the malleability of the traditional physics image and the motivational potential of identity-responsive physics instruction was presented by similar research. For example, Häußler and Hoffmann (2002) demonstrated that interventions that adapt the physics curriculum to the specific interests of girls supported physics competence beliefs and interest for the female students (Berger, 2000)– two important identity resources. Furthermore, active physics instruction (e.g., through hands-on experiments and explicit problem solving) enabled physics engagement for young women potentially because the importance of prior knowledge is reduced (Jovanovic & Steinbach King, 1998; Palmer, 2009; Huffman, 1997).

In summary, empirical evidence suggests that physics engagement for young women can be positively affected through identity-responsive interventions. However, intervention effects of the aforementioned studies were small in effect size and it remains an open question to what extent more integrated (with regards to physics identity resources) interventions can affect physics engagment of young women. Consequently, this study[1] aimed to probe effects of a more integrated intervention in the context of the Physics Olympiad in order to enable physics engagement for the participating young women.

---

[1] Note that this chapter is a revised version of the following publication: Wulff, Peter; Hazari, Zahra; Petersen, Stefan; Neumann, Knut (2018): Engaging Young Women in Physics. An intervention seminar to enhance young women's physics identity development. In: Phys. Rev. Phys. Educ. Res. 14 (2), S. 20113.

## 6.2 Research question(s)

The aim of study 3 was to probe the short-term effects of an intervention for young women's physics engagement in the context of the Physics Olympiad. The respective, overarching research question was: To what extent can a considerately designed intervention enhance physics identity for participating young women? More specific research questions arose from this question:

RQ 3.1: To what extent did the physics identity resources interest, recognition, and competence for the participating young women and men increase?

Besides the measures for identity resources, it was of interest whether the students changed their attitudes towards the Physics Olympiad. This would suggest effectiveness of the intervention, because changing attitudes in a different context (Physics Olympiad as compared to intervention) would indicate more broad shifts in underlying identity. In this line also the students' enrollment in the next year's Physics Olympiad as an indicator for the students' affiliation with the Physics Olympiad was registered as a dependent variable.

RQ 3.2: To what extent did the intervention affect young women's and men's future participation (intended and actual participation in future Olympiads) in the Physics Olympiad?

## 6.3 Method

### Design

In keeping with extreme-group or expert-novice design ideas (e.g. Preacher, 2015), this study employed students that comprised more of an expert status as compared to their classmates: students that enrolled in the Physics Olympiad were considered for participation in the intervention. These students are likely to be sensitive to changes in physics instruction, because they identify with physics as expressed through their extended engagement in physics. The experiences and perceptions of these students on effects of a physics-related intervention were particularly valuable in order to incorporate specific motivations of high-achieving young women into physics environments. Consequently, this study was situated in the Physics Olympiad's context. The intervention took place in December 2015 and was meant for students that participated in the German Physics Olympiad's second stage, which ended in November 2015. The next year's Physics Olympiad started in April 2016. Students who completed the second stage in 2015 and were young enough to also participate in the next year's Physics Olympiad (year 2016/17) were solicited for participation (typically 40 to 45 % of approx. 250 students). The intervention took approximately 6 h on a single day. Three different locations (high schools and research sites) were chosen where the students received the intervention in three separate groups. First, an introductory game to get to know each other was played and single-gender groups were formed. These groups were seated at small-group tables and a round table for discussions was available for phases in which the whole group discussions took place (e.g., when results to the problems were discussed). The students then worked through a curriculum in radiation physics: waves and

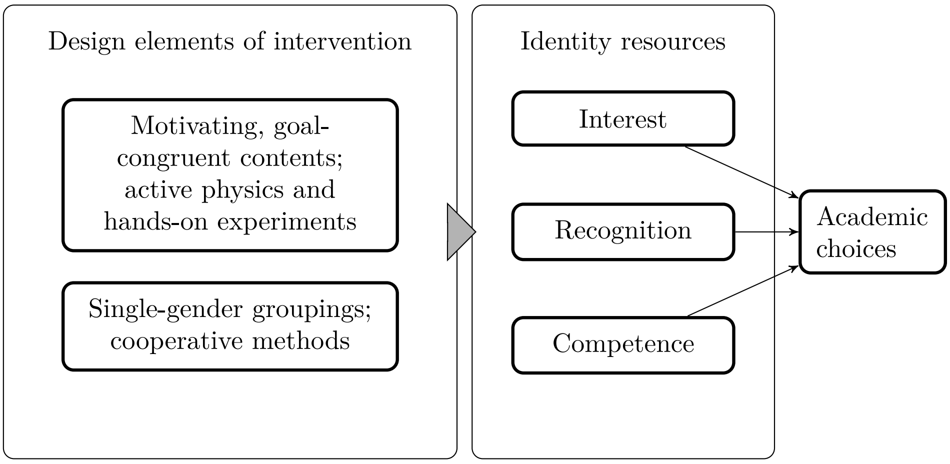


Figure 6.2: Design elements of the intervention.

oscillations, light as electromagnetic wave, properties of waves, and experiment on light diffraction (see study 2 and appendix C for materials). The participants took pre (approx. 50 min) and post (approx. 30 min) questionnaires right before and right after the intervention with measures that were identified by physics identity theory.

### Intervention

In order to create an environment that was considerate of the identity resources in physics, it was ensured that the instructional design elements for the intervention were responsive to the physics identity resources (see Figure 6.2). What was called an Active-learning instruction approach for physics formed the conceptual background for desiging the instruction (Meltzer & Thornton, 2012), so that contents were similar to study 2 in order to provide a socially and historically important context. Regarding social environment, an identity-safe context for young women was sought to be facilitated for the young women. Identitiy-safe context refers to the mechanism that the young women's gender identity does not become salient through stereotypes or outnumbering by young men. The particular design elements of the intervention were: Motivating, goal-congruent physics content, active-learning instruction in physics and hands-on experiments, single-sex groupings, positionality of instructor, and cooperative methods (see Figure 6.2).

*Motivating, goal-congruent contents:* Young women and men, on average, differ in their motives to pursue physics and in their particular interests regarding physics contents. This holds true also for high-achieving young women and men (Lubinski et al., 2014). For example, Seymour and Hewitt (1994) showed that a consistent motive for young women to switch STEM subjects away from physics was that they wanted to help other people (Eccles, 1997; M. G. Jones & Wheatley, 1990). Young women preferably chose biological science and medicine from amongst STEM fields (P. H. Miller, Rosser, Benigno, & Zieseniss, 2000; P. H. Miller, Slawinski Blessing, & Schwartz, 2006). These insights into occupational motives are replicated with interest studies in physics. Hoffmann et al. (1998) and the ROSE-study across multiple countries (Sjøberg & Schreiner, 2010) are suggest that medicine contexts are preferred by young women compared to other contexts. In these studies, young women were particularly interested in medical-biological contexts such as ”cancer–and how we can treat it” (Holstermann & Bögeholz, 2007, p. 76). Stadler, Duit, and Benke (2000) argued that many contexts that are particularly interesting to females are also interesting to male students. For example, medicine was rated equally high in terms of interest compared to technical contexts for young men (Wodzinski, 2007) such that utilizing medical context would probably not depress young men’s interest. Consequently, this intervention utilized a medical context that was also related to the human body: structural analysis of human DNA using X-ray diffraction. This context also emphasizes the societal importance of physics knowledge and pursuit. Rosalind Franklin was introduced to the students as the scientist who conducted groundbreaking experiments related to the structural analysis of human DNA resulting in her famous diffraction picture of DNA (”Photo 51”). In order to implement an experimental set-up that the students could safely use, rather than X-ray, visible light was used. The content was related to physics education research and the international Physics Olympiad 2015 problems that utilized an experimental problem with this context (Braun et al., 2011). For example, a laser pointer was used to model the radiation and thin metal wire mimicked the structure of DNA. This content specifically addressed the identity resource interest (see Figure 6.2). Furthermore, introducing Rosalind Franklin as a protagonist in structural analysis of DNA, the recognition resource was potentially facilitated as well.

*Active-learning instruction in physics and hands-on experiments:* In the intervention the physics concepts that were dealt with (focusing on light diffraction) were divided into coherent subunits. The students were provided materials and experiments in order to give them the opportunity to meaningfully engage in learning of these abstract concepts. Phases of cooperative work were usually followed by a plenum discussion, where the students discussed their results in larger groups. It was emphasized for students to draw their own conclusions as suggested in active-learning instruction in physics (Meltzer & Thornton, 2012). The qualitative understanding (as compared to a more mathematical-oriented approach) of concepts was given considerable attention throughout the intervention (Reif, 1995), because this reduces the amount of prior knowledge required to solve problems. The role of the instructor was to scaffold the students in their learning process (Häußler & Hoffmann, 2002). For women, compared to men, a known challenge is the often documented difference in prior experiences and background knowledge in physics (Bell, 2001; Hazari et al., 2007; G. Jones et al., 2000). This lack of prior experience with physics seems to be one reason that young women particularly benefit from carefully constructed active-learning scenarios and hands-on experiences such as experiments (Burkam, Lee, & Smerdon, 1997; Freedman, 2001). For those who were quick to understand the concepts (or could capitalize on more prior knowledge), supplemental materials were provided. In summary, active-learning instruction in physics and hands-on experiments particularly relate to the competence resource for physics identity.

*Single-gender groupings:* In order to facilitate more opportunities for recognition, empirical studies suggested that the ratio of males to females is an important feature. The ratio of males to females in groups has been found to make one's gender salient which leaded to more gender-stereotypical behavior, i.e. men dominating the discussion with women receiving less recognition for their ideas (Sekaquaptewa & Thompson, 2003). When gender becomes salient for young women in physics contexts their performance is negatively affected (Kessels & Hannover, 2002). Young women in same-gender classes, for example, were also shown to have a greater interest in science than those in mixed-gender classes (Hoffmann, Häußler, & Peters-Haft, 1997). In order to lower the salience of gender-group identity, young women and men were brought together in approx. equal ratios (50:50) for the entire intervention (the actual sample was slightly unbalanced: 13 females versus 16 males). Ratios of 50:50 have been found to be as effective as ratios in which young women were in the majority (Dasgupta et al., 2015). Having 50:50 ratios instead of a same-gender seminar made the social context a more authentic to what students would experience in terms of the male gender representation in the Physics Olympiad (e.g., in the later rounds of the Physics Olympiad female proportion is usually less than 15 percent). The intervention comprised enough young women to form more of a critical mass. Same-gender small group work was facilitated since men in mixed-gender groups have been found to dominate. Having same-gender groupings was proposed to allow women in the small group work to be able to recognize each other and ensure that they had a voice in the activities (Dasgupta et al., 2015). The small groups ultimately came together to communally share ideas and findings with the whole seminar group providing further opportunities for being recognized. Single-gender groupings and ratio of males to females was most important to facilitate the recognition resource of physics identity.

*Cooperative methods:* Potvin and Hasni (2014, p. 104), in their review of empirical research on cooperative learning (i.e. "learners interacting and working together to facilitate acquisition or problem solving, by sometimes sharing experiences and knowledge"), established that cooperative learning had a positive effect on interest, motivation, and attitude. Evidence from reasoning experiments supported the use of group (as compared to individual) work (summarized in: Mercier & Sperber, 2017). Especially for young women in early adolescence, contacts with friends are constitutive for their identity formation (e.g., Raffaelli & Duckett, 1989; Josselson, 1996) and young women, on average, have a strong inclination towards social aspects, e.g., communication (Baron-Cohen, 2005). In particular, female students have been found to appreciate cooperative learning methods (Parker & Rennie, 2002). In the intervention the students were encouraged through instruction to work together in pairs and with four students interchangeably. Cooperative methods were considered to be pertinent to the recognition resource for physics identity for young women in particular.

## Instruments

Most pertinent to the RQs were the scales for the physics identity resources. The physics identity resource scales were the dependent variables and these scales were adopted from physics identity research (Hazari et al., 2010). The items were worded so that they address the Physics Olympiad context. Table 6.1 gives an overview of the identity scales. In order to assure that the gender-groups were comparable (i.e., similar to each other with regards to background characteristics), a host of covariates was included. Initial differences in covariates might be responsible for differential experiences during the intervention that result in different intervention effects, which would be attributable to initial differences between the gender groups rather than differential functioning of the intervention for the gender groups.

### Dependent variables

*Interest:* The interest dimension was differentiated into subdimensions, since aggregating interest into one construct might conceal effects (e.g., Hoffmann et al., 1998). As indicated in Table 6.1 the different interest scales were Interest in physics as a subject, Interest in physics contents, and Situational interest (post). Interest in physics contents was not expected to change due to a single intervention. Consequently, Interest in physics as a subject was measured prior to the intervention as a baseline comparison for participants. Such broad measures potentially change in the course of schooling, but unlikely due to one-time interventions (e.g., Krapp, 1998). The corresponding items were measured on a 5-point Likert scale (1: "disagree" to 5: "agree"). The internal consistency was satisfactory for this variable (see Table 6.1). For test-economical reasons, Interest in physics as a subject was measured with one item where the students rated how interested students find physics as a school subject. Such one-item interest scales have been shown to be appropriate to detect gender differences in baseline interest (Kessels, 2005).[2] The item can be seen in Table 6.1. The responses for this item were measured on a 5-point Likert scale (1: ”do not like it” to 5: ”enjoy it very much”). The scale Interest in physics as a subject was a potential confounding variable and was included to rule out group differences between students with their interest for their physics class (Kessels, 2005). It was argued that Interest in physics contents and Interest in physics as a subject are distinct from each other (Hoffmann et al., 1998). Intercorrelation in this study between these two scales was $r = 0.31$, so that the assertion was supported because intercorrelation was not exceedingly high (though ceiling effects were present in these scales so that cautious interpretation is necessary). In order to check how interested the students were in the seminar topic a scale by Fechner (2009) that measures situational topic related interest was used as a post measure and was called Situational interest (post). The scale contains six items. A sample item text can be found in Table 6.1. The items were measured on a 5-point Likert scale (1: ”Not true” to 5: ”True”). Overall, Cronbach’s $\alpha$, as a measure of internal reliability, was 0.83.

*Recognition:* For recognition separate measures for the contexts of the Physics Olympiad and physics class were utilized, since recognition in the one context might differ from the other context, i.e., students might feel recognized in school as a physics persons but not in the Physics Olympiad or vice versa. However, comparing the internal consistencies of an aggregated recognition scale ($\alpha = 0.6$) versus disaggregated recognition scales (Physics identity (recognition): $\alpha = 0.45$ and Physics identity (recognition, class): $\alpha = 0.62$) suggested no preference for either option. Context-sensitive scales for self-reported measures are important (see Rabe, Meinhardt, & Krey, 2012), so that for the sake of clarity of constructs the scales were kept separated in further analyses. Table 6.1 presents a sample item text with which recognition was measured in the context of the Physics Olympiad and physics class. Recognition in Physics Olympiad was measured on

---

[2] It is noted, however, that multiple heterogenous indicators would enhance construct validity and are thus preferable.

Table 6.1: Descriptive statistics for outcomes variables and covariates.

| | Time(s) | # items | Scale | $\alpha$ | *M* (*SD*) | Sample item |
|---|---|---|---|---|---|---|
| *Outcome variables:* | | | | | | |
| Interest in physics as a subject | 1 | 1 | 1-5 | - | 4.76 (0.44) | How much do you enjoy your physics classes in school. |
| Interest in physics contents | 1 | 5 | 1-5 | 0.84 | 3.65 (0.42) | In general I enjoy doing physics. |
| Situational interest (post) | 2 | 6 | 1-5 | 0.83 | 4.06 (0.63) | The topic of the seminar was very interesting to me. |
| Recognition | 1,2 | 2 | 1-5 | 0.47 | 3.62 (0.96) | I feel that the IPhO-team recognizes my engagement in the Physics Olympiad. |
| Recognition (class) | 1,2 | 2 | 1-4 | 0.61 | 3.17 (0.6) | I feelthat my physics teacher recognizes my engagement in the physics class. |
| Competence belief | 1,2 | 2 | 1-5 | 0.84 | 3.48 (0.9) | I feel competent to solve the tasks in the Physics Olympiad. |
| Competence belief (class) | 1,2 | 1 | 1-4 | - | 3.69 (0.49) | I feel competent to solve the tasks in the physics class. |
| Likelihood of further participation | 1,2 | 1 | 0-16 | - | 11.79 (3.73) | How likely will you participate in the next year's Physics Olympiad? |
| *Covariates:* | | | | | | |
| Age | 1 | 1 | 0-100 | - | 16.4 (1) | What was your last grade in ... |
| School grades (physics) | 1 | 1 | 1-6 | - | 1.21 (0.38) | - |
| School grades (math) | 1 | 1 | 1-6 | - | 1.18 (0.37) | - |
| School grades (chemistry) | 1 | 1 | 1-6 | - | 1.42 (0.48) | - |
| School grades (biology) | 1 | 1 | 1-6 | - | 1.63 (0.66) | - |
| School grades (German) | 1 | 1 | 1-6 | - | 1.72 (0.65) | - |
| School grades (English) | 1 | 1 | 1-6 | - | 2.01 (0.76) | - |
| Job interest in physics | 1 | 1 | 1-5 | - | 4.48 (0.59) | How likely will you choose a job in physics? |
| Achievement in competition | 1 | 1 | 0-40 | - | 27.65 (7.7) | - |
| Support by teachers | 1 | 4 | 1-4 | 0.68 | 3.43 (0.53) | My teacher actively support me in my physics engagement |
| Support by peers | 1 | 4 | 1-4 | 0.82 | 2.24 (0.66) | My peers actively support me in my physics engagement |
| Support by parents | 1 | 4 | 1-4 | 0.72 | 2.64 (0.73) | My parents actively support me in my physics engagement |
| Content-knowledge test | 1,2 | 11 | 0-1 | 0.71 | 0.49 (0.24) | - |

a 5-point Likert scale (1: ”Untrue” to 5: ”True”). Recognition in physics class was measured on a 4-point Likert scle (1: ”Untrue” to 4: ”True”). The physics class recognition items were similar to the items for the Physics Olympiad, just replacing Physics Olympiad with physics class, and IPhO-team with physics teacher. The Spearman-Brown formula was used to calculate the internal consistency, since the Spearman-Brown formula more appropriately measures two-item reliability than Cronbach’s $\alpha$ (Eisinga, Grotenhuis, & Pelzer, 2013). The reliabilities were as follows: recognition in Physics Olympiad (pre: 0.47, post: 0.59), and recognition in physics class (pre: 0.61, post: 0.6). The low internal consistency of this outcome variable poses constraints on interpretability that will be discussed at the end.

*Competence belief:* The competence beliefs measures were specific to the Physics Olympiad and the physics class (Table 6.1) since it cannot necessarily be expected that the students develop broader physics competence beliefs as a result of a small-scale intervention. Furthermore, it is different for a student to feel competent in a physics competition context as compared to a physics classroom context–a well recognized phenomenon in competence beliefs research (e.g., Rabe et al., 2012). Competence belief was measured pre and post. Items were adopted that closely fit the descriptions of the dimensions of the identity resources as explicated in the literature (e.g., Hazari et al., 2010; Cribbs et al., 2015). Sample item texts can be found in Table 6.1. Competence belief in Physics Olympiad was measured on a 5-point Likert scale (1: ”untrue” to 5: ”true”). Competence belief in physics class was measured on a 4-point Likert scale (1: ”untrue” to 4: ”true”). For the two item scale (competence in Physics Olympiad) the Spearman-Brown formula was used to calculate the internal reliability (Eisinga et al., 2013). The reliabilities were as follows 0.84 for pre, and 0.96 for post. Competence beliefs in physics class were measured with only one item. One item scales are comparable to multiple item scales when the construct is simple, and has a single-meaning attribute (e.g., liking) (Bergkvist, 2015). Usually items regarding competence beliefs fulfill these requirements and show very high internal consistency, as evidenced in related research that showed one-dimensionality and very high internal consistency ($.80 \leq r \leq .90$) in German self-efficacy scales (a construct closely related to competence beliefs) (see Jerusalem & Schwarzer, 2016).

*Engagement in Physics Olympiad:* In order to measure intentions to persist in the Physics Olympiad, students placed a cross on a continuous scale that indicated how likely they thought they were to participate in next-year’s Physics Olympiad. The anchors on the scale were ”not likely” to ”very likely.” The item was scored based on the distance from the ”not likely” anchor divided by the total length of the scale. In order to account for the measurement uncertainty of the subjective choice the responses were aggregated. Therefore the scale was cut into 8 equidistant intervals and each response was classified accordingly based on its measurement for its position on the line. Students’ intentions to persist were measured pre and post. Furthermore, in order to see whether students further engaged in the competition, the students’ enrollment in the next year’s Physics Olympiad was tracked.

### Covariates

A host of covariates was used in order to compare females and males, and thus check whether the sample was similar to each other such that the young men could be utilized as a control group for the young women in order to rule out spurious effects. Demographic indicators (self-reported gender and age) were used to perform group comparisons. Students' grades in school subjects were collected to ensure that no differences in ability were present. A grade of 1.00 is best, whereas a grade of 6.00 is worst. Also the interest in the school subjects was measured with a single item ("How much do you like [subject]?"). This item had a 5-point Likert scale (1: "not at all" to 5: "very much"). For test-economical reasons, Job interest in physics was measured with one item (Berger, 2000) on a 5-point Likert scale (1: "not at all" to 5: "very much"). Prior research showed that this item was representative of the underlying construct with two-item scales through assessment of internal consistency (Berger, 2000). Support by teachers, parents, and peers with reference to the Physics Olympiad was included as a further covariate, because differences with respect to gender can be found in the support by teachers, peers, and parents (Hoffmann et al., 1998). Based on prior research where these differences have been found (Hoffmann et al., 1998), scales to measure the support by teachers, parents, and peers were developed. Each scale comprised four items and was measured on a 4-point Likert scale (1: "agree" to 4: "disagree"). Sample item text can be found in Table 6.1. Cronbach's $\alpha$ for teacher, parent, and peer support in the context of the Physics Olympiad were 0.68, 0.72, and 0.62, respectively.

Even though the current intervention was more concerned with motivational effects for physics engagement, prior knowledge and performance in physics were included as covariates because these measures are closely related to physics identity resources (see chapter 2). Prior knowledge and content knowledge gains intricately relate to competence beliefs. Performance in Physics Olympiad was collected as a baseline comparison for prior engagement in the competition. The performance was a number score given by the teacher according to a solution sheet for the first round's homework assignment (maximum was 40 points). Furthermore, a content knowledge test was administered. For item development, physics books (Tipler, 2004) and online resources (www.leifiphysik.de) were consulted. Physics problems were transformed into a multiple-choice assessment with 14 items (see appendix C for the complete test, and appendix C Table C.2 for item statistics). Each multiple-choice item had four alternatives, one correct answer and three distractors based on student preconceptions. Most importantly, the items specifically covered the content that was the focus of the intervention. Right after each content knowledge item the students were given a confidence scale where they indicated how confident they felt about their answer. This is because the degree of confidence with which a response is given to a content knowledge test is further evidence for facilitation of competence beliefs.

## Sample

All young women that passed the first round of the Physics Olympiad and were young enough to participate in the next year's Physics Olympiad ($N = 31$) were solicited for participation. This ensured that all participants had the opportunity to enroll in the next year's Physics Olympiad and it could be examined if these enrollment numbers were greater compared to the general olympian population. Young men were matched with regards to similar performance in round 1 in the German Physics Olympiad and were also solicited for participation. Similar performance was assessed through squared differences of young men's score from the median score of the young women. A sample of young men from the population who were closed to the median of the sample of young women were solicited for participation.

In total, 42 percent of the invited female and 50 percent of the invited male students participated in the intervention. Overall, 30 students took part in this intervention (13 female, 17 males). Four of the participants (3 female, 1 male) were invited despite the fact that they did not participate in the German physics Olympiad prior to the intervention due to the fact that spare places were left. They were nominated by their respective teachers with the minimal requirement to nominate one female student. All four students were familiar with the Physics Olympiad. Data for three students was missing because they did not participate in either one of the questionnaires (pre or post). Thus, complete data was available for 27 students (12 female, 15 males[3]). The students came from various places in Germany and the majority did not know each other.

Table 6.2 characterizes the participants with respect to covariates, because differences in covariates might result in differential experiences of the students throughout the intervention and thus threaten the validity of differential effects for the gender groups. Therefore, the mean values and standard-deviations of each gender group were calculated. The $t$-test indicated when one gender group differed beyond what would be extected by chance with respect to the variable from the other gender group. The participants were on average 16.4 years old. However, young women were significantly younger compared to young men. This posed a threat to generalizability of results that will be elaborated on in the discussion. Furthermore, descriptive statistics indicated that either female and male students reported a high average support by their teachers. Compared to parents' and peer support, support by teachers was ranked highest. No significant differences with regards to social support arose between the gender groups. This was positive, because social support is an important indicator for physics engagement so that differences in social support would have likely caused one group to experience the intervention as more relevant because of a perceived lack of support. Also, praticipants reported very good grades, with an average of 1.49. Young women have a lower mean value (i.e., better grades), but difference between gender groups did not reach significance. Also no significant differences for gender groups were found for competition achievement, $M(female) = 25.65, sd = 9.33; M(male) = 28.75, sd = 5.61; t(13.13) = -0.95, p = .36, r = 0.25$. No differences in grades and competition achievement was considered to be positive, because differences in school grades or competition achievement might have caused one group to be more at ease with the learning materials and be bored. With regards to interest in school subjects, both young men and young women score similar: on a 5-point Likert scale, average score was 3.76(0.56), with no gender-differential effects. This suggested that both gender groups had a similar positive attitude towards school and learning.

---

[3] Note that the students self-identified as females and males in the online platform of the Physics Olympiad and in the questionnaires administered in the intervention study. Thus, only female and male gender identities are considered in the following.

Table 6.2: Sample differences in covariates.

| | male | | | female | | | | |
|---|---|---|---|---|---|---|---|---|
| | *N* | *M* | *SD* | *N* | *M* | *SD* | *t* | *p* |
| Age | 16 | 16.79 | 0.73 | 10 | 15.67 | 0.90 | 3.31 | .004 |
| Sup. tea. | 15 | 3.46 | 0.58 | 13 | 3.48 | 0.48 | −0.13 | .901 |
| Sup. par. | 15 | 2.57 | 0.65 | 13 | 2.71 | 0.82 | −0.49 | .626 |
| Sup. peers | 15 | 2.23 | 0.79 | 13 | 2.31 | 0.62 | −0.28 | .783 |
| Grades | 14 | 1.57 | 0.30 | 12 | 1.40 | 0.40 | 1.16 | .259 |
| Job int. | 14 | 4.71 | 0.47 | 11 | 4.27 | 0.65 | 1.91 | .073 |
| Achiev. comp. | 16 | 28.75 | 5.61 | 10 | 25.65 | 9.33 | 0.95 | .36 |
| Interest | 14 | 3.58 | 0.35 | 13 | 3.95 | 0.69 | −1.74 | .098 |
| Further part. | 15 | 12.95 | 2.44 | 13 | 11.92 | 3.78 | 0.85 | .407 |

Finally, also no gender differences occurred with regards to intent for further participation. On average, the participants 12.47 (3.12). In percent, this translates into 78 (±19) %. This was considered positive, because no gender group was more engaged with the Physics Olympiad and thus might have spend more effort to learn within the intervention. The intent for further participation in the Physics Olympiad was considered to be rather high. This suggested that both gender groups would care to learn in the intervention.

In order to assess generalizability of results to the overall olympian population, differences in competition achievement for the intervention sample and the overall olympian population were examined. As compared to the overall olympian population, no difference in competition achievement was found, $M(all) = 27.5, sd = 10.22; M(sample) = 27.56, sd = 7.25; t(28.97) = -0.04, p = .969, r = 0.01$. This suggested that the intervention sample could was comparable with the overall olympian sample with regards to performance.

## Analyses

To analyze parts of RQ 1 and RQ 2 analyses of variance (ANOVA) were used. ANOVA compares several means of groups. In order to account for the dependent measures (same subjects) over time, a factorial repeated measures ANOVA was used with time and gender as within and between factors respectively. To do so the statistics software R with the package "ez" (Version 4.4-0) was used to perform these analyses (Field & Miles, 2012). Mainly type II sums of squares were used (Navarro, 2015) (others always tested as well). To report effect sizes a generalized eta-squared ($\eta^2$) was used that is comparable with the well-known eta-squared ($\eta^2$) from ANOVA (Bakeman, 2005). In order to compare group differences in means, additional $t$-tests with an effect size $r$ were used. If $r$ is bigger than .30 then the effect size is considered of medium size (Field & Miles, 2012). Even though the ANOVA is robust against violations of the normality-assumption non-parametric tests were included at times (RQ 1) in order to test the effects without making the normality assumption (Field & Miles, 2012). Wilcox-rank sum test compares group means and can be used for repeated measures as well. The effect size measure $r$ can be used to characterize the strength of an effect. An effect size of $r > .50$ would be considered a large effect (Field & Miles, 2012). When the dependent variable was not measured pre and post (RQ 1 interest), ANCOVA was used to account for other influencing variables. The R functions ”anova” and ”lm” were used here. In order to check whether the predictors are independent of a categorical variable such as gender, a MANOVA was used with the R function ”manova” from the ”stats” package.

Overall, in the dependent variables there are 9 percent of missing values. Regression random imputation (Gelman & Hill, 2007) was used as a means to retain these values for the analyses. In order to impute the values, regression models were fit where gender, age, and the respective dependent variable at the other time (where the response is not missing) were used as predictor variables.

## 6.4 Results

Before analyzing the research questions that relate to the motivational constructs of physics identity resources (interest, recognition, and competence beliefs), an analysis of the content knowledge covariate will be considered because gains in content knowledge will assure that the curriculum materials and instruction were able to address both gender groups equally. Differences in content knowledge gains and confidence over time and between genders were examined with a two-way repeated measures ANOVA. The items in the content knowledge test were solved post intervention both more accurately and with more confidence, regardless of gender group. The main effect for time is significant and large for content knowledge and confidence, $F(1,23) = 55.41, p < .001, \eta^2 = 0.24$, and $F(1,23) = 121.18, p < .001, \eta^2 = 0.48$ respectively. There were no gender differential effects either in confidence or content knowledge gains throughout the intervention.

The subsequent results section is arranged along the specific RQs: To what extent does the physics identity resources develop for both young women and men who participated in the intervention (RQ 3.1), and to what extent does the intervention affect young women's and men's intended and actual future participation in the Physics Olympiad (RQ 3.2). RQ 3.1 is discussed along the different identity resources: interest (RQ 3.1a), recognition (RQ 3.1b), and competence belief (RQ 3.1c).

### RQ 3.1: Effects on identity resources

*Interest (RQ 3.1a):* Figure 6.3 presents an overview of all measured interest scales that relate to the interest resource for physics identity. Note that the scores are scaled (around grand mean of variables) in order to highlight differences between the gender-groups. The effects of gender on Situational interest (post) will be assessed through an ANCOVA. In ANCOVA the other interest scales can be included and adjusted for in order to see gender differential effects beyond differences in these predictors. First, the independence of the predictors (Interest in physics as a subject and Interest in physics contents) from gender was assessed through a MANOVA. The predictors (Interest in physics as a subject and Interest in physics contents) were included as outcome variables in the MANOVA. The MANOVA results suggest that the predictors do not depend on gender, $F(2,24) = 1.3, p = .29$.

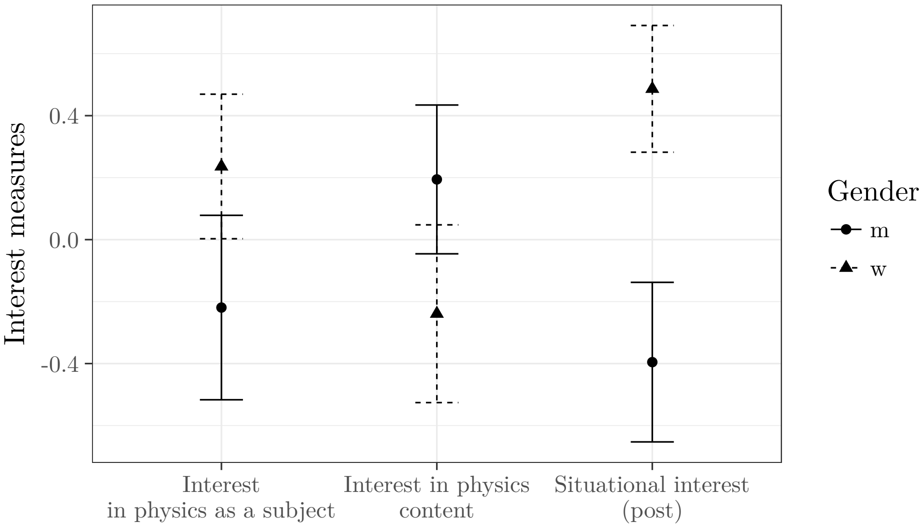


Figure 6.3: Different interest measures differentiated for gender (variables are standardized).

In order to better understand the influence of Interest in physics as a subject, Interest in physics contents, and gender on Situational interest (post) an ANCOVA was calculated with Situational interest (post) as the dependent variable. The model explained 3 percent ($R^2_{adj} = 0.18$) of the variance in Situational interest (post). Gender had a significant main effect, $\beta = 0.78, se = 0.36, t = 2.16, p < .05$, after adjusting for the other influences, with young women scoring higher in Situational interest (post). No other effects were significant.

*Recognition (RQ 3.1b):* For recognition and competence belief linear models (ANOVA) were fitted. The interesting effects in these models are main effects for time and gender, and the interaction effect of time and gender. The interaction effect is particularly interesting, because it indicates whether gender diffential effects were present. These effects will each be reported for Physics Olympiad and physics class.

When fit with repeated measures ANOVA, for recognition no time effects for Physics Olympiad, $F(1, 27) = 0, p = .99, \eta^2 = 0$, or physics class, $F(1, 27) = 0.62, p = .44, \eta^2 = 0$, appeared. A main effect for gender appeared for Physics Olympiad, $F(1, 27) = 6.73, p < .05, \eta^2 = 0.13$, with a medium effect size (see Figure 6.4). The young women felt more recognized in the Physics Olympiad than the young men. For recognition in physics class the effect for gender was marginally significant, $F(1, 27) = 2.01, p = .17, \eta^2 = 0.06$, with a small effect size. This means that the young men reported a lower feeling of recognition in their respective physics classes both before and after the intervention. The interaction effects with time and gender did not become significant, either for Physics Olympiad, $F(1, 27) = 0.76, p = .39, \eta^2 = 0.01$, and physics class, $F(1, 27) = 0.02, p = .89, \eta^2 = 0$.

*Competence belief (RQ 3.1c):* The time effects for competence beliefs were

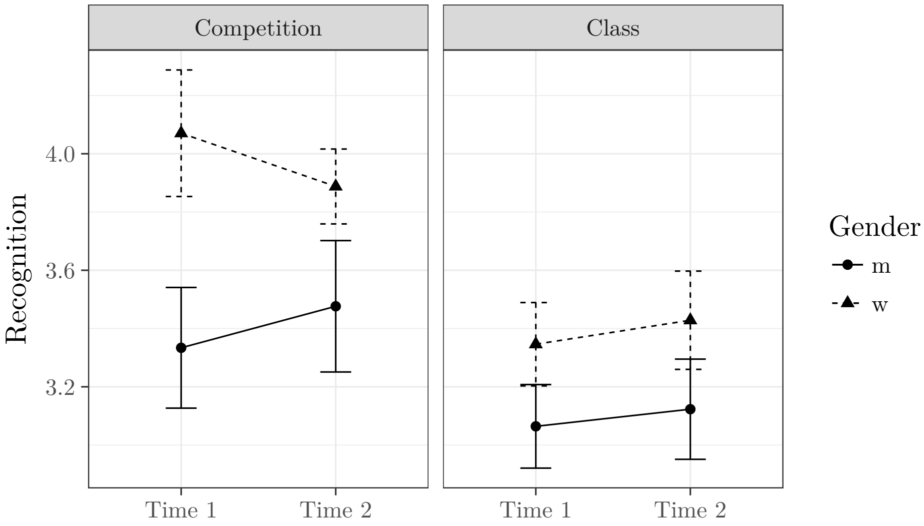


Figure 6.4: Recognition dimension of physics identity over time with regard to gender.

not significant, either for Physics Olympiad, $F(1, 27) = 1.5, p = .23, \eta^2 = 0.01$, or physics class, $F(1, 27) = 0.02, p = .89, \eta^2 = 0$. The gender effects were not significant, either for Physics Olympiad, $F(1, 27) = 1.05, p = .31, \eta^2 = 0.03$, or physics class, $F(1, 27) = 0.04, p = .85, \eta^2 = 0$. The interaction effect between gender and time was significant for Physics Olympiad, $F(1, 27) = 7.63, p < .05, \eta^2 = 0.04$, with a small effect size. This means that young women improved their perceived competence belief within the Physics Olympiad over time compared to young men (see Figure 6.5). Non-parametrical tests were used, since the variables were not normally distributed. Wilcox signed rank sum test for dependent samples was used to test effects. The change over time for the female students is significant ($V = 45, p < .01, r = 0.74$), with a large effect, whereas for the male students this effect is nonsignificant ($V = 19.5, p = .44, r = 0.19$) with a negligible effect size. For competence beliefs in physics class the interaction between gender and time was also significant for physics class, $F(1, 27) = 8.21, p < .01, \eta^2 = 0.1$, meaning the young women improved their perceived competence beliefs in physics class over time, compared to young men who maintained their level of competence beliefs. An equivalent Bayesian LMM model to the repeated-measures ANOVA was fit in order to validate the interaction effect without making the assumption that no prior knowledge is present (it can be ruled out that the interaction effect is infinitely large, for example). This model reveals that the interaction effect for time and gender on competence is positive with a certainty of 99 percent. Excluding the missings, the certainty becomes 96 percent.

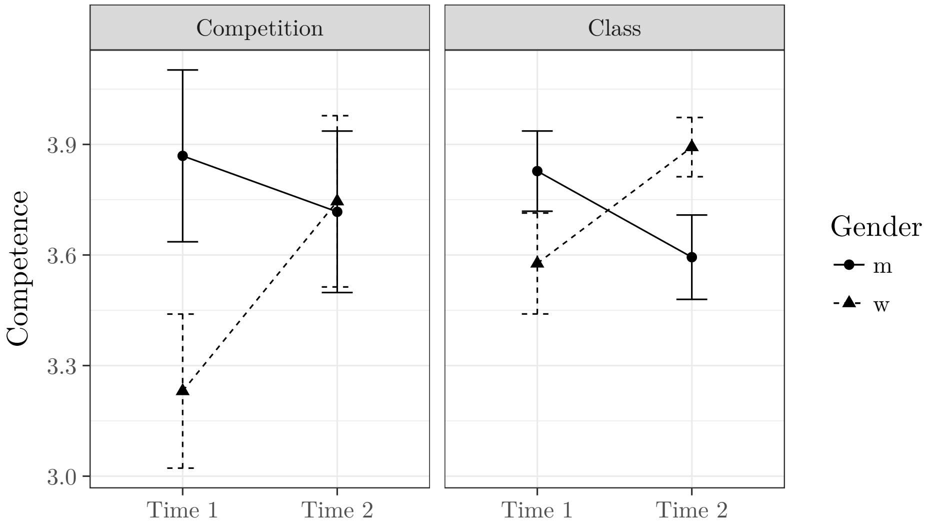


Figure 6.5: Competence dimension of physics identity over time with regard to gender.

### RQ 3.2: Further participation

The participants in the intervention seminar were asked pre and post how likely they would participate in the next year's Physics Olympiad. In the post measurement the male students scored on the 8-interval scale with $M = 6.46; (sd = 1.85)$. The mean thus falls in interval that indicated a 75 to 87.5 percent likelihood of participating again in the next year's physics Olympiad. The female students scored $M = 6.25; (sd = 1.66)$ which falls into the same interval, 75 to 87.5 percent likelihood of returning to the next year's Physics Olympiad. No significant effects for time, gender, or the interaction of both appear in the repeated measures ANOVA.

The population of competition participants in 2015/16, overall 36 percent (158 of 437) of the participants, i.e., 39 percent (125 of 322) of the males and 29 percent (33 of 115) of the females (who were not in their final grade in high school) participated again in the competition. In order to compare the olympiad population sample with the intervention sample, the four students that did not participate in the Physics Olympiad prior to the intervention were excluded from the analysis. For these participants 62 percent (16 of 26) participated in the next year's competition. 62 percent (10 of 16) of the young men in the intervention and 60 percent (6 of 10) of the young women in the intervention actually participated in the next year's Physics Olympiad.

## 6.5 Discussion

This study aimed to support young women's physics engagement in the Physics Olympiad through an intervention that is considerate of instruction/learning materials and social context with the overall RQ: To what extent can a considerately designed intervention enhance physics identity for participating young women? More specific research questions were posed vis-à-vis the design of the intervention: To what extent do the physics identity resources interest, recognition, and competence for the participating young women and men increase? (RQ 3.1), and To what extent does the intervention affect young women's and men's future participation (intended and actual participation in next Physics Olympiad) in the Physics Olympiad? (RQ 3.2) In order to answer these RQs, a design where several outcome variables (namely the physics identity resources) were tracked over time in order to examine time, gender, or interaction (time with gender) effects that indicate positive developments. Several covariates (demographics, school grades and interest, social support, and content knowledge) were considered prior the analyses in order to identify potential sources where young women and men differ and thus experience the intervention in substantially different ways. It was assured that all covariates but age were similar for the gender groups. In particular, the analysis of content knowledge development throughout the intervention confirmed that both young women and men had content knowledge gains with large effects.

Regarding RQ 3.1, the data supports the conclusion that young women were positively affected with regards to some of their physics identity resources while no detrimental effects appeared for young men. The young women appeared to be particularly interested, compared to young men, in the intervention contents. It can be further noted that the young men were not negatively affected by the intervention with respect to interest. Overall, the young men also expressed a high interest in the Situational interest (post) scale (RQ 3.1a). The young women reported a higher recognition in the Physics Olympiad than young men before and after the intervention (RQ 3.1b). With respect to competence beliefs towards the Physics Olympiad and the physics classroom (RQ 3.1c), young women differentially developed their competence beliefs. When at the beginning the competence belief values were below the values of the young men, these equalled at the end, when young women and men had the same competence belief values. Regarding RQ 3.2, no effects for the reported intent of future participation in the Physics Olympiad were found. However, a high proportion of the participants participated in the next year's Physics Olympiad. This proportion was higher compared to the overall olympian population for both young women and men.

The results regarding the interest dimension of physics identity are well in line with the research literature, namely that young women would benefit from learning materials that are considerate of communal values and that relate to the human body (Watson et al., 1994; Hoffmann et al., 1998). As a proof-of-concept, this indicates that the employed learning materials can be utilized in order to specifically foster physics engagement for young women in the Physics Olympiad. Quite unexpectedly, the young women reported a higher recognition in the Physics Olympiad compared to the young men. A possible explanation for this unexpected finding is that the young women were generally more affected that they are subject to an intervention in the context of the Physics Olympiad. Another hypothesis is that young women in general need a higher feeling of recognition by the community in order to subscribe to a program such as the Physics Olympiad (e.g., Mujtaba & Reiss, 2013). This aligns with the finding by Lock et al. (2012) who reported that women required a greater recognition in physics in order to persist. On the other hand, this result resonates with the finding that young women, compared to young men, were sometimes found to score higher in school aspiration and attitudes, such as recognition by others (Rampino & Taylor, 2013).

Regarding generalizability of the findings, the high initial motivation of these students points to a potential limitation for answering RQ 3.2, because the participating students were already motivated towards physics and the Physics Olympiad. It cannot be ruled out that the higher proportion of further participation in the next year's Physics Olympiad was an artifact from the sampling process. A fact that supports generalizability of results to the Physics Olympiad population was that the competition achievement score of the participants in the intervention was not significantly different from the Physics Olympiad's population. This indicated that the intervention sample was similar with regards to competition achievement with the overall olympian population. Another important aspect to consider was the significant difference in age between young women and men (young women are younger). Such effects cannot be adjusted for in the repeated measures ANOVA (J. Cohen & Cohen, 1983) or any other statistical technique (G. A. Miller & Chapman, 2001). A positive interpretation of the fact that the young women were younger than young men is that the age difference likely set the young women at a disadvantage in terms of prior content knowledge and experience with physics equipment, so that the positive effects and the equal content knowledge gains of the young women are evidence for the effectiveness of such an intervention. Also the small effect sizes and the great variability in the sample are threats to inferences beyond this sample.

The positionality of the instructor could have been a crucial and uncontrolled factor for young women's engagement in this intervention. According to Davies (1990) positionality accounts for the allocation of responsibility and status in local social contexts. The instructor in the intervention was the author of the dissertation. A white male instructor might have been considered as a prototypical representative for the competition context. Consequently, recognition would not necessarily be positively affected for the young women. However, this would not explain why young men did not increase their recognition, given they saw the instructor as a prototypical representative of the Physics Olympiad who was similar to the students' self.

## Conclusions

The reported results point to some important aspects for further efforts in the Physics Olympiad and similar informal science enrichment programs that particularly facilitate physics identity development for young women and potentially raise gender equity. The results are in line with findings that indicate that topics which are particularly interesting to female students do not depress the interest of male students (Häußler & Hoffmann, 1995). The fact that young women report a significantly higher situational interest for the intervention topics is an important finding to advance the understanding of how to better address specific issues that concern high-achieving young women in physics. The learning materials on the case study of Rosalind Franklin and the DNA structural analysis appeared to be particularly motivating for the young women in the sample. However, this one time intervention seemed to have no effect on the particularly important recognition construct for physics identity as it relates to the Physics Olympiad. The low reliability of the scale suggests adopting other scales for this construct (see: Cribbs et al., 2015). Improving the design to enhance recognition may be fruitful for improving the intervention since recognition has been found to be a key aspect to support young women in physics (Carlone & Johnson, 2007) and was more predictive for mathematics identity than interest (Cribbs et al., 2015). As such, intervention strategies, such as self-to-prototype matching, can play an important role to improve the students' perceived recognition to the physics community (Hannover & Kessels, 2004).

With regards to further efforts for program evaluation in physics that is linked to social evaluative mechanisms in students such as identity or stereotype threat, and to mechanisms tied to curriculum materials and instruction such as situational interest and competence beliefs, the identity theory with a focus on identity resources are a viable lens for accumulating quantitative evidence of how to improve these environments. Further research is needed to identify the underlying mechanims in the short and long run that support identity development. It was the aim of this intervention to understand the effects of an identity-responsive intervention in the context of the Physics Olympiad. Interest and competence beliefs as identity resources seem to be more easy to support, whereas design-elements for supporting recognition remain to be found.

# Chapter 7

# A Long-term intervention to facilitate physics identity development for young women in the context of the Physics Olympiad (Study 4)

## 7.1 Introduction

Study 3 suggested that a short-term intervention can positively affect some physics identity resources for young women in the context of the Physics Olympiad and thus increase physics engagement. The instructional strategy, the learning materials, and the social context were factors that enabled the young women to engage in the learning environment and facilitate their physics identity resources competence beliefs and interest. These findings are in line with the assumptions of the sitated agency model (chapter 2) that emphasized the importance of a design of the social learning context that is considerate of the identity resources such as single-gender groupings or life-related learning contexts. However, several aspects remained unsolved in study 3. For example, no effects were found for the particularly important identity resource of recognition by others. Research regarding physics identity emphasized the importance of recognition by others for engagement in physics (Carlone & Johnson, 2007). Particularly, Carlone and Johnson (2007) found that even some successful young women who persisted in STEM did not receive recognition by meaningful scientific others. Similarly, C. Good et al. (2012) demonstrated that a facet of recognition, namely the sense of belonging, predicted intent to pursue a career in mathematics. However, sense of belonging was exacerbated for young women through environmental cues such as ability related stereotypes. To my knowledge, no studies in physics considered recognition and sense of belonging for young women with respect to a physics-specific learning environment that the young women engage in. Such studies are crucial in order to better understand factors that might contribute to facilitate recognition by others and sense of belonging for young women in physics.

For the identity resources of interest and competence beliefs, study 3 indicated that young women, compared to young men, improved their competence beliefs towards the Physics Olympiad and the physics class and both young women and young men reported high interest in physics contents, physics class, and the intervention contents. Given the centrality of competence beliefs for domain-specific identity (Cribbs et al., 2015), for agency in general (Bandura, 2000), and for consideration for academic choice (Eccles, 1983), it is of particular interest how competence beliefs in the context of the Physics Olympiad evolve over extended periods of time. While research related to competence beliefs is well established (e.g., Möller & Trautwein, 2015), knowledge regarding competence beliefs in the particular context of the Physics Olympiad with high-achieving students and a developmental perspective were not investigated. This, however, is imperative in order to understand the effects of Physics Olympiad environments on the participants. For the identity resource interest study 3 suggested that facets of general interest such as interest on physics contents of the participants was high so that broad facets of physics-related interest are of less relevance to physics identity-related research. Carlone and Johnson (2007), for example, dropped analysis of the identity resource interest for high-achieving students in STEM and Cribbs et al. (2015) showed with structural equation models that recognition and interest mediate the influence of competence beliefs on mathematics identity with a larger direct effect for recognition as compared to interest. This suggests that interest as an identity resource is of less importance in the context of physics identity studies with high-achieving students.

Considering the assessment of long-term effects of identity considerate interventions in the context of the Physics Olympiad on physics identity resources, it has to be noted that study 3 was restricted to one weekend. As argued in chapter 2, it is particularly important to study effects over time in order to understand individual agency and identity development. As with recognition, to my knowledge, no studies in physics attempted to investigate long-term effects of a physics specific learning environment that is considerate of the physics identity resources on the development of the identity resources. This is necessary in order to come to understand potential mechanisms at work that affect students' choices and decisions with regards to physics. For example, physics identity theory poses that the physics identity resources are of particular importance for choices, e.g., participating and engaging in the Physics Olympiad. Study 3 suggested that the social environment affected this decision-making process, because values (such as interest) were directly affected and students enrolled to a greater extent in the next year's Physics Olympiad. However, it remained unclear whether the high enrollment numbers for the next year's Physics Olympiad were caused by positive selection effects during sampling and how stable effects on the identity resources would be over extended periods of time.

Regarding these shortcomings, study 4 builds on findings from study 3 (see chapter 6), namely that specifically designed learning materials and instructional strategies can support physics engagement for young women in the context of the Physics Olympiad. Building on these findings, this study seeks to generalize results to a developmental perspective where identity resources are examined for an extended period of time. Furthermore, relations between the experiences during the intervention, the development of the identity resources, and the academic choices will be analyzed. In particular it is asked how the supporting physics engagement on the basis of the physics identity resources has an impact on long-term choices in the context of the Physics Olympiad for young women.

## 7.2 Research question(s)

This study sought to expand the findings from study 3 insofar that the physics identity resources of recognition and competence beliefs were considered in greater depth over an extended period of time. This entailed analysis of academic choice processes such as further enrollment in the next year's Physics Olympiad that were expected to replicate based on the positive findings from study 3. These aims are summarized in the overarching research question: To what extent can a considerately designed intervention impact physics identity development for participating young women?

More specific RQs investigated the development and potential developmental mechanisms of physics identity resources and the links to more global physics-related choices in the context of the Physics Olympiad. The identity resource competence beliefs was examined as expectancy of success similar to the study by Lykkegaard and Ulriksen (2016). Expectancy of success, in particular, is a widely employed construct that has been shown to be predictive of academic choice processes. Recognition was examined with the facet of sense of belonging as investigated by C. Good et al. (2012). Regarding physics identity resources, the following RQ was assessed:

RQ 4.1: To what extent did young women and young men who participated in the intervention develop their expectancy of success and sense of belonging with regards to the Physics Olympiad?

In order to examine potential developmental mechanisms that link the environment with physics identity resources, situational interest was assessed during the intervention. It was expected that the identity-considerate environment affected students in their situational interest and that situational interest can be a measure to better understand how the intervention worked:

RQ 4.2: To what extent did situational interest impact the development of expectancy of success and sense of belonging for the participating students?

The goal of facilitating young women's physics engagement through an intervention was partly to motivate the young women to further participate in physics-related programs. As such, study 3 examined if participating students also enrolled in the next year's Physics Olympiad. This analysis was replicated in the present study. Furthermore, it was assessed what mechanisms potentially influenced the decision to enroll in the next year's Physics Olympiad. Consequently, physics identity resources and situational interest were related to the decision to enroll in the next year's Physics Olympiad in order to test the situational agency model that predicts that the design of the intervention through situational interest should have a positive impact on the decision to enroll in the next year's Physics Olympiad:

RQ 4.3: To what extent did young women and men who participated in the intervention enrolled in the next year's Physics Olympiad compared to the overall olympian population and to what extent did the physics-related study aspiration of participating students change?

RQ 4.4: To what extent were the physics identity resources and situational interest related to the actual enrollment in the next year's Physics Olympiad?

## 7.3 Method

### Design

The goal for this intervention was to probe effects of an intervention for young women, where the intervention was considerate of the identity resources. Focus was the development of recognition and competence beliefs. Based on the findings from study 3, the following design elements were kept in study 4, in order to achieve the goal of a supportive environment: balanced gender-ratio between young women and men and active-learning in physics instruction. Since study 3 did not affect the identity resource of recognition for the young women, female in-group instructors were introduced as a design feature that likely related to recognition and sense of belonging. Chapter 2 outlined potential mechanisms of how recognition might be influenced, namely through self-to-prototype matching with the instructor. Female in-group instructors were utilized in study 4 as salient feature to possibly impact recognition by others and sense of belonging to physics.

As with study 3, the sample in study 4 was drawn from students who participated in the Physics Olympiad 2015/2016. The students were invited to participate in this intervention. All participants were young enough to also participate in the next year's Physics Olympiad. This was important since RQ 4.3 and RQ 4.4 examined further participation and physics-related choices that are potentially linked to physics identity resources. The entire intervention involved two in-person seminars, each lasting for two consecutive days, spread over half a year (see Figure 7.1) in 2016/17. While study 3 utilized one in-person seminar for one day, study 4 tried to facilitate development of physics identity resources through greater exposure time to the treatment. In between the in-person seminars, the students participated in two online seminars where physics contents were provided via online learning platform. Questionaires (indicated as "Time 1...5" in Figure 7.1) were administered throughout the intervention, particularly before and after each of the in-person seminars and in between the two online seminars. A control group was utilized that engaged in all four seminars online. This can be considered a control condition because students in the control group did not experience interactions with female in-group experts nor did they experience equal gender-ratio in a physics-related learning environment in the context of the Physics Olympiad. Assessment was pre-post (see Figure 7.1), entirely based on an online survey system. The dependent variable expectancy of success in physics was measured at the beginning and at the end (see Figure 7.1). The dependent variable sense of belonging was measured at all five times spanning over the half year intervention in order to potential identify time effects with regards to sense of belonging.

#### Design features of intervention

The intervention in study 4 comprises three broad design features: female in-group experts, equal gender ration single-gender groupings, and Active-learning

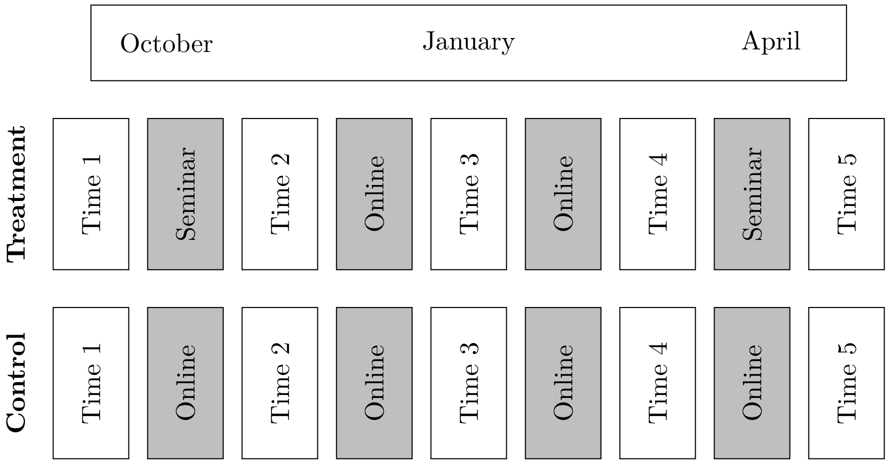


Figure 7.1: Design of the intervention.

in physics instruction (see Figure 7.2). No single causal paths are assumed from one design feature to situational interest and physics identity resources. Situational interest is considered to be a mediating variable, linking the experiences in the intervention with the development of physics identity resources.

*Female in-group instructors:* Female in-group instructors can function as prototypes for young women in order to engage in physics–particularly because high-achieving young women report a lack of prototypical examples, i.e., role-models, in competition environments (A. X. Feng et al., 2005). Female in-group mentors were found to protect sense of belonging for engineering female students (Dennehy & Dasgupta, 2017). Dasgupta (2011) advanced the idea that female in-group instructors play a particularly important role as ”social vaccines” (see stereotype-inoculation theory in chapter 2) to young women (also: Hannover & Kessels, 2004). Self-to-prototype matching was introduced (see chapter 2) as a means for students to actualize their physics-related choices such that prototypes positively influence academic choices. A prototyp’s gender is a salient feature for students and will influence who considers herself eligible for engaging in the environment and who feels recognized. For high-achieving young women, female role-models were found to increase performance (Marx & Roman, 2002) and improve their ”implicit STEM self-concepts” (Stout et al., 2011). Role-models and prototypes have to come to be viewed as similar to oneself and as experts (D. I. Miller et al., 2015; Young, Rudman, Buettner, & McLean, 2013). Consequently, in this intervention three female experts were engaged as instructors in the interventions (each for a different site where the intervention took place). The female experts were found in the alumni population of the Physics Olympiad. Three of the most successful former female participants were contacted and all three agreed to participate. All female experts studied physics-related subjects (physics, and mechanical engineering). They received a training prior to the intervention that lasted approx. three hours. In this training the motivation of this intervention was laid out to them and the learning materials were discussed.

*Equal gender-ratio and single-gender groupings:* Another feature of the social environment in order to raise gender salience is the group constellation (Kessels

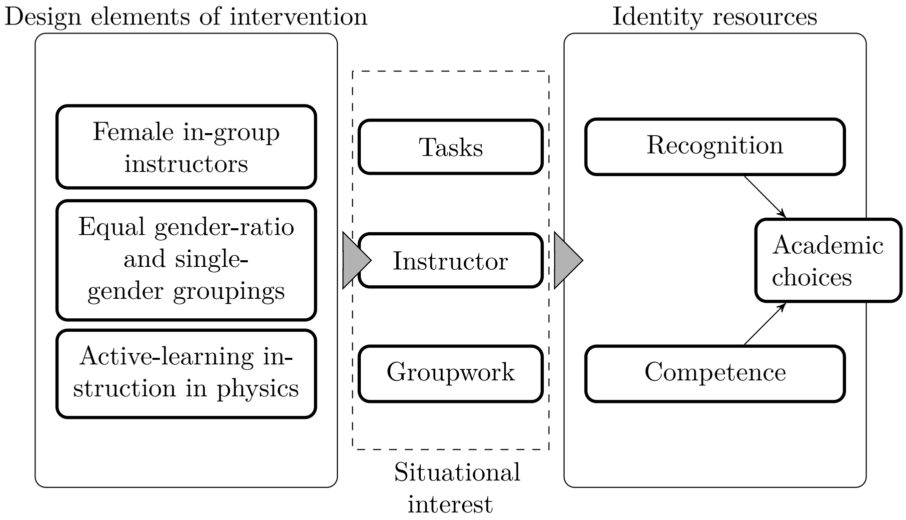


Figure 7.2: Design elements of the intervention are hypothesized to influence situational interest, which then influences the physics identity resources.

& Hannover, 2002). An equal gender-ratio was documented to be beneficial (Dasgupta et al., 2015). For example, when watching a 1:1 ratio conference video women were found to be protected from psychological distress as compared to more traditional constellations (Murphy et al., 2007). In this intervention females and males were brought together with an approx. equal ratio, which would be slightly unusal for most students who engage in the Physics Olympiad, but not so unusual as a single-gender intervention. Furthermore, single-gender groupings were employed during instruction, because males tend to dominate mixed-gender groupings (e.g., Dasgupta et al., 2015).

*Active-learning instruction in physics:* In terms of content, physics is considered a semantically rich domain with a heavy emphasis on content knowledge. Since young women were found to have less prior knowledge compared to young women, reliance on content knowledge was sought to be reduced through hands-on experiments, scaffolding through additional materials, and training of meta-cognitive skills. Physics problem solving was made explicit in order to foster physics engagement of young women (Huffman, 1997). AAPT/APS marshalled the Reform Based Physics approach (see chapter 2 for details). An effective strategy to physics teaching that transcends content-reliant physics instruction was argued to be the explicit instruction of skills like physics problem solving or scientific argumentation (Becerra-Labra, Gras-Martí, & Torregrosa, 2012; Huffman, 1997). Explicit training of physics problem solving is likely to be effective when subcomponents are trained rather than problem solving as a monolithic skill, and that physics problem solving is trained in the context in which the problem solving is later used with appropriate monitoring and meta-knowledge being made explicit (Mayer, 2013). Researchers recognized the benefits for students who identify with historically marginalized groups of explicit problem solving instruction (Fradd & Lee, 1999). For example, Huffman (1997) found in his explicit problem solving the effectiveness of his problem solving course that particularly supported the participating young women. In order teach physics problem solving explicitly, students were given a problem solving schema that was adopted from P. Heller and Hollabaugh (1992). Furthermore, in order to introduce Newton's laws the students were given a heuristic of how to tackle problems that involve Newton's axioms (Reif, 1995). The other learning materials were adoped from study 2 and study 3. Although Bandura (1986) contended that mastery experience is the most important source of self-efficacy, gender differences indicate young women, compared to young men, reported more verbal persuasive experiences than men in their mathematics learning (Lent, Lopez, Brown, & Gore, 1996; Lent, Brown, Cover, & Nijjer, 1996). Cooperative group work was utilized to enable verbal feedback from peers and instructors. Furthermore, the mentors were encouraged to provide positive feedback.

## Instruments

Table 7.1 lists the scales that were utilized in the intervention. Dependent variables, predictor variables, and covariates were included in the analyses. Table 7.1 provides a descriptive overview of the variables in order to assess the reliability of the measurements. As an indicator of reliability, the internal consistencies of the scales, as measured by Cronbach's $\alpha$, are displayed. Values over .60 were considered acceptable.

*Dependent variables:* In accordance with physics identity theory and the expectancy-value model in particular, sense of belonging and expectancy of success were included as the primary dependent variables. Sense of belonging was measured with 20 items (Good et al., 2012) on a 6-point Likert scale (1: is not true at all; 6: is completely true). The internal consistency was excellent (at Time 1: $\alpha = 0.91$), as could be expected when a construct is assessed with 20 items. Sense of belonging was assessed at all five times. A sample item (as for all other variables) can be found in Table 7.1. The aggregated mean responses were quite high for this scale: at Time 1: $M(SD) = 4.75$ (0.96). Expectancy of success was assessed with 4 items (similar to: Urhahne et al., 2012) on a 7-point Likert scale (1: do not agree at all, 7: completely agree). Expectancy of success was assessed pre and post the intervention, with good internal consistencies (at Time 1: $\alpha = 0.84$).

*Predictor variables:* The term predictor variables is used here, because these variables come closest to what would be manipulated in an experiment (though a thorough control was not possible here, which will be discussed later). Situational interest was utilized to link the perceived environment and self-related constructs. The situational interest scale was adopted from a scale from Fechner (2009). Three subdimensions of situational interest were included in the analyses, because they best map onto the design features of the intervention: task, instructor, and group work. Subdimension task included items concerning how the students liked the tasks and would be willing to work further on such tasks (see sample item in Table 7.1). The subdimension instructor included items concerning how the students liked the female in-group instructors. Finally, the subdimension group work included items concerning how the students liked the cooperative work in the intervention. All dimensions of situational interest were measured on a 5-point Likert scale (1: not at all; 5: very much) with 8, 3, and 6 items respectively. Situational interest was assessed right after the in-person seminars with the intervention. The internal consistency is very good for all subdimensions (at Time 2: $\alpha = 0.9$, $\alpha = 0.22$, and $\alpha = 0.75$ respectively), except for instructor at time 2. This is because the students almost unanimously rated the instructors with the highest scores, which resulted in loss of variance in the items such that internal consistency as measured through Cronbach's $\alpha$ is meaningless. For further analyses the three subdimensions of situational interest were aggregated into a single variable (Situational interest [all]) with 17 items and high internal consistency (at Time 2: $\alpha = 0.86$). Furthermore, self-reported gender (with the options female and male) and group (treatment versus control) were included as predictor variables.

*Covariates:* Covariates were included in the analyses in order to assess potential initial differences between the genders and the treatment group versus control group. The covariates were chosen so that confounding influences for the physics identity resources were likely captured. Consequently, covariates related to models that were introduced in chapter 2. Confounding influences for competence beliefs and expectancy of success were gleaned from the expectancy-values model (see Urhahne et al., 2012). The expectancy-value model predicts that expectancy of success and values towards tasks in a domain influence academic choices towards that domain. Expectancy of success and values are interdependent, such that values were included as a covariate. Values from the expectancy-value model comprise four dimensions: interest, attainment, cost, and utility. All dimensions were assessed with 1 item each on a 7-point Likert scale (1: do not agree; 7: completely agree). The covariate values was assessed pre intervention and the means were particularly high (at Time 1: $M(SD) = 5.93$ (1.18), at Time 1: $M(SD) = 5.84$ (1.21), at Time 1: $M(SD) = 4.51$ (1.41), and at Time 1: $M(SD) = 4.67$ (1.28) respectively), especially for interest and attainment dimension (see Table 7.1). When aggregated, the covariate values has an acceptable internal consistency, $\alpha = 0.63$, so that the scale will be analyzed as an aggregated scale. A further confounding variable for competence beliefs is extracted from mind-set theory (Dweck, 2000). Mind-set theory proposes two opposing mind-sets related to learning: entity mind set and incremental mind set. In a nutshell, Students endorsing an entity mind-set assume that abilities in a domain are fixed, whereas students who endorse an incremental mind-set assume that abilities are trainable. Both are measured with 3 items each on a 6-point Likert scale (1: disagree; 6: agree). Students largely endorsed incremental mind set more compared to entity mind set as assessed through mean comparison, $M(\text{entity}) = 2.49$, $sd = 0.98$; $M(\text{incremental}) = 4.85$, $sd = 0.75$; $t(162.96) = -17.98$, $p = 0$, $r = 0.82$. Incremental mind set is proved to be the more positive view regarding individual learning. Internal consistency for both variables is good (at Time 1: $\alpha = 0.84$, and $\alpha = 0.74$ respectively). Finally, competition achievement is expected to relate to competence beliefs (see: Hazari et al., 2010). Competition achievement was thus included as a covariate. Competition achievement refers to the points that students received (as judged by their teachers on the basis of a solution manual). Points ranged from 0 to 40 points (or 45 points for younger students) with a mean performance of the participants of at Time 1: $M(SD) = 31.08$ (7.29). Internal consistency of four scored items was acceptable ($\alpha = 0.67$).

Confounding influences for the physics identity resource of recognition is the support by meaningful scientific others. Research on physics interest development (Hoffmann et al., 1998) established the importance of support from meaningful scientific others, namely support by teachers, parents, and peers.

Study 2 confirmed the importance of social support also in the context of the Physics Olympiad (see chapter 5). Each dimension (teachers, parents, and peers) was measured with 3 items on a 5-point Likert scale (1: disagree; 5: agree). Social support was measured pre intervention. The means for teachers are comparably high (at Time 1: $M(SD) = 3.61$ (1.16)), while parents ($M(SD) = 2.98$ (1.36)) and peers ($M(SD) = 2.53$ (1.23)) are quite center in the response scale. The internal consistencies were good (at Time 1: $M(SD) = 3.61$ (1.16), $M(SD) = 2.98$ (1.36), and $M(SD) = 2.53$ (1.23) respectively). Sense of belonging as the relevant facet of recognition by others in this study is furthermore intricately related to positive science peer relations and estimated future self, called possible self (Stake & Mares, 2001). Science peer relations is closely linked to support by peers, but focuses more on the subjectively experienced science enthusiasm and expertise in a peer network for a student. Possible science self extrapolates the self into the future, where personal fit in the domain and fit between family and career is assessed (Stake & Mares, 2001). Science peer relations and possible science self are measured because self-prototype matching and physics identity theory predict that peers are particularly influential and the self-image eventually guides physics-related choices (Stake & Mares, 2001). As such science peer relations and possible science self is expected to be linked to sense of belonging. Science peer relations is measured with 4 items on a 7-point Likert scale (1: disagree; 7: completely agree). The mean is reasonably in the center of the response scale (at Time 1: $M(SD) = 4.01$ (1.75)) and internal consistency is good ($\alpha = 0.83$). Possible science self is measured with 5 items on a 7-point Likert scale (1: disagree; 7: completely agree). From the scale possible science self 3 items were excluded that did not correlate with the whole scale. 6 items remained in this scale, so that possible science self was still measured accurately (at Time 1: $\alpha = 0.7$). The mean is rather high ($M(SD) = 5.4$ (1.19)), suggesting that the participating students expressed a positive science related view of their selves.

Finally, socioeconomic background was included as a covariate because socioeconomic backgroud predicts academic success (OECD, 2008) and representativeness of the sample could be assessed. Socioeconomic background is measured with 2 items on a 6-point ordinal scale (PhD, university degree, ...). 70 percent of fathers have A-level degree and 67 percent of mothers of the participants have A-level degree. This is higher compared to the average population where the proportion of individuals eligible for study is slightly above 40 percent.[1]

## Sample

Students who participated in the Physics Olympiad in 2016 and who were also eligible to participate in the next year's Physics Olympiad were solicited for participation in the intervention. Of all invited students 29.9 percent responded positively and participated in the intervention. A dropout of participants was observed throughout the intervention (see Tabel 7.2). A total of 53.6 percent of the participants that initially subscribed to the intervention persisted until the end. The students who persisted until the end were included in the analyses, as was done in other educational studies (Zhan, Jiao, & Liao, 2017). Particularly, the males in the control group posed a problematic pattern with only

---

[1] see https://de.wikipedia.org/wiki/Abiturientenquote_und_Studienanf%C3%A4ngerquote, accessed 4 May 2019

Table 7.1: Overview of measures with interval scale.

| | # items | Scale | $M(SD)$ | $\alpha_{t1}$ | $\alpha_{t2}$ | $\alpha_{t3}$ | $\alpha_{t4}$ | $\alpha_{t5}$ | Sample item |
|---|---|---|---|---|---|---|---|---|---|
| *Dependent variables:* | | | | | | | | | |
| Sense of belonging | 20 | 1-6 | 4.75 (0.96) | 0.91 | 0.89 | 0.91 | 0.95 | 0.93 | I feel that I belong to the physics community |
| Expectancy physics | 4 | 1-7 | 4.8 (1.16) | 0.84 | | | | 0.77 | I belief that I will be better compared to my colleagues |
| *Predictor variables:* | | | | | | | | | |
| Situational interest: task | 8 | 1-5 | 3.92 (0.75) | | 0.9 | 0.9 | | 0.89 | The physics problems in this seminar were interesting to me |
| Situational interest: instructor | 3 | 1-5 | 4.8 (0.41) | | 0.22 | | | 0.73 | The instructor treated the participants fairly |
| Situational interest: group | 6 | 1-5 | 4.28 (0.73) | | 0.75 | | | 0.79 | The group work was boring |
| Situational interest (all) | 17 | 1-5 | 4.2 (0.68) | | 0.86 | | | 0.86 | |
| *Covariates:* | | | | | | | | | |
| Values physics (interest) | 1 | 1-7 | 5.93 (1.18) | - | | | | - | I will learn and experience many interesting things |
| Values physics (attainment) | 1 | 1-7 | 5.84 (1.21) | - | | | | - | It will be value to me personally to be successful in physics |
| Values physics (cost) | 1 | 1-7 | 4.51 (1.41) | - | | | | - | I is personally valueable to me to engage even though this might result in less time with friends, family, and hobbies |
| Values physics (utility) | 1 | 1-7 | 4.67 (1.28) | - | | | | - | The contents that I learn will be useful for my personal daily life |
| Support by parents | 3 | 1-5 | 2.98 (1.36) | 0.79 | | | | | My parents support me actively in my physics engagement |
| Support by teachers | 3 | 1-5 | 3.61 (1.16) | 0.75 | | | | | My physics teacher supports me actively in my physics engagement |
| Support by friends | 3 | 1-5 | 2.53 (1.23) | 0.84 | | | | | My friends support me actively in my physics engagement |
| Science peer relations | 4 | 1-7 | 4.01 (1.75) | 0.83 | | | | | My best friend likes physics |
| Possible science self | 5 | 1-7 | 5.4 (1.19) | 0.7 | | | | 0.6 | It will be possible for me to separate work and personal life - e.g., you may have a family if you want one |
| Entity mind set | 3 | 1-6 | 2.52 (1.21) | 0.84 | | | | | One has a certain amount of physics talent and one cannot really do anything about it |
| Incremental mind set | 3 | 1-6 | 4.79 (0.95) | 0.74 | | | | | You personally can strongly influence how capable you are in physics |
| Socioeconomic background | 2 | 1-6 | 3.75 (1.65) | | | | | 0.48 | Does your father have one of the following qualifications? (PhD, university degree, .) |
| Study aspiration (physics) | 1 | 0-100 | 67.53 (32.96) | - | | - | | - | Are you planning to take up a physics-related study or job? |
| Competition achievement | 1 | 0-45 | 31.08 (7.29) | - | | | | | |

Table 7.2: Recruitment process of participants in seminar program (%).

| Group | $N_1$[a] | $N_2$[b] | Time 1 | Time 2 | Time 3 | Time 4 | Time 5 |
|---|---|---|---|---|---|---|---|
| Treatment ♂ | 102 | 32 | 31 (100) | 27 (87) | 19 (61) | 21 (68) | 18 (58) |
| Treatment ♀ | 102 | 26 | 25 (100) | 23 (92) | 20 (80) | 18 (72) | 15 (60) |
| Control ♂ | 45 | 18 | 16 (100) | 10 (62) | 10 (62) | 9 (56) | 5 (31) |
| Control ♀ | 45 | 12 | 12 (100) | 10 (83) | 9 (75) | 9 (75) | 7 (58) |
| All | 294 | 88 | 84 (100) | 70 (83) | 58 (69) | 57 (68) | 45 (54) |

[a] Number of students that received an invitation.

[b] Number of students that positively responded.

31 percent of those students that initially participated persisted until the end. More informative dropout analyses will be reported in the discussion. Due to the dropout and of general interest of whether the sample was representative of the overall Physics Olympiad's population, a linear model (ANOVA) was used to find possible effects with respect to competition achievement and age differences. Therefore, gender and group (treatment, control, and general olympians) were included as predictors and competition achievement and age as outcome variables. No differences were found for competition achievement and age between the groups or the genders (see appendix D Table D.1 for effects). This indicated that the sample was representative with the olympian population with regards to competition achievement and age.

Since a priori differences between the groups (treatment versus control) and the genders in covariates might results in different experiences that the students make in the intervention and threaten the validity of the effects, an analysis for such initial differences in the covariates was performed. Some meaningful differences for either gender or group can be found for the sample (see Table D.1 in appendix D). Most notably are the differences for science peer relations at time 1 between females and males, $F(1,41) = 11.06, p < .01, \eta_p^2 = 0.21$.[2] Furthermore, support by friends, $F(1,41) = 7.51, p < .01, \eta_p^2 = 0.15$, and support by teachers, $F(1,41) = 5.43, p < .05, \eta_p^2 = 0.11$, were significantly higher for male students compared to female students. This is well supported by the literature and was also suggested in study 1. Concerningly is furthermore the gender effect for the dependent variable sense of belonging, $F(1,41) = 5.03, p < .05, \eta_p^2 = 0.08$. Regarding group effects, sense of belonging appears significantly higher in the treatment group, $F(1,41) = 6.75, p < .05, \eta_p^2 = 0.14$. This effect is of medium size. No other effects were significant. Also no interaction effects were significant. However, the gender and group effects for sense of belonging were particularly concerning with regards to validity of effects because initial differences in dependent variables pose the problem that the genders and groups interact in fundamentally different ways with the intervention. These differences had to be factored in into further interpretations.

Table 7.3: Correlation table for the outcome variables, independent variable, and covariates.

| Measure | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Dependent variables:* | | | | | | | | | | | | | | |
| 1: Sense of belonging | - | | | | | | | | | | | | | |
| 2: Expectancy physics | .49***[a] | - | | | | | | | | | | | | |
| *Predictor variable:* | | | | | | | | | | | | | | |
| 3: Situational interest | .22 | .17 | - | | | | | | | | | | | |
| *Covariates:* | | | | | | | | | | | | | | |
| 4: Values physics | .03 | .49*** | .35* | - | | | | | | | | | | |
| 5: Support by teachers | .27 | -.01 | .18 | -.12 | - | | | | | | | | | |
| 6: Support by parents | .20 | .16 | -.05 | -.02 | .07 | - | | | | | | | | |
| 7: Support by friends | .04 | -.03 | .000 | -.03 | .47** | .000 | - | | | | | | | |
| 8: Science peer relations | -.04 | -.11 | -.13 | -.14 | .30* | -.08 | .44** | - | | | | | | |
| 9: Possible science self | .19 | .33* | .09 | -.02 | -.10 | .17 | -.19 | .06 | - | | | | | |
| 10: Age | .02 | .01 | .04 | .20 | .30* | -.29 | .35* | .14 | -.16 | - | | | | |
| 11: Competition achievement | -.07 | .06 | -.06 | .07 | -.04 | -.05 | -.27 | -.07 | .14 | .000 | - | | | |
| 12: Entity mind set | -.13 | -.19 | -.27 | -.22 | .11 | -.10 | .15 | .16 | -.36* | -.20 | -.29 | - | | |
| 13: Incremental mind set | .27 | .37* | .24 | .51*** | -.10 | .11 | .04 | -.09 | .20 | .14 | .19 | -.75*** | - | |
| 14: Study aspiration (physics) | .10 | .17 | .28 | .47** | -.22 | .12 | -.14 | -.18 | .22 | .13 | .22 | -.36* | .25 | - |

[a] Note that the correlations are not adjusted for multiple testing so that $\alpha$-error rate is inflated.

## 7.4 Results

The goal for the preliminary correlational analysis is to assess internal validity of the constructs, where it will be tested whether the directions and magnitudes of the intercorrelations were as expected for the dependent variables and the predictor variable with the covariates. Furthermore, this analysis can inform modelling decisions for whether models can be fit separately for the dependent variables. This will be done, if multicollinearity is not present, i.e., if intercorrelations and variance inflation factor ($VIF$) are high (e.g., $VIF > 10$). It was hypothesized that expectancy of success as the proxy for the physics identity resource of competence belief was related to the covariates values, mind-set, and competition achievement and that sense of belonging as the proxy for the physics identity resource of recognition was related to the covariates support by meaningful others, science peer relations, and possible science self. Furthermore, it was hypothesized that expectancy of success and sense of belonging were interrelated. These hypotheses will be tested in the entire sample on the basis of intercorrelations. Gender and group (treatment versus control) will be neglected as categorical predictors in this analysis. It was confirmed that between the genders and groups no substantial changes in the correlation matrix (as assessed through change of sign of correlation between two variables) occured, so that the correlation patters in Table 7.3 can be considered representative also for the subgroups. Table 7.3 lists the intercorrelations of the employed scales. As expected, sense of belonging was significantly correlated with expectancy of success, but not so high that multicollinearity would be a problem as assessed through $VIF$ which was 1.74. Expectancy of success was furthermore significantly correlated with values, as expected based on expectancy-value theory. This means that students with a high expectancy of success also likely valued physics. Furthermore, expectancy of success was also significantly correlated with incremental mind set, as was hypothesized. Students who held a positive expectation of success towards the Physics Olympiad also tended to view that they can improve their ability in physics. A negative correlation appeared for expectancy of success with entity mind set–though not significant. Interestingly, competition achievement did not correlate with expectancy of success. Yet, possible science self did significantly correlate with expectancy of success, which means that students who see themselves as possible physicists express of higher expectancy of success for the Physics Olympiad. Sense of belonging did not significantly correlate with any other predictor variable or covariate, though positive correlations in magnitude (though not significant) with situational interest, support by teachers and parents, possible science self, and incremental mind-set appeared. Situational interest as the predictor variable was significantly correlated with values in physics. Students who held higher values also reported a greater situational interest. Note that for situational interest the same positive/negative significant correlation with incremental/entity mind set appears as for expectancy of success (the same tendency–though not significant–can also be observed for sense of belonging).

In summary, this preliminary correlational analysis confirmed that no multicollinearity between the dependent variables occured as confirmed through $VIF$.

---

[2] $\eta_p^2$ is partial $\eta^2$ as a measure of effect size. Common references for effect sizes are: $\eta_p^2 > .02$ small, $\eta_p^2 > .13$ medium, and $\eta_p^2 > .26$ large effect.

Furthermore, the intercorrelations are mostly as expected which raised internal validity and also supportes the underlying theory that predicted these relationships. Surprising, however, was the finding that competition achievement did not correlate with either expectancy of success or sense of belonging.

### RQ 4.1: Effects for sense of belonging and expectancy of success

Figure 7.3 depicts the regression lines that indicate time development for expectancy of success and sense of belonging with respect to gender and group, where the shaded area marks the 95% confidence interval for sense of belonging and expectancy of success. Judging from this graphical depiction, it can be hunched that the intervention had, if any, more subtle effects in this sample that are potentially linked to the predictor variable situational interest or the covariates.

In order to examine possible differences in development with regards to gender and group, hierarchical linear models were fitted, more precicely linear mixed-effects regressions with correlated random effects and homogenous variance assumption. To get an understanding for the data, the parsimonious models with gender, time, and group as predictor variables will be presented first (`SoB/Exp` $\sim$ `time + gender + group + time` $\times$ `gender + time` $\times$ `group` ). Afterwards, covariates will be added to the models as predictor variables. In all models a homoscedastic variance structure over time points was assumed. This assumption seems reasonable when checked with Levene test for homogeneity of variance. The respective $F$-statistics were: Sense of Belonging: $F(4, 214) = 1.41, p = 0.23$; Expectancy physics: $F(1, 88) = 0.13, p = 0.72$.

Long (2012) suggested the presentation of fixed-effects estimates, with SEs, $t$-values, and estimates of the variance components. In addition to these values, the explained variance $R^2$ as a measure of absolute effect size for a model will be reported for the models (see Long, 2012, p. 427). Instead of $t$-values the 95% confidence intervals ($CI$) will be reported instead. Both contain essentially the same information, yet $CI$s make it easy to judge if zero is included in the possible effects. Considering the research question for time development, the fixed effects for time and the interaction effect with time and gender/group were of most importance. For sense of belonging significant (as judged by the $t$-values) main effects for gender and group appeared. Male students reported a higher sense of belonging compared to female students. Furthermore, the control group started off with significantly lower values compared with the treatment group (see Table 7.4, or Figure 7.3). This is particularly unfortunate, because higher values often relate to smaller increases in the dependent variable. This was also seen in the present model: the correlations of the random effects (slope and intercept) were negativ. This means that students who started with a lower initial value had a more positive development over time. This is a representative finding in longitudinal research (e.g., Long, 2012) and poses problems to possible effects for the treatment group, because they started with higher values for sense of belonging. Furthermore, the interaction effect with group and time is also significant. The interaction effect indicates that the control group improves its sense of belonging more strongly compared to the treatment group. The model explained 11 percent of the variance in sense of belonging. For expectancy of success no significant main effects or interaction effects were found. In fact, the model fit is poor and only 3 percent of the variance in expectancy of success

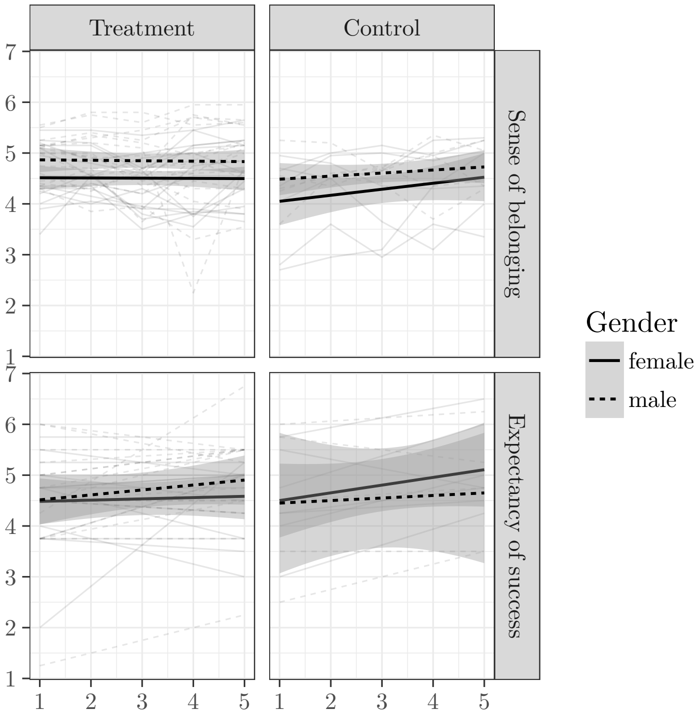


Figure 7.3: Development for sense of belonging and expectancy of success.

Table 7.4: Estimates multilevel models for sense of belonging.

|  | Sense of belonging |  |  | Expectancy of success |  |  |
|---|---|---|---|---|---|---|
| Name | *b* | *SE*(*b*) | 95% *CI* | *b* | *SE*(*b*) | 95% *CI* |
| Intercept | 4.50 | 0.15 | [4.2,4.8] | 4.44 | 0.28 | [3.88,5] |
| Time | 0.00 | 0.04 | [-0.08,0.08] | 0.05 | 0.05 | [-0.05,0.15] |
| Group (control) | -0.53 | 0.21 | [-0.95,-0.11] | -0.07 | 0.39 | [-0.85,0.71] |
| Gender (male) | 0.39 | 0.19 | [0.01,0.77] | -0.02 | 0.35 | [-0.72,0.68] |
| Time × GroupControl | 0.10 | 0.05 | [0,0.2] | 0.05 | 0.07 | [-0.09,0.19] |
| Time × Gendermale | -0.02 | 0.05 | [-0.12,0.08] | 0.03 | 0.06 | [-0.09,0.15] |
| Var(Inter) | 0.24 |  |  | 1.02 |  |  |
| Var(Slope) | 0.01 |  |  | 0.02 |  |  |
| Corr. | -0.32 |  |  | -0.63 |  |  |
| $R^2$ | 0.11 |  |  | 0.03 |  |  |

could be explained.

In a next step, the covariates were added into the model, in order to adjust for initial differences between students that are beyond the predictor variables gender and group. The main effects for sense of belonging (gender, group, and interaction group and time) remained stable (see Table D.2 in appendix D). Additionally, a main effect for possible science self appeared, i.e., students who envisioned their future self more compatible with physics reported a higher sense of belonging. Furthermore, science peer relations was negatively related to sense of belonging. This means that students with a close friend who likes physics reported a lower sense of belonging. No effects for covariates reached significance for expectancy of success.

### RQ 4.2: Seminar feedback

In order to assess effects of the design feastures (as measured through situational interest) on the dependent variables, the situational interest scales were first analyzed. In particular, situational interest was utilized as an outcome variable with gender and group as predictor variables. This would detect differences with regards to gender and group in situational interest and indicate potentially differences in experiences in the intervention. All subdimensions for situational interest (task, instructor, and group) in this intervention were rated above average (see appendix D Table D.4). Treatment group and control group received approximately the same tasks and reported how much they liked the tasks. When the subdimension task was set as outcome variable in a 2-way ANOVA with gender and group as predictor variables, no effects were found, gender effect: $F(1,41) = 0.07, p = .79, \eta_p^2 = 0$, group effect: $F(1,41) = 0.14, p = .71, \eta_p^2 = 0$, gender × group effect: $F(1,41) = 1.62, p = .21, \eta_p^2 = 0.04$.

The subdimensions instructor and group were only rated by treatment group participants (the control group rated only tasks because they neither worked in groups nor experienced instructors in the online seminars). At both in-person seminars, the instructors were rated highest by the treatment group students by young women and young men. A *t*-test for mean differences between group with situational interest instructor as outcome variable yielded no significant differences, *M*(female) = -0.07, *sd* = 0.5; *M*(male) = 0.22, *sd* = 0.42; *t*(27.55) = -1.81, *p* = .082, *r* = 0.33. Almost all students in the treatment group rated the instructors with the highest possible rating. Regarding situational interest group, no differences between young women and men appeared either as assessed with a *t*-test, *M*(female) = 0.01, *sd* = 0.41; *M*(male) = -0.05, *sd* = 0.47; *t*(30.94) = 0.4, *p* = .692, *r* = 0.07.

RQ 4.2 regards the link between design features and the dependent variables of the intervention. In order to examine effects of the design features, situational interest was included as predictor variable in the multilevel regression models with sense of belonging and expectancy of success as dependent variables. In particular, the interaction between time and situational interest in these models would indicate a differential development for sense of belonging and expectancy of success for students who reported a higher or lower situational interest. For sense of belonging as dependent variable, the interaction effect between situational interest and time becomes significant, $b^* = 0.15, SE(b^*) = 0.05$ (see Table 7.5). The main effect for situational interest is also significant, $b^* = 0.6, SE(b^*) = 0.22$. Overall, this model explains 70 percent of the variance in sense of belonging. Situational interest had no effect on expectancy of success (see Table 7.5).

### RQ 4.3 and 4.4: Further engagement and study intent physics

As a means to assess the effects that an identity-considerate intervention in the context of the Physics Olympiad would have, RQ 4.3 and RQ 4.4 relate to actual and intended academic choices regarding physics and the Physics Olympiad that the participants made that were potentially affected by their participation in the intervention. Actual physics-related choice was further enrollment in next year's Physics Olympiad and intended physics-related choices in this analysis was study aspiration for physics. Further participation in the next year's Physics Olympiad was utilized as a new outcome variable, where 0 indicated no further participation and 1 indicated further participation. Actual further participation in the following competition was analyzed based on the enrollment scores of the students, who were tracked on whether they subscribed to the follow-up competition. Considering the general population of the Physics Olympiad, 41 percent (male: 41 %, females: 41 %) of the eligible students participated in the next year's Physics Olympiad. In the treatment group in this intervention 55 % (male: 50 %, female: 60 %), and in the control group 50 % (male: 40 %, female: 57 %) participated in the next year's Physics Olympiad. A $\chi^2$-test with further participation and group (treatment vs. general population) was utilized in order to test the hypothesis that actual participation in the treatment group was significantly higher compared to the general population. The hypothesis that the differences in actual participation were significant, was not supported, $\chi^2(2) = 2.65, p = .27$.

In order to examine influences for actual further participation, the identity resources sense of belonging and expectancy of success, the predictor variables gender, group, and situational interest, and the covariates were included in a logistic regression as predictor variables, where further participation was the dependent variable. A logistic regression was used in order to estimate the effect of the predictors on future participation in the next competition. Effects on further participation appeared for expectancy of success, science peer relations, and possible science self (see Table 7.6).[3] Higher values in expectancy of success and science peer relations related to a greater probability of enrolling in the next-year's Physics Olympiad, with large effect sizes as judged by the odds ratios ($OR$). For example, one standard deviation higher in expectancy of success is associated with an increase in the $OR$ of 5.02. Possible science self was negatively associated with further participation. This means that students who reported a higher possible science self were less likely to enroll in the next year's Physics Olympiad.

Intended physics-related choice was assessed through study aspiration for physics. Descriptive statistics for females in treatment group were $M_{t1}(SD) =$ 60.5 (32.9) $\rightarrow M_{t5}(SD) =$ 54.5 (35.7). The intent to study physics declined as assessed by descriptive statistics. For the young men in treatment group means were $M_{t1}(SD) =$ 67.1 (31.6) $\rightarrow M_{t5}(SD) =$ 66.6 (34). So for males, intent to study physics remained constant, as assessed through descriptive statistics. In the control group, young women, $M_{t1}(SD) =$ 82 (14.2) $\rightarrow M_{t5}(SD) =$

---

[3] The effects did not change when possible interaction effects with gender and group were added as predictors.

Table 7.5: Multilevel model with situtational interest and gender as predictor variables for the dependent variables.

| | Sense of belonging | | | Expectancy of success | | |
|---|---|---|---|---|---|---|
| | $b^*$ | $SE(b^*)$ | 95% $CI$ | $b^*$ | $SE(b^*)$ | 95% $CI$ |
| Intercept | 4.53 | 0.11 | [4.31,4.75] | 4.47 | 0.30 | [3.87,5.07] |
| Time | -0.00 | 0.03 | [-0.06,0.06] | 0.03 | 0.06 | [-0.09,0.15] |
| Gender (male) | 0.27 | 0.16 | [-0.05,0.59] | -0.08 | 0.41 | [-0.9,0.74] |
| Situational interest | 0.60 | 0.22 | [0.16,1.04] | 0.48 | 0.58 | [-0.68,1.64] |
| Time × Gendermale | 0.01 | 0.04 | [-0.07,0.09] | 0.07 | 0.08 | [-0.09,0.23] |
| Time × Situational int. | 0.15 | 0.05 | [0.05,0.25] | 0.03 | 0.11 | [-0.19,0.25] |
| $R^2$ | 0.70 | | | 0.28 | | |

Table 7.6: Logistic regression models for further participation.

| | Further Participation IPhO | | | |
|---|---|---|---|---|
| | $b^*$ | $SE(b^*)$ | $OR$ | 95% $CI$ |
| Sense of belonging | 0.47 | 0.75 | 1.61 | [-1.02,1.97] |
| Expectancy physics | 1.61 | 0.64 | 5.02 | [0.33,2.9] |
| Gender | 1.79 | 1.27 | 5.98 | [-0.76,4.34] |
| Group | 0.65 | 1.32 | 1.92 | [-1.99,3.29] |
| Competition achievement | -0.32 | 0.53 | 0.72 | [-1.37,0.73] |
| Situational interest | -1.14 | 0.95 | 0.32 | [-3.05,0.76] |
| Science peer relations | 1.84 | 0.82 | 6.29 | [0.2,3.48] |
| Support by teachers | -0.4 | 0.53 | 0.67 | [-1.47,0.67] |
| Support by parents | 0.08 | 0.48 | 1.08 | [-0.89,1.05] |
| Support by friends | -1.42 | 0.78 | 0.24 | [-2.98,0.14] |
| Possible science self | -1.15 | 0.56 | 0.32 | [-2.26,-0.03] |

87.1 (18.7), and young men, $M_{t1}(SD) = 69.6$ (23.2) $\rightarrow M_{t5}(SD) = 82.4$ (21.4) started with nominally higher values at time 1 compared to the treatment group and increased their intent to study physics.

These nominal differences in study intent were then checked through multilevel models with study intent as dependent variables and time, gender, and group as predictor variables with their respective interaction effects. Multilevel models suggested that there were no significant differences in study intent (time: $b^* = -1.58, SE(b^*) = 1.37, t = -1.15, p = .26$, gender: $b^* = 0.02, SE(b^*) = 9.46, t = 0, p = 1.00$, group: $b^* = 9.92, SE(b^*) = 10.7, t = 0.93, p = .36$). Given the large error for the group effect, it can be hunched that the higher values for the control group occured by chance due to the small size of the control group.

In order to examine potential influences of sense of belonging, expectancy of success, situational interest, gender, group, and the covariates on study intent, a multiple regression model was fit, where effects of one predictor were adjusted for the other variables including study aspiration at time 1 (pre). As could be expected, the value for study aspiration at time 5 was strongly associated with study intent at time 1 (pre) in a positive direction, $b^* = 0.67, SE(b^*) = 0.15, t = 4.49, p < .001$. Students who had a higher study intent at time 1 had also a higher study intent at time 5. No other predictors were significantly associated with study intent at time 5. Gender was slightly associated (marginally significant) with study aspiration at time 5, $b^* = 0.65, SE(b^*) = 0.34, t = 1.92, p = .07$. Female students tended to express a lower study aspiration at time 5 compared to male students.

Study intent for physics was further analyzed with a regression model where study intent (time 5) was the dependent variable. Gender was retained as a predictor, and the identity resources sense of belonging and expectancy of success were included with pre and post values, as was done in Good et al. (2012). This was done to assess whether change in sense of belonging and expectancy of success had an impact on study aspiration (an effect that was found for sense of belonging in the study of Good el at., 2012). Table 7.7 displays the model estimates. Estimates indicated that sense of belonging (time 5) and expectancy of success (time 5) were significantly correlated with study aspiration when adjusting for initial sense of belonging and expectancy of success, respectively. In other words, the slope in sense of belonging and expectancy of success were associated with study intent in physics at time 5. Effects remained when study intent at time 1 was included as predictor variable.

## 7.5 Discussion

This study sought to explore and confirm possible effects of an intervention that is considerate of physics identity-related issues for young women in the context of the Physics Olympiad. An intervention was implemented in the context of the Physics Olympiad that offered the young women a potentially identity-safe environment where they worked on advanced topics in physics together with female mentors (as in-group experts) that were recruited from the population of formerly most successful female participants in the Physics Olympiad. Studies 1, 2, and 3, and prior research on gender differences informed the design of this intervention. For example, equal gender-ratios, Active-learning physics instruction, and female in-group experts as mentors were meant to facilitate feelings of belonging and promote expectancy of success amongst the participating young women. Study 4 employed a treatment-control-group design in order to isolate potential effects of the social environment as compared to the learning materials. Physics identity tbeory informed the posed research questions. In RQ 4.1 it was assessed to what extent the participating young women and young men developed their expectancy of success and sense of belonging with regards to the physics Olympiad. In RQ 4.2 the relationship between design features of the intervention and physics identity resources was assessed. In particular, the question the question to what extent situational interest related to the development of expectancy of success and sense of belonging for the participating students was examined. Finally, effects regarding actual and intended physics-related choices for the participating students were assessed in RQ 4.3 and RQ 4.4. The particular questions were to what extent the young women and men that participated in the intervention enlisted in the next year's Physics Olympiad as compared to the overall olympiad population and to what extent the study intent for physics of participating students changed as also related to the identity resources.

Regarding RQ 4.1, no main effects for time appeared which means that the overall identity resources did not develop either way for both young women and men in treatment or control group. What was found is that the control group started off with significantly lower values in the identity resource sense of belonging. The control group furthermore increased their sense of belonging significantly as verified through a significant interaction effect with group and time. This initial difference in sense of belonging (dependent variable) threatens comparability of treatment and control group. In particular, lower initial values in sense of belonging leave more room for improving sense of belonging. The treatment group started with very high levels that eventually makes further improvement unlikely. Such effects are often found in longitudinal research, and the negative correlation of the random effects in the multilevel models confirm the mechanism that lower initial values more likely relate to higher rates of improvement. Such differences need to be eliminated through random selection procedures when soliciting participants for intervention studies. An improved

Table 7.7: Regression on study aspiration (time 5) with outcome variables as predictors.

| | Sense of belonging | | | Expectancy of success | | |
|---|---|---|---|---|---|---|
| | $b^*$ | $SE(b^*)$ | 95% $CI$ | $b^*$ | $SE(b^*)$ | 95% $CI$ |
| Intercept | -0.18 | 0.17 | [-0.52,0.16] | -0.17 | 0.17 | [-0.51,0.17] |
| Outcome var. (time 1) | -0.26 | 0.29 | [-0.84,0.32] | 0.08 | 0.21 | [-0.34,0.5] |
| Outcome var. (time 5) | 0.72 | 0.22 | [0.28,1.16] | 0.44 | 0.21 | [0.02,0.86] |
| $R^2$ | 0.33 | | | 0.21 | | |

selection procedure for this intervention might have assessed the questionnares prior to group assigment (treatment or control). Allocation procedures that factor in the dependent variables would have assured that both groups have similar values in the dependent variables. Neither time, nor group or gender effects appeared for the physics identity resource expectancy of success as dependent variable in the model.

Regarding RQ 4.2, it was be descriptively examined that all situational interest subdimensions were rated positive by the students. Especially the dimension instructor for situational interest had the highest ratings among females and males. When assessing the relation of situational interest to the identity resources, it was confirmed that situational interest had an impact on the development of sense of belonging but not on expectancy of success. This was confirmed through a significant interaction effect between time and situational interest with sense of belonging as dependent variable. Students who rated situational interest higher, also developed a more positive sense of belonging. This was evidence that the intervention could affect the development of the physics identity resources. Where study 3 found no effect for recognition, it could now be affirmed in study 4 that effects on recognition as operationalized through sense of belonging likely happen on a longer time scale and are related to the experiences in the intervention. It was particularly reaffirming that no gender differential effects appeared for situational interest. However, some students also decreased their sense of belonging. This requires further research where an explanatory design, where these students would be interviews in particular, would be necessary in order to better explain the mechanisms that potentially disengage students with physics through this intervention.

Finally, RQ 4.3 and RQ 4.4 affirmed that participants in the intervention enrolled more likely in the subsequent Physics Olympiad compared to the overall olympian population, regardless of gender, which is also in keeping with the finding from study 3 where it was also found that the participating students were more likely to enroll in the next year's Physics Olympiad. In an attempt to relate physics identity resources, gender, group, situational interest, and the covariates to future participation, it was found that expectancy of success and science peer relations were positively related to future participation while support by friends was negatively related to future participation. Another physics-related choice variable was study intent. Descriptively, the control group started off and ended with higher values for study intent. However, this descriptive finding was not replicated in multilevel models. It could be hunched that the small sample size of the control group caused the power for findings effects to decrease. In analyzing associations with study intent, it was found that gender was marginally associated with study aspiration (post), namely young women reported lower study aspiration at the end. When examining how the physics identity resources sense of belonging and expectancy of success related to study intent at time 5, it was confirmed that change in sense of belonging and expectancy of success was positively associated with study intent at time 5, adjusting for sense of belonging and expectancy of success at time 1. This confirms that some variance in study intent at time 5 was due to positive changes in sense of belonging and expectancy of success, which confirms the importance of facilitating sense of belonging and expectancy of success both for male and female students.

Limitations for the interpretation of the results were introduced through the low return rate of solicited participants and the dropout throughout the intervention (see section 7.3). It is unlikely that all factors that motivated dropout and low initial participation will be assessed, however, in order to identify factors that were related to dropout, dropout (0: no, 1: yes) was linked to identity resources, gender, situational interest, and covariates with a logistic regression with dropout as outcome. Three predictors turned out to affect dropout. First, achievement in the competition was a crucial factor, $b^* = -2.43, SE(b^*) = 0.95, OR = 0.09, z = -2.56, p < .01$. Scoring one point higher in the competition resulted in a decrease of the odds ratio of dropout (versus non-dropout) of 0.09. This indicates that the tasks that were utilized in the intervention were likely too difficult for some students, i.e., those who also scored lower in the Physics Olympiad. Knowing that one performed weakly in the Physics Olympiad could become salient in the intervention seminars. For example, students could communicate their results in the problems and some students shy away from engaging in these conversations which demotivates them to further engage in the intervention. Competence discourses are particularly important and future interventions need to assure that the students perform on similar levels. Otherwise, students with lower performance are likely to drop out. Furthermore, female gender (after controlling for the other variables) protected students from dropout. Males increased the odds ratio of dropout by 20.47 ($b^* = 3.02, SE(b^*) = 1.53, OR = 20.47, z = 1.97, p < .05$). This could indicate that the design features resonated more with female students while some male students eventually felt uninterested or identity threatened. When checked for differences in subdimensions of situational interest, no significant effects between students who dropped out and those who stayed until the end appeared so that it cannot be decided which design elements might be responsible for repelling some students. Finally, situational interest was significantly related to dropout. Students who reported a higher situational interest decreased their odds ratio for dropout by 0.25 ($b^* = -1.4, SE(b^*) = 0.66, OR = 0.25, z = -2.1, p < .05$). This finding supports the assumption that students who experienced a high person-environment fit were facilitated in their physics engagement as operationalized through prolonged enrollment in the interventions. This finding also points to the complex problem of designing an environment that is suitable to all students. Certain design decisions might always repell some students and it could be conceptualized as an optimization problem to maximize the amount of students who report a high situational interest. Apparently, the present design did not appeal to all students. Possible solutions might be stronger facilitation of difficulty-adequate learning materials or employing varying instructors and group constellation so that genders are mixed more regularly. When assessing the dropout factors in the control group, no estimates were significant. This could be an artifact of the small sample size of the control group. Or, this finding could point to different mechanisms that influence dropout in seminars versus online seminars.

In summary, the findings in study 4 point to some important aspects for advancing physics identity research. For example, no significant drop of sense of belonging for females over the course of this half-year intervention was found. In the studies by C. Good et al. (2012) and Hausmann et al. (2007) sense of belonging for the young women decreased significantly over a similar period of time. This was promising, given the fact that sense of belonging was positively related to study intent at time 5. Furthermore, situational interest was related to a more positive development for sense of belonging in physics. This suggests that the design features of the intervention resonate with some students and facilitate their physics identity development as assessed through sense of belonging. Overall, this buttresses the claim that identity-considerate learning environments are able to facilitate development in the physics identity resources. Furthermore, no gender differential effects appeared. Similar to study 3 and prior research (see: Wodzinski, 2007), this suggests that young women and men can equally be supported at the same time.

The identity resources sense of belonging and expectancy of success seem also be related to physics-related choices. For example, C. Good et al. (2012) presented an analysis of study intent in mathematics and they found that sense of belonging in the post measure was significantly related to study intent (post), after adjusting for initial sense of belonging. This effect was replictated in the present study: sense of belonging at time 5 was significantly related to study intent at time 5 after adjusting for sense of belonging at time 1 (same holds for expectancy of success). This analysis indicates that the development of a sense of belonging is a significant predictor for the intent to study physics and provides evidence that the increase in sense of belonging that was observed for some students (particularly those who reported a high situational interest) is a desirable outcome. The findings also indicate the importance of expectancy of success for further participation in the Physics Olympaid (see also: Urhahne et al., 2012).

Even though this study was exploratory in nature, study 3 and prior research enabled hypothesizing about potential effects. Given the vast literature that was included in order to design this intervention, it was a sobering result that the participating young women as a group were not positively affected in their overall development of sense of belonging or expectancy of success. It is possible that the intervention design was promising in theory, but ineffective in practice. Effects could have also played out on more subtle layers such as stereotype threat or gender-identity threat that were not assessed in the present study. Especially since the variance in the sample was restircted to high-achieving students in physics, more specific effects might have appeared that could not have been detected with the employed scales. It was assured that the students enjoyed the design through measuring situational interest and confirming that situational interest was high. However, reporting high situational interest could also be an effect of answering in accordance with what would be socially desirable. For example, the students might think that they rate the seminar positive because they liked the social event or they felt indebted to the Physics Olympiad community for taking efforts to organize such an event. Better evaluation would move beyond self-report scales and assess the learning and behavioral level (e.g., Kirkpatrick & Kirkpatrick, 2016). For example, it was not assessed in the present intervention whether the students learned explicit problem solving or improved their content knowledge.

## Conclusions

Besides the shortcomings and limitations, the findings suggest that the social context was an important enabler for physics engagement and development of physics identity resources. Thus, this study supports the assumptions of situational learning theory (Lave & Wenger, 1991; Vygotsky, 1978) that stress the social nature of identity development. It was found that situational interest differentially impacted the development of sense of belonging which indicates that perceiving a social environment (here: the intervention) and the personal feeling of belonging to the communtiy are related with each other (see also: J. Wang & Hazari, 2018). Particularly, a high situational interest facilitated students' physics engagement and protected them from dropout. Consequently, social circumstances are important factors in physics engagement. Intervention strategies are well advised to address the social context in which physics is taught in order to raise gender inclusiveness, rather than primarily relying on changing the contents or the instructional method (however, these are also important). Particularly, female in-group experts as instructors, gender-balanced group work, challenging of gender stereotypes, and goal-congruent learning materials seem important features that have to be considered when designing intervention that seek to facilitate young women's physics identity development (see: Hannover, 2000; Kessels et al., 2006; Dasgupta, 2011).

The utilized learning materials and the implemented social learning environment seemed to have put no gender at a disadvantage (though no treatment checks were devised in this study). This would confirm the results in study 2 and 3 where the same learning materials were found to work well in contexts that are meant to support the physics engagement of young women. Furthermore, expectancy of success was an important predictor for persistence and future participation. This reinforces that necessity to align the difficulty level of the learning materials with students ability levels and competence beliefs (Bandura, 1977).

However, on a broad scale, physics identity development is not well understood. This study suggest that important identity resources such as sense of belonging can be increased through interventions also in the long run. However, no studies outline the mechanisms that increase sense of belonging. Furthermore, this study gives no further clues about the structure of physics identity as a theoretical concept. For example, Cribbs et al. (2015) established for mathematics identity that competence beliefs and performance are the foundation of mathematics identity while recognition and interest mediate the effects of competence beliefs on mathematics identity. Only hypotheses can be generated from the present study that would add to this model of domain identity. Expectancy of success and competition achievement, as a proxies for the identity resources competence beliefs and performance, were certainly the foundational for engagement in this intervention. For example, expectancy of success was predictive of further engagement and competition achievement was predictive of dropout. Both indicate that competence beliefs and acutal performance are a necessary condition for further developing physics identity through this kind of intervention. While it was not assumed that sense of belonging mediates effects of expetancy of success, it can be confirmed that sense of belonging can develop without affecting expectancy of success. Furthermore, this study did not utilize the identity item ("I see myself as a physicist.") that is often employed in physics identity studies (e.g., Hazari et al., 2010). Therefore, it could not be assessed whether the development in sense of belonging was related to physics identity as operationalized through this item. This study would have certainly benefitted from follow-up interviews (explanatory design) that shed light on the mechanisms that led students to develop sense of belonging.

# Chapter 8

# Discussion

Enrichment programs such as the Physics Olympiad are means to identify and promote potentially high-achieving students in physics. These programs strive to support students irrespective of students' characteristics such as gender. However, some physics environments such as the Physics Olympiad show large disparities in praticipation between gender–much higher than would be expected by ability distributions (see chapter 2). Female students show less overall engagement in the Physics Olympiade, e.g., they enroll to fewer proportion as would be expected by number of females in physics classrooms and they leave the Physics Olympiad disproportionally towards higher stages of the Physics Olympiad such that young men get increasingly overrepresented in higher stages. Research efforts to tackle the problem of female underrepresentation in physics and enrichment programs such as the Physics Olympiad addressed motivational, social, cultural, and structural mechanisms that potentially constrain the engagement for young women in physics environments, but failed to factor in the complex interplay between these mechanisms. This dissertation sought to probe effects of interventions that are considerate of multiple potential mechanisms that constrain young women's physics engagement in the context of the Physics Olympiad. Since a theoretical integration of findings for targeted interventions in the Physics Olympiad context was missing, a literature review was conducted in chapter 2. In particular, gender-related research in physics from multiple disciplines such as physics education research, social psychology, and anthropology was reviewed. A situated agency model was derived that is considerate of these literatures on female underrepresentation. Three levels of constraints for young women's physics engagement and agency were outlined in this model. The broadest level is the macro level of constraints which comprises mechanisms such as gender-related stereotypes that exacerbate young women's physics agency. On a finer grained scale, the meso level comprises constraining mechanisms for young women's physics agency particularly related to situational cues from social learning contexts in physics that potentially hamper young women's physics agency. The most detailed level is the micro level of constraint where individual motivations, attitudes, and interests can hamper young women's physics agency. This model informed the design of the intervention that were developed in the scope of this dissertation.

Two important assumptions followed from the situated agency model. First, for the discussion of young women's underrepresentation in physics, constructs such as interest or self-efficacy alone fall short to capture important factors that constrain young women's physics agency such as the sense of belonging to the physics community. Sense of belonging factors in the young women's perceived interaction with meaningful others in the physics community and reflects more embodied aspect of engagement (i.e., engagement need reinforcement from meaningful others). As such, the importance of the social context is emphasized for engagement. The social context lends much to feelings of isolation or perceptions of competence and thus should be reflected in the theoretical framing. Since social contexts and meaningful others (e.g., teachers, parents, peers) in physics tend to hold explicit or implicit gender stereotypes that negatively affect young women, the meaningful others are important instances in the theoretical framework. Overall, efforts to support young women's physics engagement without simultaneously adapting physics learning contexts seem not sustainable (e.g., Logel et al., 2009). Second, the intricate entanglement of an individual's cognitions and the social learning context can be partly captured in a situated agency model. For example, studies were presented that indicate that the group affiliation in a social context was more important than the things a student knew. Hence, a student's cognitions are related to the social context that she engages in (e.g., Eckert, 1990). Principles for interventions were then derived from the situated agency model and prior research. For example, equal gender ratio, female ingroup experts as instructors, or an integration of young women's motivations into the curriculum were identified as potentially effective factors that can be implemented. However, these findings were derived from studies with students not necessarily in STEM or physics. It is thus crucial to validate these findings for contexts of high-achieving students in STEM and physics, in particular, in order to get a handle on the mechanisms that particularly constrain high-achieving young women in physics.

In this dissertation a two-fold research effort was pursued in order to implement and evaluate interventions that supported the physics engagement for high-achieving young women. The context of the Physics Olympiad was considered to be a promising context for engaging high-achieving young women in physics. In order to advance the understanding of enabling and constraining mechanisms that relate to young women's physics engagement (as outlined in the situated agency model), study 1 applied a personal narratives approach to study facets of physics engagement of young women in the context of the Physics Olympiad. Studies 2, 3, and 4 build on findings from study 1 and addressed some of the outlined constraining mechanisms through interventions. Addressing constraining mechanisms was achieved through specifically designed learning materials and identity-considerate social learning contexts. Study 2 probed to challenge the mechanism of constraining physics image. In particular, study 2 sought to alter the physics environment in a way that challenged the traditional physics image of university students. This was meant to understand possible effects of an environmental adaptation on students' beliefs about physics. Similar to study 2, study 3 implemented and evaluated an intervention in the context of the Physics Olympiad, which was the focus for evaluation for this dissertation. Study 2 explored effects with regards to the physics engagement of the participating young women in this intervention and related these effects to physics identity development. This was important, because chapter 2 motivated that physics identity was an important predictor for long-term physics engagement and few studies explored design features that potentially relate to young women's physics identity resources. Based on findings from study 3, study 4 probed effects of a long-term intervention in the context of the Physics Olympiad on physics identity-related outcomes. Study 4 employed specifically designed learning materials based on studies 2 and 3, and an instructional context, and social context adaptations based on study 3.

The studies in this dissertation added insights related to the overarching goal of exploring effective strategies to raise gender equity in the context of the Physics Olympiad. The findings will be discussed alongside the specific RQs as outlined in chapter 3:

### RQ 1) What are facets of physics engagement for high-achieving young women that participated in the Physics Olympiad?

Study 1 (chapter 4) sought to explore facets of high-achieving young women's physics engagement in order to validate potential mechanisms as outlined in the situated agency model for the Physics Olympiad's context. A first finding was that the interviewed high-achieving young women in the Physics Olympiad depicted physics participation with regards to gender stereotypical notions (e.g., women are better in languages and reading). Gender appeared also in the interviews when the young women narrated about their engagement in the Physics Olympiad. For example, the young women reported that they also expected young women to be in a minority position in the Physics Olympiad. Stereotypical depictions and expectations about representation are mechanisms that are captured in the macro and micro level of the situated agency model. It was motivated in chapter 2, that gender stereotypes impact young women's physics engagement and agency. A smart girl in science is potentially less conceivable to students that construe girls as rather into languages (e.g., Steffens & Jelenec, 2011; Nosek et al., 2002). Such experiences likely impair the physics engagement and agency for these successful young women, and it is likely that these attributions require some young women to apply coping mechanisms in order to justify their physics engagement for themselves via-à-vis their social environment.

More enabling instances of physics engagement for the high-achieving young women were found to be supportive persons (teacher, parents, or peers) in the surrounding of the young women. Young women were found to report on meaningful support from teachers, parents, or peers that helped them to get engaged or persist in the Physics Olympiad. It seemed important for the young women to have someone who supported their engagement in order to engage in physics, a result that is buttressed by prior research (e.g., Mujtaba & Reiss, 2013; Hazari et al., 2017). The narratives of the high-achieving young women furthermore pointed to intrinsic motivation that drove the young women into physics. For example, the high-achieving young women narrated about mastery experiences that they felt when engaging in the physics problems of the Physics Olympiad and they construed themselves as competent physics problem solvers. The social support and the instrinsic motivation of the young women for physics were potentially enablers for these young women's physics engagement.

Taken together, study 1 could outline potential mechanisms that are also reflected in the situated agency model for the context of high-achieving young women in the Physics Olympiad. For example, gender stereotypical depictions seem to comprise a constraint to the physics engagement of the young women in the Physics Olympiad. Furthermore, the social context (e.g., teachers, parents, and peers) formed an enabler for physics engagement. Also, the outlined mechanisms in the situated agency model on the micro level, where individual cognitions such as self-efficacy and mastery experiences were connected to engagement, relate to the narratives of the young women. It was found that the intrinsic motivation for physics seemed to be constitutive also for the physics engagement of the interviewed young women.

### RQ 2) To what extent can specifically designed learning materials challenge the perceived physics image for university students who participated in the intervention?

In order to probe possible learning materials for an integrated intervention in the context of the Physics Olympiad, study 2 (chapter 5) utilized a historical case-study of Rosalind Franklin's seminal work in the context of the structural analysis of the human DNA in order to assess potential effects with regards to the students' physics image. The learning materials were designed to challenge the traditional image of physics (e.g., physics as low in empathizing features and high in fixed ability). Physics has a value-laden image that potentially constrains students' agency in physics learning environments (e.g., Kessels et al., 2006). The students in study 2 received learning materials that portrayed Rosalind Franklin and her (often unrecognized) contributions for the discovery of the DNA. In order to evaluate the effectiveness of the intervention, the physics image was assessed as dependent variable, and operationalized through empathizing features and fixed ability. Findings indicate that an alteration of the physics image was in fact possible. A main effect for time for the empathizing dimension of the physics image was found for both male and female students, irrespective of ethnicity. This means that all students increased their awareness that interpersonal conflicts can be part of physics, especially for female students. No such effect was found for the empathizing dimension of the biology image which was utilized as a control criterion. No changes in physics image were found with regards to fixed ability in physics image or biology image.

With regards to RQ 2, it can be said that the materials are a potential means for raising awareness for empathizing features in physics. The fixed effects dimension could not be changed for the students, though it should be noted that they started with unexpectedly low values in fixed ability. Whether similar effects of challenging the physics image with regards to empathizing features and fixed ability could also be observed in the Physics Olympiad context remains an unanswered question.

### RQ 3) To what extent can a specifically designed intervention enhance physics identity resources for participating young women?

Besides facets of physics engagement and challenging students' physics image, it was the goal of this dissertation to probe effects of an intervention on young women's physics identity resources, because the physics identity resources are connected to physics-related academic choices and engagement. Consequently, study 3 (chapter 6) sought to probe effects of an intervention on the physics-identity resources, interest, recognition, and competence beliefs/performance. Finally, possible relations of the physics identity resources and physics-related academic choices were examined. Study 3 utilized similar learning materials as study 2 in the Physics Olympiad context (chapter 5). In this short-term intervention the participating young women reported a particularly high situational interest for the intervention learning materials, compared to young men. This indicates that the young women were particularly positively affected compared to young men when engaging with these learning materials. Neither time nor gender effects were found for the recognition resource for physics identity. However, the young women, compared to young men, improved their competence beliefs in the Physics Olympiad and in physics classrooms. This means that the young women, who started with lower values in competence beliefs compared to young men, improved their competence beliefs to the level of young men throughout the intervention. Regarding physics-related choices, young women appeared to enlist in the next year's Physics Olympiad to a higher percentage compared to the overall female population.

In summary, it can be concluded that the design features of the intervention (equal gender-ratio, and cooperative group work) likely supported the young women in their physics engagement with regards to some physics identity resources–without depressing young men at the same time. These results raised the question whether similar effects would appear on a longer-term basis so that physics engagement for young women could be sustainably supported. In order to evaluate this long-term effects, study 4 was designed as the follow-up study.

**RQ 4) To what extent can a specifically designed long-term intervention facilitate physics identity development for participating young women?**

Study 4 (chapter 7) took a longitudinal perspective and sought to identify effects that occurred throughout an intervention that lasted over half a year with regards to young women's physics identity resources in the context of the Physics Olympiad. The situational agency model outlined the mechanisms that a positive interaction of the social context with the learner should have in the long term, namely that physics-related choices should be positively impacted. Consequently, the social context in the intervention in study 4 was adapted such that female in-group experts were the instructors, the gender ratio was approx. equal, and the instruction comprised, amongst others, cooperative group-work and hands-on experiments. These design elements were motivated based on prior research that showed that they can be identity-protective for young women. In order to assess development of physics identity resources, two physics identity resources, namely recognition (as operationalized through sense of belonging) and competence beliefs (as operationalized through expectancy of success) formed the dependent variables alongside physics-related academic choices. Results indicate with respect to the dependent variables sense of belonging and expectancy of success no time effects for the treatment group. In contrast, the control group improved in sense of belonging over time. The analysis of feedback revealed that the feedback on the design elements of the intervention was particularly positive for young women and men (feedback for instructors was almost consistently rated with the highest possible score). Further analyses suggested that situational interest had a significant interaction with time on sense of belonging such that students that reported a higher situational interest increased their sense of belonging more over time compared to students who reported a lower situational interest. Regarding actual and intended physics-related choices, it was found that the young women in study 4 were more likely to enroll in the next year's Physics Olympiad compared to the overall olympian population, which replicated the finding from study 3. Further enrollment in the next year's Physics Olympiad was significantly related to competition achievement, science peer relations, and situational interest, which suggested that the intervention potentially contributed to further enrollment. Findings for changes in study intent indicated that both dependent variables (sense of belonging and expectancy of success) at time 5 were significantly related to study intent at time 5. This supported the importance of the dependent variables in evaluating the intervention.

Study 4 provided evidence for different mechanisms that are outlined in the situated agency model. For example, the sense of belonging to the Physics Olympiad community seems malleable with identity-considerate interventions. Furthermore, identity-considerate interventions over an extended period of time seem to have the potential to enable young women's physics engagement as evidenced through increased enrollment in the next year's Physics Olympiad as compared to the overall population. Finally, expectancy of success as a competence belief seems to moderate enrollment and dropout.

## 8.1 Limitations

The studies in this dissertation sought to illuminate strategies to facilitate physics engagement for young women in the context of the Physics Olympiad and beyond. Subsequently, specific limitations that relate to the designs and methods of the studies will be discussed, followed by a reflection on general limitations to the conclusions of this dissertations that follow from the setting and utilized constructs for this dissertation.

Specific limitations to generalizability of the results from study 1 arose, amongst others, from the selected sample and from the interview setting that the young women experienced. Regarding sample, the interviewed young women were amongst the highest-achieving young women in the context of the Physics Olympiad. Therefore, the experiences of the interviewed young women cannot be generalized to young women who dropped out of the Physics Olympiad at earlier stages, because young women who dropped out at earlier stages might construe their engagement differently due to different feedback they received in their engagement. Regarding context, the interview context in study 1 posed constraints to generalizability of the results. For once, the young women in study 1 (part A) were interviewed by a male mentor of the Physics Olympiad staff. This might have posed the risk that the young women might not share all their experiences as they might have otherwise, e.g., when a female external researcher might have interviewed them. This mechanism is plausible based on the reviewed literature (see chapter 2) where gender-identity is amongst the first group identities that becomes salient in social contexts and impacts cognition. Furthermore, the interview context did not specifically motivate the young women to narrate on experiences of social exclusion or gender discrimination that they might have experienced. This potentially distorts the picture that study 1 presents of the young women's experiences in the context of the Physics Olympiad, because potential constraining mechanisms (that might well exist, see Steele, 1997) for the young women remain unidentified.

For study 2, specific limitations for generalizability of the results resulted from the small sample size that decreased statistical power to find an existing effect. The time effect for empathizing could have occured by mere chance, such that generalizability to a population of students is not possible. Furthermore, the design features in the intervention were complex and it is likely that multiple design elements impacted the students' construal of physics image. The physics background of the instructors could have also impacted the students' perceived physics image because this was the first time the students experienced this instructor (i.e., the author) in this course. Since the materials were hands-on and affectively appealing (large laser diffraction pattern), these contextual factors could have contributed students to change their physics image.

Similar limitations as for study 1 and study 2 also apply for study 3. With regards to generalizability of results the small and selected sample appears to be problematic. The sample appeared to be a selective subsample of the overall olympian population. Only a fraction of the invited participants enrolled to participate in the intervention. Since no information on students who did not enroll for the intervention was available, comparability of the sample could not be assessed so that generalizations with regards to the overall population cannot be made. The small sample size threatens generalizability, because the statistical power was reduced. The small sample size increases the likelihood to fail in detecting existing effects (e.g., Bortz & Döring, 2002). Furthermore, gender differences in the sample appeared for age, which raises issues of comparing female and male students, because age can be an important moderator variable. Finally, the high initial motivation of the participants for physics and the Physics Olympiad pointed to constraints in interpreting the high enrollment rate in the next year's Physics Olympiad. For example, the fact that these students were already more motivated to participate in the Physics Olympiad compared to the overall Olympian population could have caused the difference in enrollment in the next year's Physics Olympiad.

Specific limitations for study 4 relate to the dropout throughout the intervention and to initial group differences in the sample. Dropout in study 4 posed threats to the validity of the conclusions. The dropout analysis in study 4 indicated that dropout from the intervention appeared primarily related to achievement in the competition, gender, and situational interest. Students with lower achievement in the Physics Olympiad, males, and students with lower situational interest were more likely to drop out, after adjusting for the other variables. Thus a positive selection effect appeared with regards to these variables, meaning that only students with a higher achievement in the competitions, females, and students with a higher situational interest persisted. This means that dropout was not random and the found effects for the intervention might not generalize to the students who dropped out. Furthermore, it appeared that the control group started with significantly lower values in the dependent variable sense of belonging. This causes threats to comparability of the treatment with the control group because students with an initial lower sense of belonging had more opportunity for improving their lower sense of belonging. Longitudinal research often yields effects where students with lower initial values have a more positive development compared to students with higher initial values (Long, 2012).

Abstracting from the individual studies, more general limitations for the interpretability of results for this dissertation relate to the special settings of enrichment programs that the studies were situated in and to the utilized constructs of agency, engagement, and physics identity. The settings of the Physics Olympiad restricted the studies to selected samples of students who are interested in physics above average and who have often been selected by their teachers to be eligible for participation. The selectiveness of students constrains the studies to be explorative and hypothesis-generating in nature, because otherwise it is unclear how other students might have experienced the interventions. The context of the Physics Olympiad also restricted the sample sizes to be small, because students needed to be recruited on the basis that they agreed to travel far from home and meet unfamiliar students. The overall pool of students comprised only approx. 150 young women who were eligible for participation based on the design requirements for the interventions. Design required the young women to be young enough to participate in next year's Physics Olympiad and to be high-performing so that they advanced to the second round of the Physics Olympiad. These requirements ensured that young women's physics engagement could be tracked over longer periods of time and that the young women were likely to be intrinsically motivated for physics. Researchers have argued that a direct transfer of results for high-achieving young women onto less achieving young women is not warranted because these groups face different kinds of issues (e.g., Steele, 1997). This difference threatens generalizability of the findings in this dissertation.

The present studies employed the constructs agency, engagement, and physics identity. These constructs were operationalized through self-report scales. However, self-report scales comprise the most shallow level of evaluation, where more performance based measures are expected to yield an in-depth evaluation of educational programs compared to self-report scales (e.g., Kirkpatrick & Kirkpatrick, 2016). Large parts of students' identity are not accessible through self-report constructs such as utilized in studies 2, 3, and 4. The utilized constructs also relate to a more quantitative research paradigm and address narrated, self-conscious parts of identity (Kane, 2016). However, it has also been argued that identity is ingrained into students' cognitions and behaviors such that access to narrated identity captures only a fraction of a students' identity. It is particularly problematic that these variables only account for individual students' conceptions, rather than measures of students' actual interactions that have been found to be predictive for development of physics identity resources (e.g., Dou et al., 2016).

Furthermore, the situated agency model is considered to be a conceptualization of constraining mechanisms for young women's physics engagement. In this dissertation, it functioned as a theoretical framework rather than a testable model that would outline viable ways to faciliate physics engagement for young women. The situated agency model fails to provide a conclusive rationale for the design of gender inclusive physics classrooms or for policy measures that potentially improve young women's physics engagement. Therefore, this model could not have been tested in the present dissertation and (despite its theoretical value) it remains unclear how the model can guide equity efforts in physics. Potentially, much finer grained models are necessary that outline specific mechanisms that might constrain young women's physics agency and engagement (e.g., Kessels & Hannover, 2002). There are also no specific pathways to an instructional theory for genderinclusive physics that would be needed in order to promote school physics.

Once again, the explorative and hypothesis-generating nature of the studies in this dissertation needs to be stressed. This nature resulted from specific circumstances during implementation of the four studies, overall design decisions and utilized constructs for the studies.

## 8.2 Implications and conclusions

The findings in this dissertation bolster some of the theoretical underpinnings of the situational agency model.

- The situational agency model emphasizes the role of social immersion into the physics community as centrally important. For example, as would be expected from the stereotype inoculation model, female in-group experts likely protected young women's physics engagement (see chapter 2). As also suggested in the research by C. Good et al. (2012), sense of belonging proved to be an important construct in this dissertation, because it was positively related to situational interest as shown in study 4. This points to the malleability of sense of belonging through intervention. Sense of belonging also relates to the reported social ostracism for some of the young women in study 1 that they experienced in their respective physics environments. Stigmatization and social ostracism lead to isolation, and–in reference to the belongingness hypothesis and attachment theory (Baumeister & Leary, 1995; Bowlby, 1969)–these are amongst the most distressing experiences that a student can make due to her or his commitment in social environments. Erikson (1963) identified isolation in adolescence as a lever for what he called exclusivity, meaning that the ability for social functionings (e.g., commitments to others) are deprived.

- The situational agency model also emphsizes the importance of the situational context for agency and engagement in physics. Findings from study 4 support the claim that an identity-protective environment (i.e., where gender is not emphasized) would facilitate identity development, agency, and engagement for young women in physics. This is because the perception of a high situational interest was related to positive development of sense of belonging, a measure closely linked to recognition.

- Finally, the situational agency model is based on social-cognitive learning theory. The appropriateness of social-cognitive learning theory for tackling female underrepresentation in physics can be stressed on the basis of this dissertation. Social-cognitive learning theory establishes the role of agency in social settings where experiences of personal or collective agency are factors for engagement. Meaningful others have important functions in this theory because they provide role-models that enable vicarious experiences for agency and encourage the students (Hazari et al., 2007). Furthermore, social-cognitive learning theory emphasizes the role of mastery experiences, and feelings of competence for engagement in a domain. The feeling of mastery experiences appeared in the narratives of the high-achieving young women in study 1. Mastery experiences comprise an important source for young women's physics engagement and physics identity development. It was furthermore shown that study 3 improved the competence beliefs such that it can be concluded that the social context was affirmative for the young women with regards to their physics identity resources.

Given the nature of this dissertation, final implications and conclusions will be discussed with regards to prolonging the research efforts that have been started in this dissertation in order to make design, implementation, and evaluation of the studies stronger and potentially affect the physics community. In particular, the following three topics will be discussed: 1) empirical educational research on physics identity, agency, and engagement, 2) the design for interventions and conceptualization for strategies in physics with the goal to raise gender equity, and 3) the discourse about gender equity in physics.

### 1) Empirical educational research on physics identity, agency, and engagement

Carlone and Johnson (2007) contended that an operational definition of identity is pending such that researchers need to present a broad conceptualization of the constructs in order to get ”methodological and analytic direction” (Carlone & Johnson, 2007, p. 1189). Sociological, social-psychological, and educational research accumulated empirical evidence that buttress facets of identity development. By implication, important connections were captured in the situated agency model that can function as a research model to outline potential mechanisms that constrain young women’s physics engagement in the context of the Physics Olympiad and in physics classrooms. With the situated agency model, a critical perspective is endorsed in order to help changing the problem of female underrepresentation in physics through research. Critical perspectives include the questioning of taken-for-granted assumptions of engagement, e.g., that high-achieving young women are well integrated in the physics community. Findings from study 1 suggest that even for these young women constraints such as stereotypical notions and social isolation impair physics engagement. The requirement of critical research and complex constructs (identity, agency, and engagement) motivates the integration of qualitative and quantitative research methods in order that findings can be triangulated and taken-for-granted assumptions that might be inscribed into closed-form questionnaires can be detected. Education research is particularly powerful when qualitative and quantitative data mutually inform each other (e.g., Creswell, 2003). A mere quantitative assessment might conceal experiences that students made (see: Lykkegaard & Ulriksen, 2016; Stake & Mares, 2001). For example, students might be reactant to disclose their change of personal attitudes in a questionnaire[1], but they might be more responsive to a dialogic situation such as a personal interview where rapport is created.

For both qualitative and quantitative studies care should be taken for conceptualizing the scope of impact that the intervention might have. Researchers noted that ”perhaps the greatest challenge has to do with finding the appropriate level of specifity for measurement” (Tschannen-Moran, Woolfolk-Hoy, & Hoy, 1998, p. 219) of self-reported efficacy scales. It is usually desirable to achieve

---

[1] Instructive are the examples where adolescents are taught that smoking is bad and they liked smoking in the post measure even more (this and other examples for adolescent reactance in: Oyserman, 2015)

change in measures such as the sense of belonging to the physics community that have a broad scope. However, what interventions more likely do is change the perceived sense of belonging more specific to the context the students acted in (e.g., the Physics Olympiad). Measures for physics identity resources should be contextualized (belonging to the physics community versus belonging to the Physics Olympiad community) in order to be closely tied to the student's experiences and in order to track changes that alterations in the Physics Olympiad environment can make. What exactly the context is, remains an open question. Even when asked for expectancy of success in the Physics Olympiad, different students might associate the term Physics Olympiad with different instances based on their prior experiences in the Physics Olympiad. Guidelines for item design for evaluation studies with educational programs would have to include a discussion of the desired context.

Assessing identity, agency, and engagement should be supplemented by measures that are reflective of student's experiences in the social contexts. In this dissertation, closed-form questionnaires were most widely applied. More novel measures in order to capture students' experiences could include diary studies that have been utilized to assess autonomy in science classroom settings (Patall, Vasquez, Steingut, Trimble, & Pituch, 2017). Diary studies might even capture more motivational mechanisms for students, because writing about experiences is seen as a process of self-clarification and self-assessment (see also "saying is believing technique": Aronson, Fried, & Good, 2002). Such novel measures could even fulfill another goal, namely to motivate students to participate in social science surveys. Participation in questionnaires was identified as a growing concern for social research (Bijleveld, Catrien C. J. H. et al., 1998). Also in the present study 4, dropout was a major limitation for generalizability of the findings. Measures that are tied to students' experiences might leverage new motivations for students to feel more involved such that overall persistence might be positively influenced.

As with the studies in this dissertations, the use of within-person assessment of target constructs seems advantageous in order to identify developmental mechanisms for identity. In particular, within-person assessment that is tied to students' experiences may give access to self-reflected aspects of agency, within-person effects and developmental processes of identity (see: Gelman & Loken, 2013). In order to illuminate the developmental processes, measures that are reflective of the social context are important to include. Heinicke, Paffhausen, Zeisberg, and Diehl (2017) found that young men showed assertiveness in experimental sessions in physics which constrained young women's roles during experimental sessions to minute takers. These findings suggest to include measures where young women and men are asked for their roles during experimentation and where actual roles are registered.

Studies 1, 3, and 4 sought to measure facets of physics agency, engagement, and physics identity in the context of the Physics Olympiad. However, the instruments for measuring these constructs are in development. Concerning identity assessment, Lichtwarck-Aschoff et al. (2008) motivated a finer-grained conceptualization of identity. Since the notion that a student has an identity (or not) is dichotomizing and thus likely to be a poor conceptualization (e.g., D. L. Schwartz, Cheng, Salehi, & Wieman, 2016), these efforts are necessary for better understanding of identity. Lichtwarck-Aschoff et al. (2008) distinguished a mirco-macro dimension and a dynamic-static dimension for measuring identity. In the current dissertation, identity was mostly conceived on the macro-static level (i.e., self-reports of sense of belonging). However, nuanced measures (as, for example, in diary studies) might even unveil the structure and development of the physics identity resources in social contexts. Identity relates also to performing in a social context, and therefore social network measures can be another promising means for contextualized understanding of identity. For example, Dou et al. (2016) sucessfully employed a social network lens to measure self-efficacy in physics of students based on algorithms that capture the income/outome metrics of student interactions with each other. It can be expected that the dynamics in classrooms, as measured through social network metrics, capture also facets of agency (a construct closely related to self-efficacy) and even physics identity because the immersion in social networks is an indicator for identity achievement.

### 2) Designing interventions and conceptualizing strategies in physics with the goal to raise gender-equity

A viable means to incite policies for raising gender equity in physics are targeted interventions. The studies in this dissertation yield some implications of how the findings can be transferred to physics instruction in regular physics classrooms. However, intervention can also relate to the institutional level where gender equitable policies and strategies should be devised. As suggested with the situated agency model, engagement in physics is a complex process. Panacea strategies are unlikely to exist and versions of them were shown to be ineffective. A more rigorous orientation to empirical research seems necessary. Figure 8.1 depicts the logic of the implementation (evaluation model) and perpetuation of efforts related to interventions such as the studies in this dissertation. Based on the findings from study 4 (upper intervention cycle in Figure 8.1), the results can be utilized to inform the redesign of a follow-up intervention. On top of the learning materials that are established and the adaptation of the social context (equal gender ratio, female in-group experts as instructors), further motivational interventions (e.g., growth-mindset, values affirmation; see chapter 2) can be implemented that were also outlined in chapter 2 and that can potentially further support gender equity interventions in the context of the Physics Olympiad.

In keeping with the situated agency model, intervention strategies have to be conceptualized on the basis of macro, meso, and micro levels of constraints for engagement: traditional gender stereotypes, situational cues that might pose identity threat, and individual motivations and goals that need to be reflected in the curricula. Therefore, the intervention studies in this dissertation were designed to specifically address the physics identity resources for students because the physics identity resources were found to predict engagement in physics. Strategies should include acquisition of female role-models. As predicted by stereotype-inoculation theory and self-to-prototype matching the inclusion of female in-group experts as mentors seems to support agency and engagement for young women in physics. More research is necessary to shed light onto the mechanisms that lead from positive perception of instructors to development of physics identity resources. Stereotype-inoculation theory and self-to-prototype matching also predict that group constellation positively influences female engagement in physics contexts. Group work with homogenous gender groups can

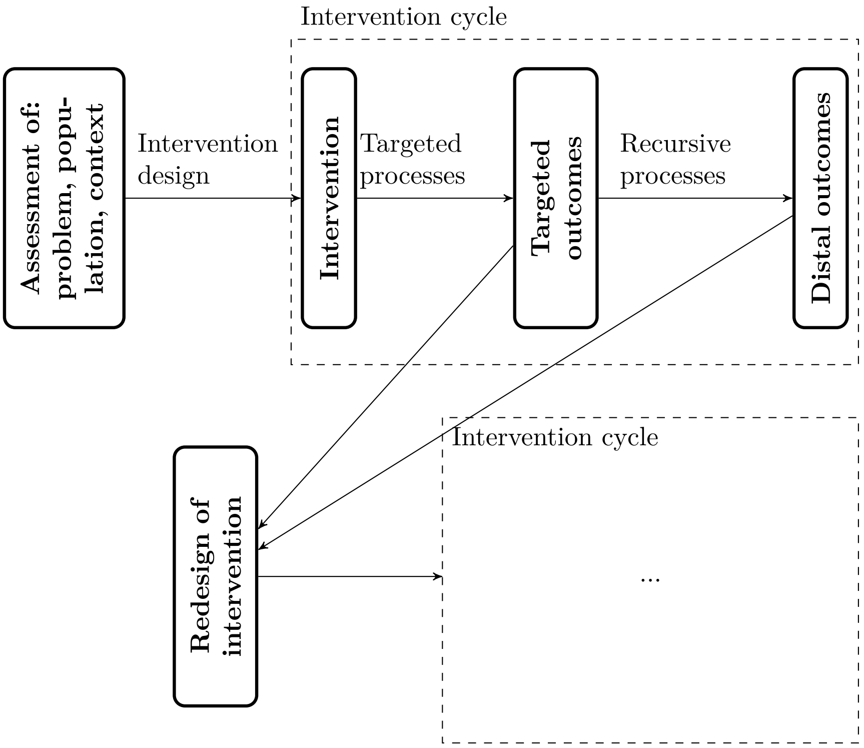


Figure 8.1: Revisited: conceptual model of targeted interventions.

be utilized as a means to facilitate identity-protective environments for young women where young women can better explore learning materials without interference of young men. The learning materials can include famous female scientists (e.g., Rosalind Franklin) in order to promote self-to-prototype matching. Struggles of famous scientists should be elaborated, because young women otherwise potentially develop the conviction that they need to be especially talented to achieve at the depicted levels (e.g., Ziegler, 2004; Lin-Siegler et al., 2016). Providing role-models for young women is not restricted to women. Drury et al. (2011) supported the idea that males should function as well as role-models and mentors, so that diversification is not seen as a female issue but rather a societal issue (see also: Hannover & Kessels, 2004; Marx & Roman, 2002). The critical question here is which qualities characterise effective male role-models for young women. Further research is necessary to advance understanding of such characteristics.

Strategies for raising gender equity in physics start as early as pre-kindergarten. It has been shown that gender stereotypes become relevant in early education (Bian et al., 2017) and become part of students' identities, where schools as mainstream institutions are major reinforcing instances for gender stereotypes (e.g., Olitsky, 2006). Mainstream physics classrooms are powerful instances that might nullify positive effects in extra-curricular interventions due to traditional expectations of young women. Challenging these institutions at primary and secondary school level is imperative to promote gender equitable learning environments in STEM from early on such that young women and men develop the expectations that females and males can equally be normal scientists. Even worse, engagement in extra-curricular programs such as the Physics Olympiad could have also led to more stigmatization in regular school, especially for the young women (e.g., Ziegler, 2004; Tirri, 2002). Identification with a geeky identity was documented to be particularly challenging for young women (see chapter 2), such that the education community has to find ways that challenge processes of stigmatization and social ostracicms for young women who immerse themselves into enrichment programs. It was found that peer pressure to fit into feminine identity was a factor that constrained young women's physics engagement in enrichment programs (e.g., chapter 4). A valuable effort to connect young women and facilitate recognition is the cyber-mentor program (Stoeger, Duan, Schirner, Greindl, & Ziegler, 2013). The program is successfully implemented and particularly relates to the belongingness and recognition for young women in STEM. Teachers in regular schools or mentors in enrichment programs should inform their female students who are interested in physics about this program. The cyber-mentor program goals relate well to the assumption in the situated agency model that recognition and social belonging are fundamental needs that have to be addressed in order to facilitate physics engagement for young women.

Finally, specifically designed learning materials that are reflective of young women's motivations and goals are a viable means to challenge traditional notions of physics and promote gender equity. Easy strategies for promoting gender equity include surface adaptations of learning materials such as coloring or depicting more female scientists. More difficult to implement is the design of learning materials that address also the deep structure such as conceptual coherence and clarity of presentation. McNamara, Kintsch, Butler Songer, and Kintsch (1996) demonstrated that less experienced learners benefit from high coherence in learning materials, compared to more experienced learners who benefit more from incoherent learning materials. In this context, it was found that young women in physics have less prior experience with physics content and equipment compared to young men. Hence, coherent learning materials would particularly benefit young women. In order to develop conceptually coherent learning materials, a cycle of iterative design is necessary that is reflective of the targeted population, e.g., students in the Physics Olympiad. The learning materials (see appendices B to D) in this dissertation can be considered a first draft to develop coherent learning materials. In order to select contexts for the learning materials, the physics identity resources are a viable guide. Prior research provided evidence that competence beliefs (such as expectancy of success) are central for engagement. Scaffolding with regards to competence beliefs such as explicit instruction of problem solving enable mastery experiences and facilitate students' physics engagement. A variety of difficulty levels in the problems gives rise to a better reflection of variability in students achievement levels. Students are then encouraged to ask more questions to each other and engage in the learning materials as suggested in Active-learning instruction in physics and peer instruction (Mazur, 1997). The physics identity resources of recognition and interest further motivate the implementation of contexts that depict female scientists as expert role-models and relate to medicine and human body.

### 3) Discourse about gender equity in physics

In chapter 1 the DPG and APS concerns for "policies and procedures that give the same opportunities and encouragement to the study of physics by girls and boys," and impoving "the recruitment, retention and treatment of women in physics at all levels of education and employment" were introducted. "Policies and procedures" particularly relate to the macro-level constraints of agency and engagement. Effective strategies need to consider the level of discourses, where discourses relate to local facts in a social context that are considered true by the students. On the basis of the situational agency model and the four studies in this dissertation the following conclusions will be made for challenging the traditional discourse in physics (i.e., physics is for male geniuses): raising knowledge about gender inequity in physics insitutions and integrate female and male motivations into curricula and learning practices in physics.

Knowledge about gender inequity entails the knowledge about traditional organization of society and the changes that are necessary in modern society in order to empower young women to fully engage in a technology reliant world. This will be an effort for both women and men, since Beck (1986) registered that the unresolved tensions that arise from young women that strive into traditionally male dominated fields can produce conflicts. It is important to challenge gender stereotypes in classrooms. It was found that cognitive skills are malleable and changing life conditions (e.g., social stereotypes and contexts) will have lasting influences on cognitive abilities. Especially what meaningful persons such as teachers think of their students is intricately linked to what the students feel themselves capable of achieving and becoming. These ideas need to be implemented in school curricula, in order to fuel students' understanding of societal mechanisms that constantly reallocate roles and responsibilities amongst individuals. Explanations of gender differences have to acknowledge the historical organization of societies and the advances in technology that enable humans to restructure responsibilities and roles. It is also important to emphasize that no sound scientific evidence suggests that either gender is by nature more able for STEM occupations or that differences are not retrainable if society is in favor of it. The most convincing evidence for this is the emancipation of women over the last century (see: Eagly et al., 2004).

However, it seems particularly difficult to implement these ideas into policies and curricula, and societal pratices. The identity-based cognition research points to the fact that students endorse or reject stereotpyes based on how this makes them appear in their peer-group, rather than on the basis of what they know. Therefore, simply addressing stereotypes in mainstream educational institutions is likely to be ineffective, as was evidenced by the backfiring in the EU strategy to make physics girly. The simple acclamation that females are able to do physics was considered a poor strategy for challenging stereotypes. Research such as intergroup contact theory posits that under certain conditions intergroup contact is one of the most effective ways to reduce prejudice between groups (Allport, 1954). Young women and men have to be taught together (Halpern et al., 2011) so that they develop shared behavioral norms that are mutually endorsed by young women and men.

Integrating female and male motivations into physics curricula is necessary, because it has been registered that the physics curriculum is narrow, and the views about who could be a physics person are constrained particularly to males (Nespor, 1994; Eisenhart & Finkel, 1998). The average student considers physics as uncreative (e.g., Hannover & Kessels, 2004) and hardly take meaningful experiences from their physics instruction as measured through failing rates in post-secondary concept inventories (see: Wieman & Perkins, 2005)–it was estimated that something like 20 percent of undergraduates in university master the force concept as measured through the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992). For women, this dissertation has mustered a plethora of mechanisms that constrain their engagement and thus preclude them from excelling in concept inventories such as the Force Concept Inventory. Raising gender equity can facilitate better outcomes in these inventories. In order to raise gender equity in physics, more motivational research findings need to be considered when designing curricula and best-practice examples for instruction, such as the reform based Active-learning in physics by AAPT and APS (see chapter 2). A significant reduction of content load in traditional curricula and an integration of aspects of what a physics identity entails are but two aspects of what curriculum designers should be wary about. Curricula in physics have a blind spot of what it socially means to engage in physics and performing a physics identity. Baron-Cohen (2012) introduced the idea that systemizing thinking and autism are related with each other and encourages society at large to more appreciate these thinking styles. An adequate reflection of physics identities and a repertoire of how to navigate social contexts with a physics identity might benefit young women who, on average, struggle to pick up a geeky identity. Curriculum developers should furthermore integrate the motivations of why students should value physics contents. In traditional curricula these aspects appear only marginally. However, boys get these values in their early socialzation (their peers endorse them too). A gender inclusive curriculum would make these values transparent so that particularly young women are more motivated to engage with the materials.

Overall, supporting engagement for young women in physics can be conceptualized through the reflection of agency, as outlined in social-cognitive learning theory. In line with the situated agency model, agency in physics learning contexts for young women evolves when the learning context is responsive to motivations and identities of the young women and thus free from implicit and explicit biases (e.g., traditional gender stereotypes). Young women should be given more opportunities to experience themselves as competent problem solvers in physics and deal with personally relevant contexts (e.g., DNA diffraction experiments) that they can discuss with their peers who recognize the young women in their competence. These experiences would facilitate young women in developing an identity as a physics person.

# Appendix A

# Materials study 1

Table A.1: Interview topics and sample questions in study A.

| Topic | Sample questions |
|---|---|
| Introduction of interviewer | The interviewer welcomed the participants and presented his own background. This was followed by presenting the purpose of the study (improve the competition). |
| Motivations to participate in the Physics Olympiad | How did you first got in contact with the Physics Olympiad?; What do you particularly like about the Physics Olympiad? |
| Student's perception about gender-differential engagement | To your opinion, what would be hurdles for students to not participate in the Physics Olympiad? |
| Measures that could be taken to promote adolescent girls in the Physics Olympiad | What measures could you think of that particularly help female students in the Physics Olympiad? |
| Positive experiences in the Physics Olympiad | Why is the pre-final stage of the Physics Olympiad interesting to you? |

Table A.2: Interview topics and sample questions in study B.

| Topic | Sample questions |
|---|---|
| Introduction of interviewer and purpose of study | The interviewer explained her background and mentioned the purpose of the study (improve the competition) |
| Experiences when first encountering the Physics Olympiads' problems | "How did you first got in contact with the Physics Olympiad?" |
| Support from parents, peers, and teachers in physics engagement | "Where do you take your motivation from to deal with such hard physics problem. Do you get supported by family/teachers/peers" |
| Positive experiences during participation in the Physics Olympiad | "What is the most interesting thing that you learned in your participation in the Physics Olympiad?" |
| Negative experiences in the Physics Olympiad | "Have you had experiences where you didn't wanted to participate further?" |
| Measures that could be taken to promote their own engagement in the Physics Olympiad | "Imagine you could come up with supporting features in the Physics Olympiad. What would you think would be most important?" |

Table A.3: Selected scales used in the questionnaire to all participants.

| Scale | Source | Sample items |
|---|---|---|
| School grades, age, SES | Frey et al., 2009 | What is the highest educational certificate of your father/mother? |
| Support by parents (additionally in study 2: peers and teacher) | Hoffmann et al., 1998 | My teacher supports me actively in my physics engagement. |
| Gender role inventory | Kessels, 2002 (only in study 2) | Which of the following adjectives describes yourself appropriately/inappropriately? (emotional, lazy, intelligent, .) |
| Interest in subject physics and content | Hoffmann et al., 1998 | Please indicate how much you like the following subjects (physics, math, computer science, German, .) |
| Attitudes towards gender stereotypes related to physics | Hoffmann et al., 1998 (only in study 1) | Girls are less talented in physics than boys are. |
| Motivations to participate in the Physics Olympiad | adapted from: Blankenburg et al., 2015 | Study 1: How important were the following aspects to your participation? Challenging tasks/ Meeting people with similar interests/ Material reward/ . |
| | study 1: 5 items on challenging tasks, meeting others, material reward, authentic environment of how scientists work, and compete with others<br>study 2: 15 items on dimensions competence, autonomy, social, recognition, and prospective job | Study 2: I would participate at a competition, if I learn something new in content/ meet people with similar interests/ . |

## Appendix B

# Materials study 2

Table B.1: Ethnicity differences in sample.

| | Ethnicity | | | |
|---|---|---|---|---|
| Scale | Asian | African Am. | Hispanic | White |
| GPA | 20.00 | 25.00 | 21.62 | 23.67 |
| Age | 25.00 | - | 24.43 | - |
| ACT | 1540.00 | 1250.00 | 1642.50 | 1950.00 |
| SAT | 3.14 | 2.86 | 2.93 | 2.91 |

Table B.2: Overview of measures with interval scale (male/female).

| | Physics | | | | Biology | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measure[a] | female | | male | | female | | male | | $F_{\mathrm{Ge}}$[b] | $p$ | $F_{\mathrm{Gr}}$ | $p$ | $F_{\mathrm{Ge}\times\mathrm{Gr}}$ | $p$ |
| Emp | 2.13 | 0.61 | 2.90 | 1.37 | 3.50 | 1.44 | 3.45 | 1.52 | 0.87 | .35 | 8.87 | $< .01$ | 1.29 | .26 |
| Syst | 4.75 | 1.49 | 4.45 | 1.12 | 5.38 | 0.62 | 4.75 | 1.44 | 2.00 | .16 | 2.18 | .15 | 0.23 | .64 |
| Fix | 2.59 | 0.95 | 2.52 | 0.68 | 2.12 | 0.75 | 2.80 | 0.86 | 1.77 | .19 | 0.75 | .39 | 2.56 | .12 |

[a] Note that Emp refers to empathizing, Syst to systemizing, and Fix to fixed ability theory.

[b] $F_{Ge}$ refers to gender effects, and $F_{Gr}$ refers to group effect.

Table B.3: Correlation table of measured variables.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 Systematizing physics | - | 0.45** | 0.31* | 0.21 | -0.26 | -0.08 | 0.06 | -0.11 |
| 2 Systematizing biology | | - | 0.19 | 0.34* | -0.11 | -0.22 | -0.03 | -0.06 |
| 3 Empathizing physics | | | - | 0.68*** | 0.08 | 0.21 | -0.13 | -0.03 |
| 4 Empathizing biology | | | | - | 0.22 | 0.22 | 0.15 | -0.23 |
| 5 Fixed ability physics | | | | | - | 0.77*** | 0.1 | -0.22 |
| 6 Fixed ability biology | | | | | | - | -0.08 | -0.13 |
| 7 Content knowledge | | | | | | | - | -0.04 |
| 8 Quiz | | | | | | | | - |

Table B.4: Repeated measures ANOVA for Empathizing physics.

| Effect | DFn | DFd | $F$ | $p$ | $\eta^2$ |
|---|---|---|---|---|---|
| Gender | 1.00 | 20.00 | 0.99 | .33 | 0.04 |
| Time | 1.00 | 20.00 | 16.41 | $< .001$ | 0.15 |
| Gender:Time | 1.00 | 20.00 | 2.50 | .13 | 0.03 |

Table B.5: Repeated measures ANOVA for Empathizing biology.

| Effect | DFn | DFd | $F$ | $p$ | $\eta^2$ |
|---|---|---|---|---|---|
| Gender | 1.00 | 21.00 | 0.83 | .37 | 0.03 |
| Time | 1.00 | 21.00 | 2.43 | .13 | 0.02 |
| Gender:Time | 1.00 | 21.00 | 3.18 | .09 | 0.02 |

Table B.6: Repeated measures ANOVA for Systematizing physics.

| Effect | DFn | DFd | $F$ | $p$ | $\eta^2$ |
|---|---|---|---|---|---|
| Gender | 1.00 | 21.00 | 0.12 | .73 | 0.00 |
| Time | 1.00 | 21.00 | 2.89 | .10 | 0.04 |
| Gender:Time | 1.00 | 21.00 | 0.09 | .77 | 0.00 |

Table B.7: Repeated measures ANOVA for Systematizing biology.

| Effect | DFn | DFd | $F$ | $p$ | $\eta^2$ |
|---|---|---|---|---|---|
| Gender | 1.00 | 21.00 | 1.21 | .28 | 0.04 |
| Time | 1.00 | 21.00 | 0.07 | .80 | 0.00 |
| Gender:Time | 1.00 | 21.00 | 0.52 | .48 | 0.01 |

Table B.8: Repeated measures ANOVA for Fixed ability physics.

| Effect | DFn | DFd | $F$ | $p$ | $\eta^2$ |
|---|---|---|---|---|---|
| Gender | 1.00 | 24.00 | 0.00 | .95 | 0.00 |
| Time | 1.00 | 24.00 | 2.88 | .10 | 0.02 |
| Gender:Time | 1.00 | 24.00 | 0.13 | .72 | 0.00 |

Table B.9: Repeated measures ANOVA for Fixed ability biology.

| Effect | DFn | DFd | $F$ | $p$ | $\eta^2$ |
|---|---|---|---|---|---|
| Gender | 1.00 | 24.00 | 1.76 | .20 | 0.06 |
| Time | 1.00 | 24.00 | 0.40 | .54 | 0.00 |
| Gender:Time | 1.00 | 24.00 | 3.21 | .09 | 0.03 |

# Appendix C

# Materials study 3

## Grundlagen zu Wellen

### Elektromagnetische Strahlung als Welle – Eine Einführung

#### Was zählt zu Elektromagnetischer Strahlung?

Sichtbares Licht, wie der Mensch es zum Sehen benötigt, aber auch Röntgenstrahlung, Mikrowellenstrahlung, Radiowellen, Infrarot- und Ultraviolettstrahlung sind aus physikalischer Sicht ein und dasselbe, nämlich Elektromagnetische Strahlung. Was genau aber Strahlung ist, ist eine der spannendsten Fragen in der Physik. Ein bereits über ein Jahrhundert andauernder Streit in der Physikwelt dreht sich um diese Frage. Nach heutigem Wissen ist Strahlung sowohl Welle als auch Teilchen. Je nach Versuch zeigen sich andere Eigenschaften von Strahlung, die einmal der Welle zugeordnet werden und ein anderes Mal dem Teilchen. Einige Versuche (z.B. Photoeffekt) können mit der Wellenvorstellung nicht erklärt werden! Andere (z.B. Interferenzversuche) können nicht mit der Teilchenvorstellung erklärt werden. In diesem Seminar lernen Sie die Elektromagnetische Strahlung in seiner Erscheinung als Welle genauer kennen.

#### Wie beschreibt man Strahlung als Welle?

Möchte man Strahlung verstehen, ist es wichtig zu verstehen, wie sich Wellen verhalten. Grundsätzlich können sich alle Wellen auf zwei verschiedene Weisen ausbreiten. Dies ist in der nebenstehenden Abbildung illustriert. Bei einer Longitudinalwelle erfolgt die Schwingung der Teilchen um ihre Ruhelage längs in Ausbreitungsrichtung. Bei einer Transversalwelle ist dies anders. Die Teilchen schwingen senkrecht zur Ausbreitungsrichtung um ihre Ruhelage. Es gilt für beide Ausbreitungsarten, dass nur Energie, aber keine Materie transportiert wird. Ein typisches Beispiel für eine Longitudinalwelle ist der Schall. Schall ist eine Druckschwankung in der Luft, was etwas mit der Dichte der Luftteilchen zu tun hat, die sich periodisch ändert. Man kann in Versuchen zeigen, dass bei elektromagnetischer Strahlung Felder schwingen. Es handelt sich dabei um das elektrische und magnetische Feld, die im Allgemeinen in Phase zueinander schwingen (siehe Figure C.1). Damit handelt es sich bei elektromagnetischer Strahlung um eine Transversalwelle.

Elektromagnetische Strahlung als Welle ist auch in anderer Hinsicht besonders. Wasserwellen und Schallwellen zeichnen sich dadurch aus, dass diese ein

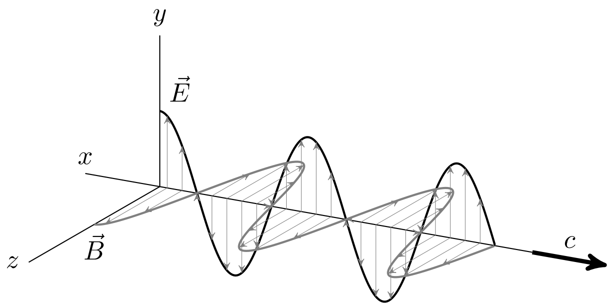


Figure C.1: Schematische Darstellung einer Elektromagnetischen Welle.

Medium zur Ausbreitung benötigen (Wasser und Luft). Einzig der Sachverhalt, dass wir unsere Sonne sehen können, demonstriert, dass elektromagnetische Strahlung sich durch ein annäherndes Vakuum (das Weltall) ausbreiten kann! Elektromagnetische Strahlung benötigt kein Trägermedium und breitet sich auch im Vakuum aus. In der Anfangszeit der Erforschung elektromagnetischer Strahlung nahm man noch an, dass es einen Äther gibt (eine Art undurchsichtiges Trägermedium), in welchem sich Licht ausbreitet. Mit einem Experiment konnte man aber zeigen, dass so etwas wie ein Äther nicht existiert. Der Grund, warum sich elektromagnetische Strahlung im Vakuum ausbreiten kann, ist darin zu suchen, dass sich das elektrische und magnetische Feld gegenseitig selbst erhalten durch elektromagnetische Induktion.

### Charakteristische Größen elektromagnetischer Strahlung

Wie allen Wellen kann man auch elektromagnetischer Strahlung als Welle eine Frequenz $f$ (auch $\nu$, griech: ”nü”) zuordnen, die beschreibt, wie viele Schwingungen das elektrische oder magnetische Feld in einer Sekunde ausführt. In Figure C.1 sehen Sie das sogenannte elektromagnetische Spektrum dargestellt. Man erkennt, dass beispielsweise sichtbares Licht eine Frequenz von 470 THz bis 790THz hat, wobei der untere Bereich rotem Licht und der obere Bereich blauem Licht entspricht. Mikrowellenstrahlung (bspw. WLAN) hat eine Frequenz von $2,45$ GHz, und Röntgenstrahlen von 5.000 THz bis 60.000 THz.

Die Energie der Strahlung hängt mit der Frequenz zusammen. Je größer die Frequenz von Strahlung ist, desto energiereicher ist diese. In gleicher Weise hat elektromagnetische Strahlung eine Wellenlänge $\lambda$. Diese hängt über die Ausbreitungsgeschwindigkeit unmittelbar mit der Frequenz zusammen über: $c = \lambda \cdot f$ mit $c$ der Lichtgeschwindigkeit. Sichtbares Licht hat Wellenlängen von ca. 400 nm (1 nm [Nanometer]$= 1 \cdot 10^{-9}$ m) bis 700 nm. Mikrowellen liegen im Bereich einiger Zentimeter usw.

Eine bedeutende Naturkonstante ist die Ausbreitungsgeschwindigkeit von elektromagnetischen Wellen im Vakuum. Diese breiten sich mit der höchst möglichen Geschwindigkeit aus, der sog. Lichtgeschwindigkeit. Diese beträgt $c = 300.000.000$ m s$^{-1}$ $= 3 \cdot 10^8$ m s$^{-1}$. Um die Lichtgeschwindigkeit in brechenden Medien zu berechnen, muss die Lichtgeschwindigkeit im Vakuum noch durch den Brechungsindex des Materials $n$ geteilt werden $c' = c/n$.

### Anwendungsbeispiele Elektromagnetischer Strahlung

Das Wissen um Elektromagnetische Strahlung versetzt den Menschen in die Lage, sich Strahlung zunutze zu machen. Die Anwendungsbezüge elektromagnetischer Strahlung sind so zahlreich, dass hier nur eine kleine Auswahl aufgezeigt werden kann. Eine praktische Anwendung im Alltag ist der Mikrowellenherd. Darin wird elektromagnetische Strahlung genutzt, um Speisen zu erwärmen. Doch wie funktioniert das? Im Mikrowellenherd sorgt eine Strahlungsquelle dafür, dass Strahlung den Innenraum des Mikrowellenherds durchsetzt. Diese Strahlung ist mit der Frequenz so eingestellt (Mikrowellen), dass sie $H_2O$-Moleküle zu starken Schwingungen anregt. Starke Molekülschwingungen bedeuten aber, dass hierbei Energie übertragen wird. Da Speisen zu großen Teilen aus Wasser bestehen, werden diese dadurch erwärmt. Metallgitter an dem Sichtfenster sorgen dafür, dass die Strahlung nicht austritt. Dies wäre beispielsweise für die menschlichen Augen, die zu großen Teilen aus Wasser bestehen, sehr gefährlich. Eine weitere alltägliche Mikrowellenquelle ist das Mobiltelefon, WLAN, Rundfunk und Fernsehen. All diese Geräte arbeiten so, dass es irgendwo einen Sender gibt, der Strahlungspakete aussendet, die dann von Nutzern empfangen werden. Hierbei wird Energie (als Information) übertragen. Eine zu starke und lange Exposition dieser Strahlung kann zur leichten Erwärmung von Körperregionen führen. Ob dies allerdings schädlich für den menschlichen Organismus ist, ist eine noch ungeklärte Frage.

In der Medizin findet Röntgenstrahlung zu diagnostischen Zwecken breite Anwendung. Eine weitere sehr wichtige Anwendung für die biologische und medizinische Forschung ist die Darstellung kleinster Strukturen. Rosalind Franklin leistete bei der Darstellung der DNA-Struktur Pionierarbeit. Diese schoss mit Röntgenstrahlen auf eine DNA-Probe. Das entstehende Interferenzbild konnte dann weiterverwendet werden, sodass es gelang die räumliche Struktur der menschlichen DNA zu entschlüsseln. Am DESY (Deutschen Elektronensynchrotron in Hamburg) wird heute daran geforscht, mit Strahlung komplexe Proteine darzustellen, um so Wirkmechanismen dieser Proteine (Makromoleküle) zu verstehen und beispielsweise dieses Wissen in der Medikamentenentwicklung zu nutzen.

### Aufgaben

1. Wodurch unterscheidet sich elektromagnetische Strahlung als Welle von anderen Wellen wie Schall oder Wasserwellen?

2. Welche Wellenarten transportieren Energie, welche dahingegen Materie?

3. Charakterisieren Sie rotes Licht, wie es beispielsweise aus einem Laserpointer kommt.

4. Finden Sie mindestens 2 weitere Anwendungsmöglichkeiten Elektromagnetischer Strahlung.

5. Bewerten Sie folgende Aussage: ”Alles was Menschen wahrnehmen, ist veraltet!”. Wie veraltet erscheint uns die Sonne?

**Lösungsvorschläge**

1. Es gibt verschieden Aspekte, nach denen man Wellen unterscheiden kann (Ausbreitungsmedium, Ausbreitungsart, …). Wie im Text dargelegt, sind EM-Wellen vom Wesen anders als beispielsweise Schall- oder Wasserwellen. Schallwellen sind sogenannte longitudinale Wellen. Das bedeutet, dass die Schwingungsrichtung der Teilchen (bspw. Teilchen der Luft) in Ausbreitungsrichtung erfolgt. Bei EM-Strahlung dahingegen schwingen die Größen senkrecht zur Ausbreitungsrichtung. In EM-Strahlung schwingen sehr abstrakte Größen, nämlich elektrische und magnetische Felder. Es ist bekannt, dass Schall zur Ausbreitung ein Medium benötigt (bspw. Luft). Bei EM-Strahlung ist das nicht notwendig. Diese breitet sich selbst im Vakuum aus.

2. Aus physikalischer Sicht transportiert KEINE Welle Materie von einem Ort A zu einem anderen Ort B! Alle Wellen aber transportieren Energie. Objekte, die Wellen aussenden, senden deshalb auch Energie aus. Um den Prozess der Energieabstrahlung durch Wellen aufrechtzuerhalten, muss dem Sender deshalb ein gleiches Maß an Energie zugeführt werden. In der Sonne beispielsweise findet Kernfusion statt, bei der Energie frei wird, sodass die Sonne noch lange Zeit strahlen wird.

3. EM-Strahlung kann anhand des Elektromagnetischen Spektrums charakterisiert werden. Sichtbares Licht überdeckt ungefähr einen Bereich von 400 bis 700 nm. Rotes Licht hat eine geringere Energie als blaues Licht. Mit der Formel $E = h \cdot c/\lambda$ ($\lambda \ldots$ Wellenlänge,$h \ldots$ Plancksches Wirkungsquantum, eine Konstante) wird klar, dass Licht großer Wellenlänge eine kleinere Energie hat als Licht kleiner Wellenlänge. Rotes Licht hat eine Wellenlänge am oberen Rand des sichtbaren Lichtes, meist 635 bis 750 nm. Ansonsten besitzt rotes Licht die gleichen Eigenschaften wir alle anderen Formen elektromagnetischer Strahlung.

4. Die Anwendungsmöglichkeiten elektromagnetischer Strahlung sind sehr vielseitig. Sie haben sicherlich schon einmal von der Radiologie gehört. Dies bezeichnet einen Bereich in der Medizin, der sich ausschließlich mit Strahlungswirkung beschäftigt. Nebenbei bemerkt ein Bereich, in dem exzellent qualifizierter Physikerinnen und Physiker gesucht werden. Dies ist wichtig in der Funktionsdiagnostik. Beispielweise kann in einer Computertomographie ein 3D-Abbild des menschlichen Körpers erzeugt werden. Hierbei ist das Wissen, um die Wirkung von Strahlung, essentiell. Selbst Materieteilchen besitzen Welleneigenschaften! So werden in der Schwerionenforschung gezielt Teilchen dazu genutzt Tumore im Körper zu zerstören. Ein weiteres Anwendungsfeld ist die Astronomie. Heutzutage basiert die Theoriebildung in der Astronomie maßgeblich auf Daten, die von Supernovae, Neutronensternen und fernen Galaxien gewonnen werden. Selbst die kosmische Hintergrundstrahlung ist EM-Strahlung im Mikrowellenbereich. Sterne senden Licht zu uns, und Neutronensterne senden teilweise Gammastrahlung bei der Kollision, wo gigantische Energiemengen frei werden. EM-Strahlung ermöglicht den Blick in ferne Galaxien und in die Extrembereiche unseres Kosmos. Ebenso als Hilfsanwendung steht EM-Strahlung Pate. Vor nicht langer Zeit wurde bekanntgegeben, dass erstmals Gravitationswellen detektiert worden (Nobelpreiskandidat!). Die Messung erfolgt mittels Laserinterferometrie, sodass auch in diesem Bereich EM-Strahlung wichtig ist.

5. Die Ausnahmeerscheinung Albert Einstein stellte korrekt fest, dass sich Licht im Vakuum mit der höchst möglichen Geschwindigkeit, der Lichtgeschwindigkeit $c$ ($c \sim 3 \cdot 10^8$ m s$^{-1}$) ausbreitet. Dies setzt die Grenze jeglicher Information-

Wellenfront.

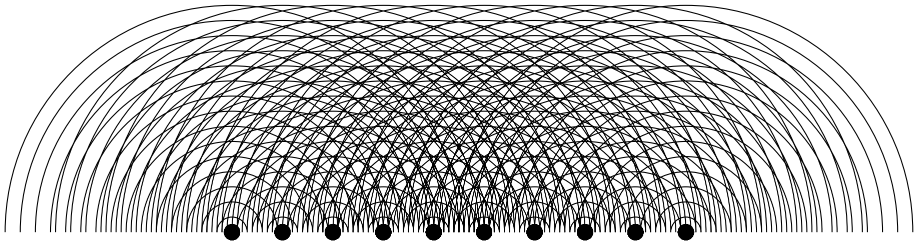


Figure C.2: Mehrere Quellen von Elementarwellen senden Wellen aus. Die Einhüllende stellt die Wellenfront dar.

sübertragung. Keine Information kann schneller als mit Lichtgeschwindigkeit übertragen werden. Diese obere Geschwindigkeit bedeutet gleichermaßen, dass Licht, dass von Objekten, die weiter von uns entfernt sind, ausgesendet wird, einen längeren Weg zurücklegt und demzufolge bei konstanter Geschwindigkeit eine längere Zeit benötigt! Unsere Sonne ist beispielsweise ca. 8 Minuten alt (Entfernung Erde-Sonne $150 \cdot 10^6$ km $\rightarrow t = (150 \cdot 10^9 \text{ m})/(3 \cdot 10^8 \text{ m s}^{-1}) = 8,33$ min).

## Erklärung der Wellenausbreitung – Das Huygenssche Prinzip

Um das Ausbreitungsverhalten von Wellen zu verstehen, schlug Huygens im 17. Jh. ein Prinzip vor, welches das Ausbreitungsverhalten von Wellen in vieler Hinsicht passend beschreibt. Dieses Prinzip wird Huygenssches Prinzip genannt. Um das Prinzip zu verstehen, ist es notwendig, die Begriffe Wellenfront und Elementarwelle zu klären.

Eine Elementarwelle ist nichts anderes als eine Quelle einer Welle, die periodisch mit konstanter Frequenz eine Welle aussendet. Der Begriff Wellenfront wird dann wichtig, wenn viele Elementarwellen zusammen betrachtet werden (siehe Figure C.2). Jeder dargestellte Punkt sendet eine Elementarwelle aus. Alle Wellen haben die gleiche Wellenlänge. Diese Wellenfront breitet sich im Raum aus.

**Das Huygen'sche Prinzip sagt nun: Jeder Punkt einer Wellenfront ist der Ausgangspunkt einer Elementarwelle.**

Tatsächlich können mit dieser Überlegung zahlreiche Phänomene in ausreichender Weise beschrieben (erklärt) werden. Zwei einfache Anwendungen dieses Prinzips sind die Brechung und die Reflexion von Wellen. Eine Wellenfront wird dazu als Strecke dargestellt. Table C.3 veranschaulicht dieses Prinzip. Wenn hierbei kein Medienwechsel (bspw. Luft – Glas) stattfindet, haben an der Grenzfläche entstehenden Elementarwellen die gleiche Wellenlänge und Frequenz wie die einfallende Welle. An Punkten, an denen die Wellenfront zuerst auftrifft, werden Elementarwellen zuerst ausgesendet. In Table C.3 kann so auf einfachem Wege die Reflexion an einer Grenzfläche nachvollzogen werden.

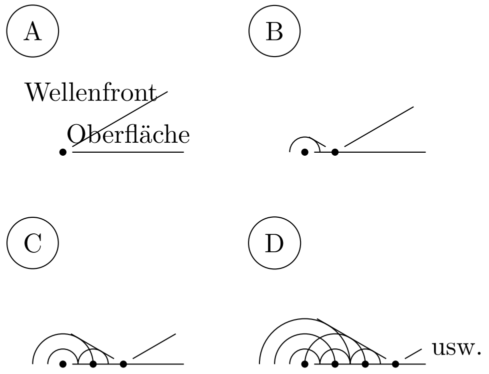


Figure C.3: Das Huygen'sche Prinzip: Die schwarze Strecke stellt jeweils die Wellenfront dar.

### Aufgaben

1. Welche Bedingungen müssen erfüllt sein, dass zwei Wellen miteinander interferieren (sich überlagern)?
2. Zeichnen Sie die resultierende Welle in Abbildung C.4 ein? (Hinweis: Verwenden Sie hierzu gern ein CAS-System wie die kostenfreie Software GeoGebra.)
3. Konstruieren Sie die Brechung nach dem Huygensschen Prinzip (Hinweiskarte).
4. *Licht trifft auf eine Grenzfläche Luft-Glas. Was folgt nach Ihrer Ansicht aus dem Huygensschen Prinzip für das Auftreten von Reflexion und Brechung?
5. *Erklären Sie die folgende Abbildung C.5 und leiten Sie anhand dieser Abbildung das Snelliussche Brechungsgesetz ($n_1 \cdot \sin\phi_1 = n_2 \cdot \sin\phi_2$, mit $n$ als Brechungsindex) her:

### Hinweiskarte

In Figure C.6 ist die Brechung dargestellt. Wichtig ist, dass an der Grenzfläche der Medien (graue Linie) die Wellenlänge kürzer wird. Die Richtung der Ausbreitungsrichtung der Welle ändert sich hier!

### Lösungsvorschlag

1. Wellen erfüllen das Superpositionsprinzip. Das bedeutet, dass zwei Wellen, die sich im Raum treffen, interferieren. Es gib keine Bedingungen. Anders ist die Frage danach, wann ein statisches Beugungsbild zustande kommt. Hierbei müssen die Wellen eine konstante Phasendifferenz zueinander haben.

2. Siehe Figure C.7.

3. (Siehe Hilfekarte) Wichtig ist, dass an jedem Ort, an dem die Wellenfront auftrifft eine neue Elementarwelle entsteht und sich fortpflanzt.

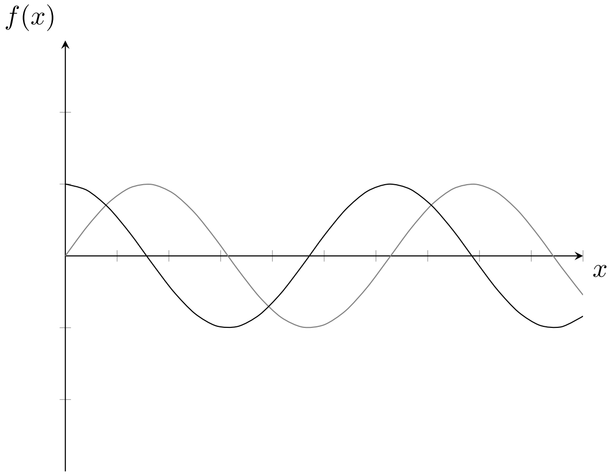


Figure C.4: Zwei Sinus-Funktionen, die sich überlagern.

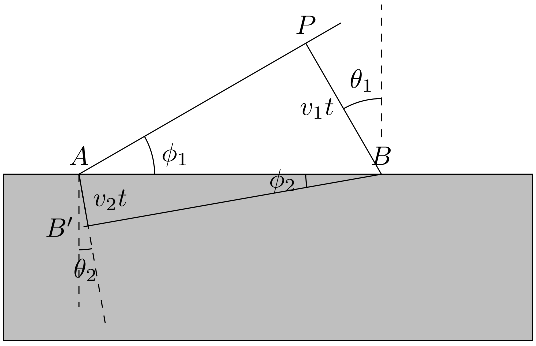


Figure C.5: Analog zu Abbildung C.3 stellen hier die roten Linien die Wellenfronten dar. Die dunkle Fläche stellt eine Region höheren Brechungsindex dar, als die weiße Region. Damit ist die Wellenlänge in dieser Region kleiner. Angelehnt an: Tipler, S. 1028.

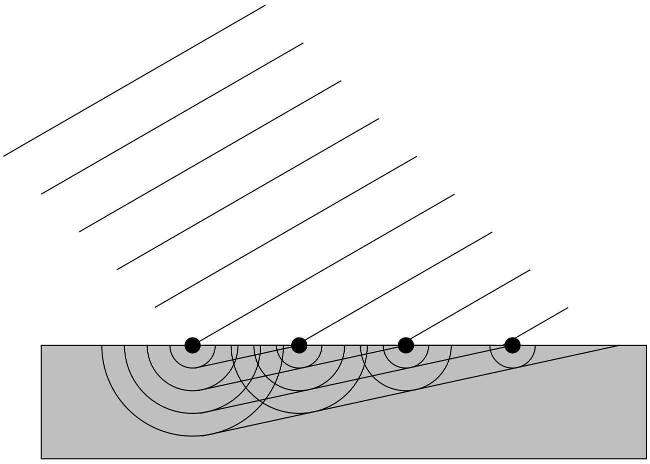


Figure C.6: Eine Welle trifft von einem Medium in ein zweites Medium (grau). Dabei ändert sich die Wellenlänge der Welle.

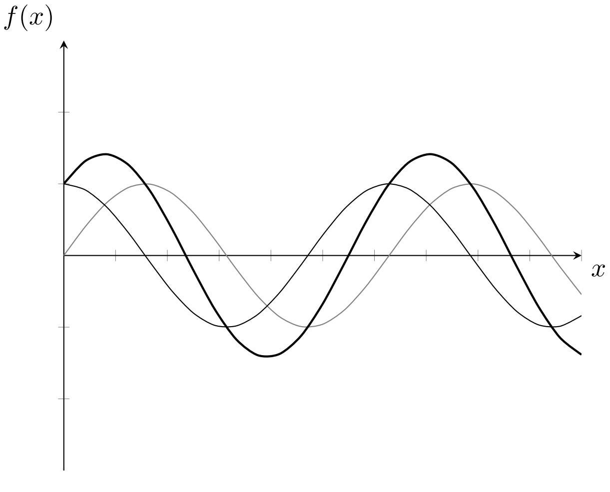


Figure C.7: Superposition zweier Wellen. Die resultierende Welle ist fett dargestellt.

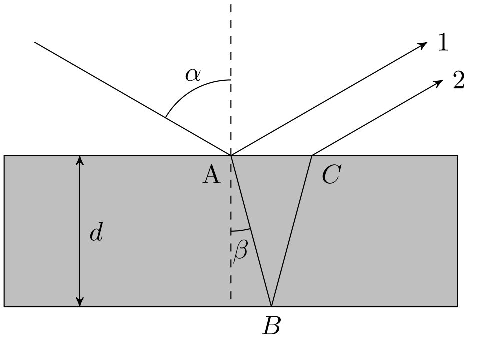


Figure C.8: Schematische Darstellung des schrägen Einfalls von Licht auf eine dünne Schicht.

4. Aus dem Elementarwellenprinzip folgt, dass an Punkten an denen eine Wellenfront auftrifft, eine Elementarwelle entsteht. Trifft eine Wellenfront auf eine Grenzschicht, entstehen dort Elementarwellen. Das bedeutet, dass an jeder Grenzfläche, auf die eine Wellenfront trifft, immer Reflexion und Brechung auftreten.
5. Siehe Tipler (2004), S. 1028.

## Ist Interferenz auch ohne Beugung möglich?

Es gibt auch Interferenz ohne Beugung. Um solche Interferenzerscheinungen zu beobachten, ist es hilfreich zu wissen, wo man hinsehen muss. Tatsächlich ist die Interferenz dafür verantwortlich, dass bei Seifenblasen beeindruckende Farbspiele entstehen. Auch auf Ölpfützen sind solche Farbspiele zu beobachten und bei manchen Schmetterlingen oder auf Libellenflügeln entstehen Farben durch Interferenz. Interferenz bedeutet, dass bestimmte Wellenlängen im reflektierten Licht sich gegenseitig auslöschen und andere sich verstärken.

### Interferenz an dünnen Schichten

Zur Demonstration der Interferenz an dünnen Schichten wird folgender Versuch durchgeführt: Vor eine Quecksilber- oder Natriumlampe wird ein dünnes Glimmerblatt (Dicke ca. $0,05$ mm) gehalten, so dass das reflektierte Licht auf einen Schirm bzw. auf eine Wand fällt. Auf dem Schirm entsteht ein ringförmiges Interferenzmuster.

**Erklärung:** Das Licht wird sowohl an der Vorder- als auch an der Rückseite des Glimmerblattes reflektiert und interferiert miteinander. Je nach Gangunterschied, der von verschiedenen Faktoren abhängt, kommt es zur Verstärkung oder zur Abschwächung bzw. Auslöschung. In Figure C.8 werden die möglichen Lichtwege der reflektierten Teilstrahlen dargestellt.

Das Licht trifft unter dem Winkel $\alpha$ auf die Grenzschicht zwischen Luft und Glimmerblatt (Punkt A). Dort wird eine Teil des Lichts reflektiert (Teilstrahl 1). Es gilt das Reflexionsgesetz. Ein anderer Teil des Lichts dringt in das Glimmerblatt ein und wird erst an der Rückseite des Glimmerblattes (Punkt B) reflektiert. Beim Eintritt in das Glimmerblatt wird das Licht gebrochen. Da das Glimmerblatt optisch dichter ist als Luft, wird das Licht zum Lot hin gebrochen

($\beta < \alpha$). Wenn das Licht das Glimmerblatt an der Grenzschicht zwischen Glimmerblatt und Luft (Punkt C) wieder verlässt, wird es erneut gebrochen, diesmal vom Lot weg. Teilstrahl 2 verlässt das Glimmerblatt unter dem gleichen Winkel wie Teilstrahl 1 - beide Teilstrahlen sind also parallel. Da die Schichtdicke $d$ in Wirklichkeit sehr klein ist, treffen Teilstrahl 1 und Teilstrahl 2 praktisch am selben Punkt auf den Schirm bzw. ins Auge und interferieren miteinander. Ob die beiden Teilstrahlen konstruktiv oder destruktiv miteinander interferieren, hängt vom Gangunterschied $\delta$ ab. Die beiden Teilstrahlen 1 und 2 haben aus verschiedenen Gründen einen Gangunterschied:

- Die beiden Strahlen 1 und 2 legen verschieden lange Wege zurück
- Bei der Reflexion tritt unter Umständen* ein Phasensprung auf
- Der Umweg von Strahl 2 führt zum Teil durch das Glimmerblatt. Dort hat das Licht eine kleinere Wellenlänge (und Ausbreitungsgeschwindigkeit) als in Luft

*Von mechanischen Wellen wissen wir, dass bei der Reflexion am festen Ende ein Phasensprung von 180° bzw. $\lambda/2$ auftritt, bei der Reflexion am freien Ende gibt es jedoch keinen Phasensprung.

### Aufgaben[1]

1. Grenzen Sie die Begriffe optische Weglänge und geometrische Weglänge voneinander ab.
2. Ermitteln Sie den Gangunterschied der Wellen bei senkrechtem Lichteinfall. Leiten Sie daraus Bedingungen für Auslöschung und maximale Verstärkung ab (Hinweiskarte: Dünnfilminterferenz).
3. *Warum tritt dieses Interferenzphänomen nur an sehr dünnen Schichten auf?

### Lösungsvorschläge

1. Zur Unterscheidung von optischer und geometrischer Weglänge ist Abbildung C.9 aus dem Text hilfreich. Im oberen Bereich (über dem optisch dichteren Medium) bewegt sich das Licht in Luft. Die Brechzahl von Luft ist nahe 1, sodass sich das Licht mit annähernder Lichtgeschwindigkeit bewegt. In diesem Fall entspricht die geometrische Weglänge exakt der optischen Weglänge. Im optisch dichteren Medium, dessen Brechzahl $n$ größer als 1 ist, bewegt sich das Licht langsamer als in Luft! Die Geschwindigkeit beträgt dann $c' = c/n'$, wobei $c$ die Lichtgeschwindigkeit im Vakuum (Luft) und $n'$ die Brechzahl des optisch dichteren Mediums ist. Wenn die Geschwindigkeit auf diesem Weg kleiner wird, dann folgt daraus, dass in der gleichen Zeit $t$ nur ein kleinerer Weg zurückgelegt werden kann. Der "neue" Weg lautet dann: $l' = c' \cdot t = \frac{c}{n'} \cdot t = \frac{l}{n'}$, wenn $l = c \cdot t$ die Weglänge in Luft ist. Hierbei steht $l$ für die Länge. Die optische Weglänge ist diejenige Weglänge, für die ein Lichtstrahl in einem Medium die gleiche Zeit $t$ benötigt wie im Vakuum.

---

[1] Adaptiert von: http://physikunterricht-online.de/jahrgang-11/interferenz-an-duennen-schichten/, aufgerufen am 23.08.2016

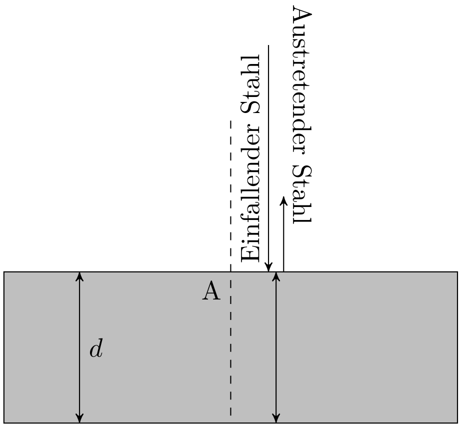


Figure C.9: Senkrechter Lichteinfall. Teilstrahl 2 durchquert zusätzlich die dünne Schicht, wir am Ende reflektiert und überlagert sich dann mit Teilstrahl 1, der bereits an der Oberfläche reflektiert wird.

4. Das Phänomen eines statisches Beugungsbildes tritt nur dann auf, wenn die zwei interferierenden Lichtstrahlen kohärent zueinander sind. Das Problem an allen gängigen Lichtquellen ist allerdings, dass die Kohärenzlänge sehr klein ist (Größenordnung $10^{-6}$). Das bedeutet, dass ein Beugungsbild nur entstehen kann, wenn die optische Weglänge beim Durchgang (z.B. durch das dichtere Medium in Abbildung C.9) in dieser Größenordnung ist. Laser haben teilweise Kilometerlange Kohärenzlängen. Aus diesem Grund sind Laser für Interferenzexperimente hervorragend geeignet.

### Hinweiskarte mit Lösung zu Aufgabe 2: Dünnfilminterferenz

Um den Gangunterschied zu ermitteln, betrachten wir nacheinander alle genannten Gründe. Der Einfachheit halber beschränken wir uns zunächst auf den Spezialfall, dass das Licht senkrecht auf die Grenzfläche trifft.

1. Geometrische Weglänge: Bei senkrechten Einfall muss Teilstrahl 2 gegenüber Teilstrahl 1 zusätzlich die Schicht zweimal durchlaufen. Der geometrische Wegunterschied beträgt also $\Delta s = 2d$.

2. Optische Weglänge - Änderung der Wellenlänge im Glimmerblatt: Da sich das Licht im Glimmerblatt um den Faktor $n$ (Brechungszahl) langsamer ausbreitet als in Luft, verringert sich die Wellenlänge um den gleichen Faktor. Die Wellenlänge im Glimmerblatt beträgt also nicht $\lambda$, sondern $\lambda/2$. Der Gangunterschied wird entsprechend um den Faktor $n$ größer. Der Gangunterschied unter Berücksichtigung der Brechung beträgt beim senkrechten Einfall also $\delta = 2dn$. Man spricht hierbei auch von optischer Weglänge. Wie wir wissen, kommt es zur Auslöschung, wenn der Gangunterschied einem ungeradzahligen Vielfachen der halben Wellenlänge entspricht: $\delta = \frac{(2k+1)\lambda}{2}$.

**Bedingung für Auslöschung:** Demnach müsste für die Auslöschung gelten: $2dn = \frac{(2k+1)\lambda}{2}$. Allerdings gibt es einen weiteren Grund für einen Gangunterschied:

**3. Phasensprung durch Reflexion:** Bei der Reflexion des Lichts am optisch dichteren Medium (Punkt A) kommt es zu einem Phasensprung von

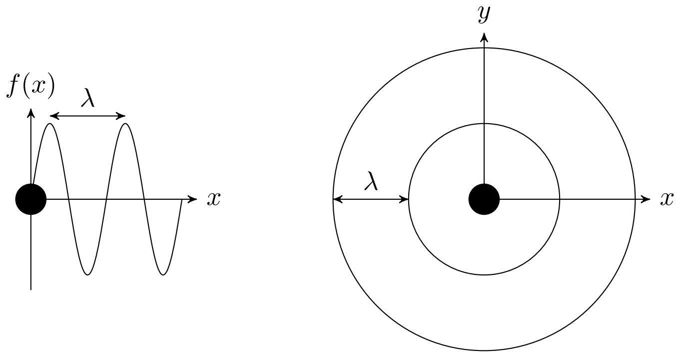

Darstellung 1: Darstellung 2:

Figure C.10: Darstellungsformen von Wellen (links: Seitensicht, rechts: Draufsicht).

180° bzw. $\lambda/2$. Das bedeutet: Aus einem Wellenberg wird ein Wellental und umgekehrt. Bei der Reflexion am optisch dünneren Medium (Punkt B) gibt es keinen Phasensprung. Da der Phasensprung also nur bei einem der beiden Teilstrahlen auftritt, kommt zusätzlich zum o.g. Gangunterschied noch eine Phasenverschiebung um $\lambda/2$ hinzu.

Der gesamte Gangunterschied beträgt damit: $\delta = 2dn + \frac{\lambda}{2}$. Damit lautet die Bedingung für Auslöschung: $2dn + \frac{\lambda}{2} = \frac{(2k+1)\lambda}{2}$. Nach Auflösen der Klammer und anschließendem Kürzen ergibt sich: $2dn = k\lambda$. Die Bedingung für Verstärkung lautet $2dn = \frac{2k-1}{2}\lambda$ mit $k = 1, 2, 3, \ldots$. Trifft Licht senkrecht auf eine dünne planparallele Schicht, tritt bei der Reflexion unter folgenden Bedingungen Auslöschung bzw. maximale Verstärkung auf: Bedingung für Auslöschung: $2dn = k\lambda$. Bedingung für maximale Verstärkung: $2dn = \frac{2k-1}{2} \cdot \lambda$.

## Interferenz und Beugung Elektromagnetischer Strahlung

Wellen kann man auf verschiedene Arten darstellen. Als Sicht von der Seite und als Sicht von oben. Diese Darstellungsformen haben beide ihre Vor- und Nachteile. Bei der Darstellung von oben, kann man sehr gut die räumliche Ausbreitung von Wellen und damit deren Interaktion mit Objekten darstellen. Hierbei werden die Maxima der Wellen eingezeichnet. Diese haben bei ungestörter Ausbreitung der Wellen die Form konzentrischer Kreise mit dem Erzeuger der Welle als Mittelpunkt. Die Minima dieser Welle liegen genau zwischen den Maxima.

Die Darstellung von der Seite hingegen ist für die räumliche Ausbreitung der Wellen schlecht geeignet, da sie die Welle in nur einer Dimension darstellt. Sie stellt jedoch die Amplituden dar, wodurch sie sich zur Darstellung der Überlagerung mehrerer Wellen eignet.

### Aufgabe 1

Skizzieren Sie eine Welle mit einer Wellenlänge von 4 cm und einer Amplitude von 2 cm in beiden Darstellungsformen für Wellen.

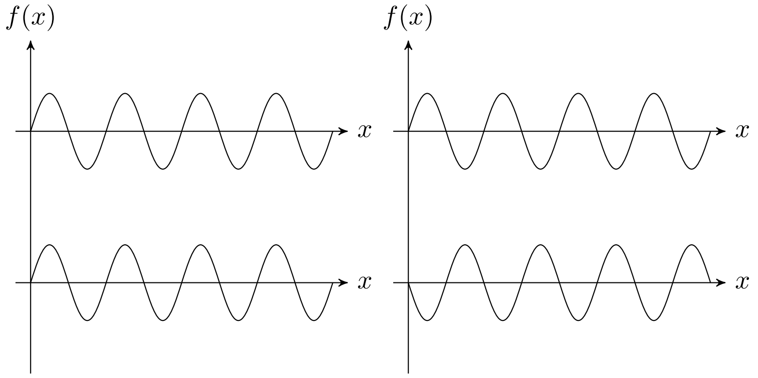


Figure C.11: Die Wellen schwingen in Phase (links) oder außer Phase (rechts).

Betrachtet man zwei EM-Wellen gleicher Frequenz, so müssen sie nicht immer gleich schwingen. Es kann vorkommen, dass die Maxima der einzelnen Wellen real um $\Delta s$ verschoben sind, z.B. $\Delta s = 2$ m. Man nennt dies eine Phasenverschiebung. Mit Wellen rechnet man meistens im Bogenmaß. Die Umrechnung erfolgt über die Formel $\varphi = (\Delta s/\lambda) \cdot 2\pi$. Wenn im Beispiel die Wellenlänge $\lambda = 8$ m beträgt, so resultiert eine Phasenverschiebung von $\varphi = (2$ m$/8$ m$) \cdot 2\pi = \pi/2$.

Sollte die Phasenverschiebung Null oder ein gerades Vielfaches von $\pi$ sein ($\varphi = 2k\pi$ mit $k \in \mathbb{N}$), so fallen die Maxima und Minima beider Wellen aufeinander, da eine Welle um genau eine oder mehrere Wellenlängen im Vergleich zur anderen verschoben wurde. Man sagt die Wellen schwingen in Phase.

Ist die Phasenverschiebung jedoch ein ungerades Vielfaches von $\pi$ ($\varphi = (2k+1)\pi$ mit $k \in \mathbb{N}$), so schwingen beide Wellen außer Phase und es fällt ein Minima der einen Welle auf ein Maxima der anderen. Der Zusammenhang zur Wellenlänge lautet für Wellen, die in Phase schwingen: $\varphi = k\lambda$ mit $k \in \mathbb{N}$. D.h., sobald die Phasenverschiebung eine Wellenlänge beträgt, löschen sich die Wellen nicht aus. Bei Wellen außer Phase lautet der Zusammenhang: $\varphi = \frac{2k+1}{2} \cdot \lambda$ mit $k \in \mathbb{N}$.

### Aufgabe 2

Skizzieren Sie eine um $\pi$ und um $\pi/2$ phasenverschobene Welle zu den beiden in der vorigen Aufgabe skizzierten Wellen ein.

Diese Begriffe sind wichtig für das Superpositionsprinzip, welches besagt, dass sich zwei Wellen an einem Ort verhalten, wie eine neue Welle, deren zeitliche Auslenkung sich als die Summe der Auslenkung der beiden Wellen darstellt. Das bedeutet für zwei gleichphasige Wellen mit gleicher Amplitude, die sich an einem Ort treffen, dass die z.B. die Amplitude der resultierenden Welle die Summer der Amplituden der Ausgangswellen ist. Man nennt dieses Phänomen eine konstruktive Überlagerung (siehe Abbildung C.12).

Sind diese Wellen mit gleicher Amplitude jedoch außer Phase, so steht zu jedem Maximum ein Minimum der anderen Welle. Die Wellen löschen sich aus, da die Summe an jedem Punkt Null ergibt. Dieses Phänomen nennt man eine destruktive Überlagerung.

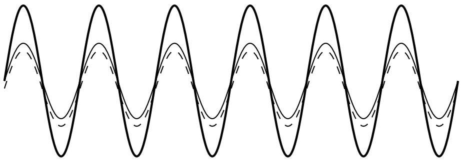


Figure C.12: Die dünne schwarze und die gestrichelte Welle überlagern sich konstruktiv zur dick gezeichneten Welle.

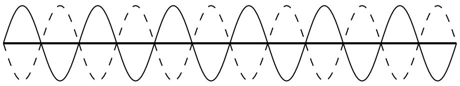


Figure C.13: Die dünne schwarze und die gestrichelte Welle überlagern sich destruktiv zur dick gezeichneten Welle.

Diese beiden Fälle sind Spezialfälle der Superposition. Dort sind sowohl Amplitude als auch Wellenlänge gleich. Sie spielen in Theorie und Praxis eine wichtige Rolle, wie Sie später in Experimenten sehen werden. Figure C.14 zeigt die Superposition zweier Wellen unterschiedlicher Wellenlänge und Amplitude. Hier ist alles komplizierter.

**Aufgabe 3**

Skizzieren Sie in der Seitenansicht die Welle, die bei der Überlagerung der Ursprungswelle und der um $\pi/2$ phasenverschobenen Welle entsteht.

In Figure C.15 sind zwei Wellen skizziert. Markieren Sie alle Punkte, an denen Sie konstruktive Interferenz erwarten mit einem X und alle Punkte an denen Sie destruktive Interferenz erwarten mit einem O. Was fällt Ihnen auf?

**Lösungsvorschläge**

1. Siehe Figure C.16.
2. Siehe Figure C.17.
3. Siehe Figure C.18.

# Interferenz

## Interferenz am Einzelspalt

Fällt monochromatisches (eine Wellenlänge), kohärentes (gleiche Phase zueinander) Licht auf ein Hindernis oder einen bzw. mehrere Spalte, so entsteht dahinter ein Interferenzmuster ähnlich Figure C.19. Dieses Phänomen kann mit dem huygensschen Prinzip hinreichend gut erklärt werden. Das huygenssche Prinzip besagt, dass jeder Punkt einer Welle eine neue Welle (Elementarwelle) mit gleicher Frequenz und Amplitude erzeugt.

Trifft nun monochromatisches, kohärentes Licht auf einen Spalt, so kann man den Spalt gemäß dem Huygensschen Prinzip durch viele kleine Lichtquellen (Elementarwellen) ersetzen, die alle in Phase schwingen. Nutzt man Laserlicht

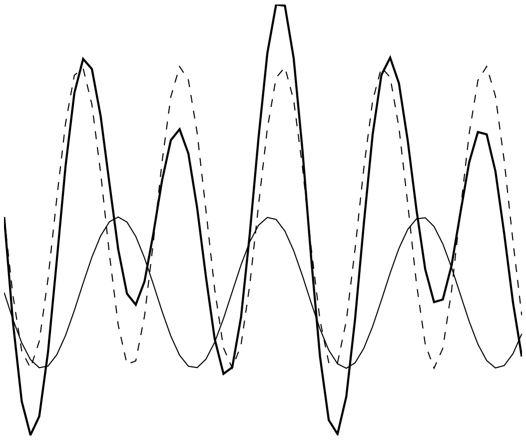


Figure C.14: Eine allgemeine Superposition mit Wellen verschiedener Amplituden, Wellenlängen und Phasenverschoben. Es überlagern sich hier die dünne schwarze und die gestrichelt gezeichnete Welle zur Grünen.

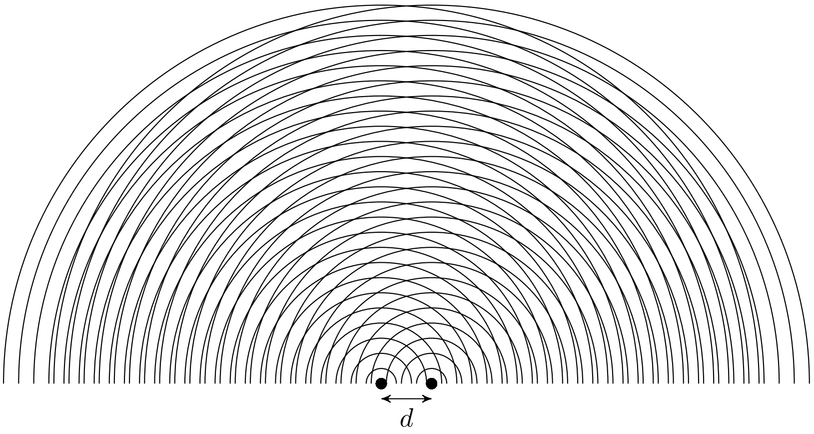
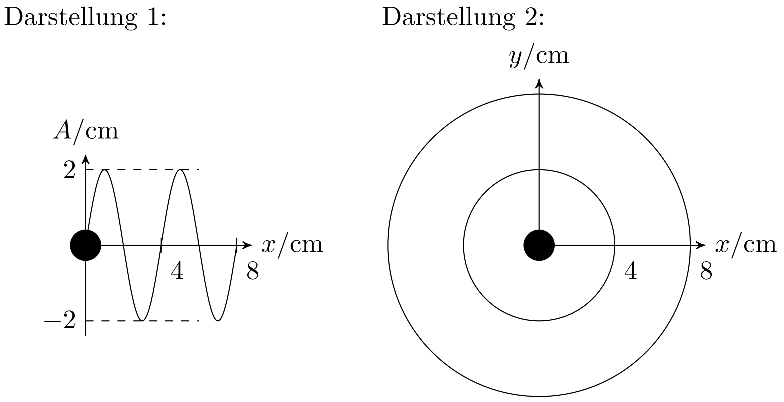
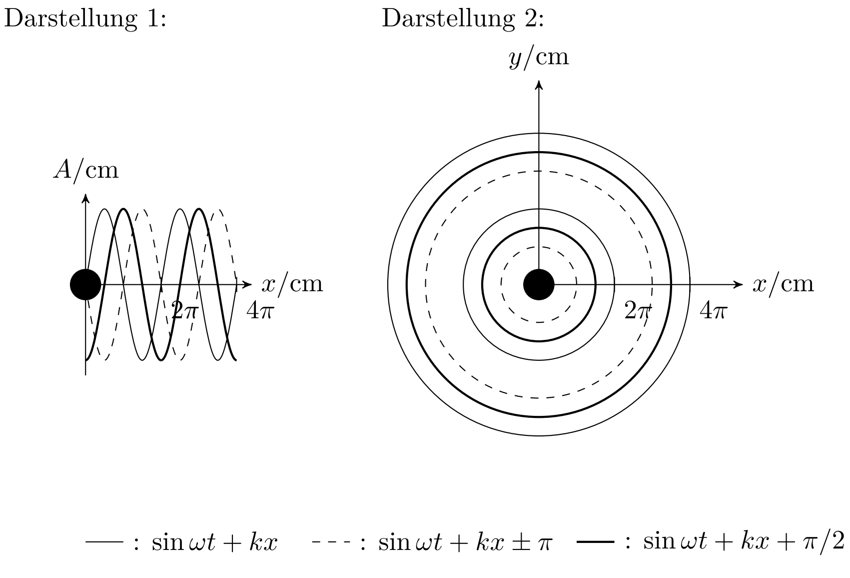


Figure C.15: Draufsicht zweier Wellen, die einen Abstand von $d = 2,5\lambda$ besitzen.


Darstellung 1:

Darstellung 2:

Figure C.16: Darstellung als Seitenansicht (Darstellung 1) sowie Darstellung als Draufsicht (Darstellung 2).


Darstellung 1:

Darstellung 2:

Figure C.17: Darstellung als Seitenansicht (Darstellung 1) sowie Darstellung als Draufsicht (Darstellung 2).

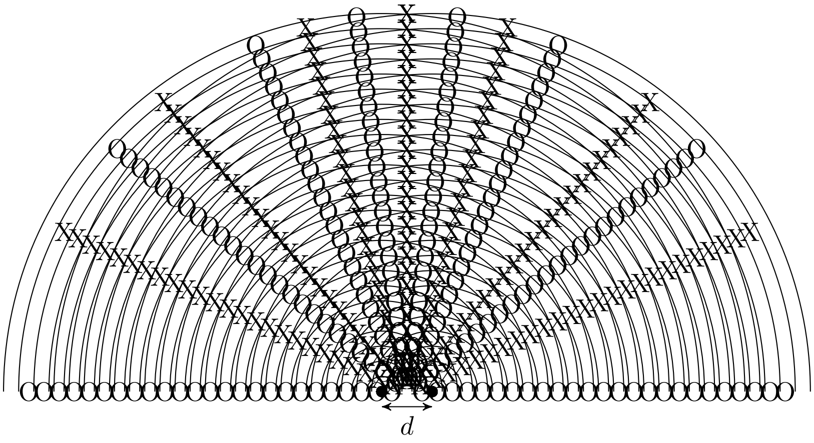


Figure C.18: Achtung: Es sind nicht alle Stellen eingezeichnet, an denen konstruktive oder destruktive Interferenz auftritt.

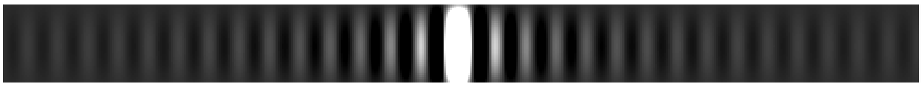


Figure C.19: Beugungsbild eines Einzelspaltes.

zur Beleuchtung, treffen die Annahmen der Kohärenz sowie der monochromatischen Eigenschaft in guter Näherung zu. Bei einer normalen Lampe würde kein Interferenzbild entstehen, da die Kohärenzlänge zu kurz ist.

Die ausgesandten Elementarwellen sind nun in Phase zueinander und somit findet Interferenz statt. Aus Abbildung C.20 wird ersichtlich, dass sich ein komplexes Muster hinter dem Spalt ergibt, in welchem bestimmte Bereiche auffällig hell (z.B. eingezeichnete Strecke von den Elementarwellen zum Punkt $P$) und andere sehr dunkel sind. Dies sind jeweils besondere Orte im Beugungsbild hinter dem Spalt. An hellen Stellen treffen stets zwei Wellenberge aufeinander, sodass sich die Wellen konstruktiv überlagern. An dunklen Stellen ist dies umgekehrt. Dort trifft Wellenberg auf Wellental, sodass sich die Wellen gegeseitig auslöschen. Mathematisch kann man diese Orte bestimmen. Dazu wird ein Zusammenhang zwischen Spaltbreite $d$, Abstand Schirm-Spalt $s$, Wellenlänge $\lambda$ und Abstand der Nebenmaxima zum Hauptmaximum $x_n$ abgeleitet (siehe Figure C.21).

### Zur Herleitung der Berechnung der Spaltbreite:[2]

Wenn man einen Punkt $P'$ betrachtet, der in Abbildung C.20 genau gegenüber vom Spalt liegt ($\theta = 0°$), so legen Elementarwellen vom rechten Ende des Spaltes und vom linken Ende des Spaltes den gleichen Weg bis zu diesem Punkt zurück. D.h., dass dort konstruktive Interferenz stattfindet. Liegt der Punkt allerdings am Ort $P$ (mit $\theta \neq 0°$), so haben Wellen einer Elementarwelle am linken

---

[2] Nach: Tipler, Paul (2004): Physics. For Scientists and Engineers. New York: W. H. Freernan and Company. S. 1092ff.

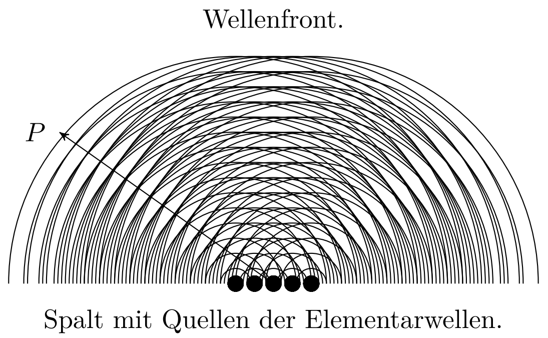


Figure C.20: Ausbreitung einer Welle nach einem schmalen Spalt mithilfe des huygensschen Prinzips. Da die Wellenfronten sich in den Maxima überschneiden und somit weniger Fläche ausfüllen, werden die Maxima als helle Bereiche dargestellt.

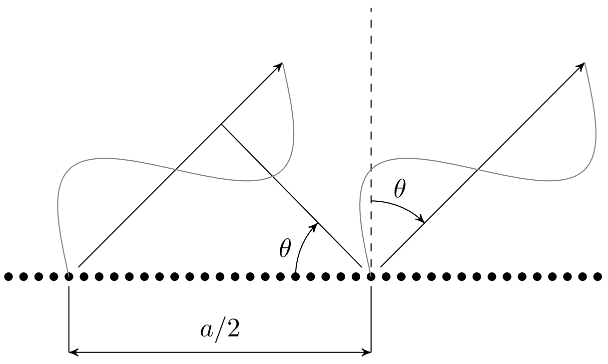


Figure C.21: Einzelspalt der Breite $a$, bestehend aus 40 Quellen von Elementarwellen.

Ende des Spaltes einen kürzeren Weg als Elementarwellen vom rechten Ende des Spaltes. Die Wellen, die an diesem Punkt $P$ zusammentreffen, weisen deshalb eine Phasenverschiebung zueinander auf und es kann, je nach Abstand, zu Auslöschung oder Verstärkung kommen.

Nach dem huygensschen Prinzip kann man sich den Spalt aus beliebig vielen Quellen von Elementarwellen vorstellen (z.B. 40, siehe Figure C.21). Der Spalt habe die Breite $a$. Zwei Elementarwellen werden nun von einer Quelle in der linken Hälfte des Spaltes (z.B. Nummer 5) und von einer Quelle in der rechten Hälfte des Spaltes (z.B. Nummer 25) ausgesandt. Treffen diese in einem Punkt $P$, der weit vom Spalt entfernt ist, zusammen, so haben die ankommenden Wellen einen unterschiedlich langen Weg zurückgelegt. Der sog. Gangunterschied (entspricht hier dem Wegunterschied) ist gerade $a/2 \cdot \sin\theta$, mit $a/2$ als Hypotenuse des rechtwinkligen Dreiecks in Figure C.21. Wenn dieser Gangunterschied gleich einer halben Wellenlänge ($\lambda/2$) ist, so löschen sich die beiden Wellen am Punkt $P$ aus. Auf dem Schirm macht sich dies dadurch bemerkbar, dass keine Intensität vorhanden ist. Es gilt für die Lage des ersten Minimums: $a \cdot \sin\theta_1 = \lambda$. Genauso wie die Wellen der Quellen 5 und 25, so löschen sich auch die Wellen der Quellen 3 und 23 usw. aus, sodass tatsächlich keine Intensität am Schirm vorhanden ist. Wie in Figure C.19 zu sehen, gibt es mehrere Bereiche, in denen die Intensität Null ist. Die Wellen löschen sich an diesen Stellen aus.

Nun interessiert uns der nächste Ort der Auslöschung. Dazu kann man annehmen, dass folgende Gleichung erfüllt sein muss: $a \cdot \sin\theta_2 = 2\lambda$. Man kann nun die Spaltbreite vierteln ($a/2$) und sich überlegen, dass jeweils eine Punktquelle des ersten Viertels mit einer zweiten Punktquelle des zweiten Viertels (und ebenso des dritten mit dem vierten Viertel) sich gegenseitig auslöscht. Auch hier gelangt insgesamt keine Intensität zum Schirm. Es wurde gezeigt, dass $a \cdot \sin\theta_1 = \lambda$ sowie $a \cdot \sin\theta_2 = 2\lambda$ gelten. Dies legt den Schluss nahe, dass folgende Gleichung für die Winkel der Minima des Beugungsbildes gilt:

$$a \sin\theta_m = m\lambda, \qquad m \in \mathbb{N}^*.$$

Für kleine Winkel genähert gilt dann:

$$\theta_m \sim \frac{m\lambda}{a}. \tag{C.1}$$

Da man die Winkel nur umständlich messen kann, stellt man die folgende geometrische Überlegungen an. Für das Dreieck in Abbildung C.22 gilt folgende Beziehung zwischen dem Winkel $\theta$ und den (messbaren) Variablen $L$ und $y_1$: $\tan\theta_1 = y_1/L$. Da die Länge $L$ viel größer als $y_1$ ist, handelt es sich bei $\theta$ in guter Näherung um sehr kleine Winkel, sodass die folgende Näherung gilt:

$$\theta_1 \sim \frac{y_1}{L}. \tag{C.2}$$

Setzt man nun Gleichung C.1 und Gleichung C.2 gleich, so erhält man die wichtige Beziehung:

$$\frac{m\lambda}{a} = \frac{y_m}{L}.$$

Anhand dieser Gleichung kann man beispielsweise die Breite eines Einzelspaltes bestimmen.

### Aufgaben

1. Skizzieren Sie das Interferenzbild für zwei gekreuzte Drähte.
2. Was passiert mit dem Abstand der Beugungsmaxima höherer Ordnung, wenn die Spaltbreite a abnimmt.
3. Sie haben nun den Versuch am Einzelspalt mit einem Laserpointer durchgeführt. Folgende Messwerte (Table C.1) haben Sie dabei erhalten. Berechnen Sie die Breite des Spaltes. Der Abstand Spalt-Schirm betrage hierbei 1 m. Die Wellenlänge des Lasers ist 650 nm.
4. Schätzen Sie mit einer geeigneten Methode den Fehler dieses Experimentes ab.

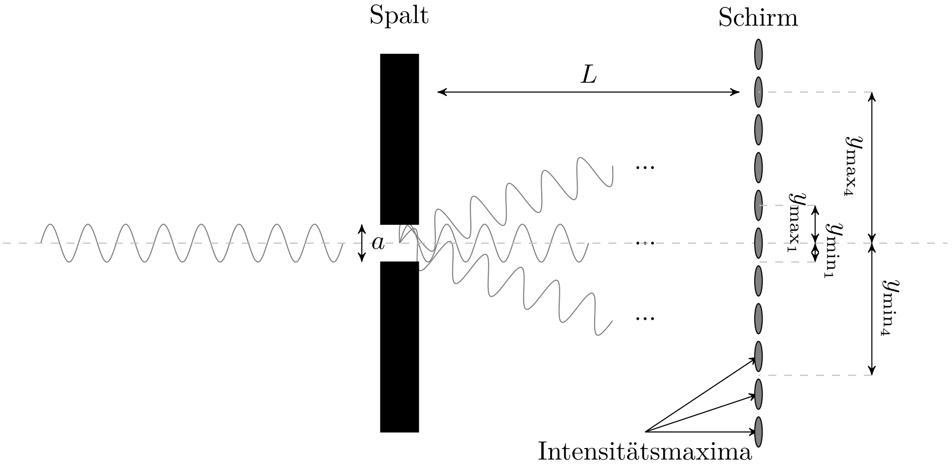


Figure C.22: Einzelspalt der Breite a. Eingezeichnet ist der Winkel zur Berechnung des Abstandes zum ersten Minimum.

Table C.1: Messwerte des Versuches.

| | Messung 1 in m | Messung 2 in m | Messung 3 in m | Messung 4 in m |
|---|---|---|---|---|
| m = 1 | 0,010 | 0,011 | 0,010 | 0,010 |
| m = 2 | 0,023 | 0,022 | 0,023 | 0,021 |
| m = 3 | 0,032 | 0,033 | 0,032 | 0,030 |
| m = 4 | 0,045 | 0,044 | 0,044 | 0,042 |

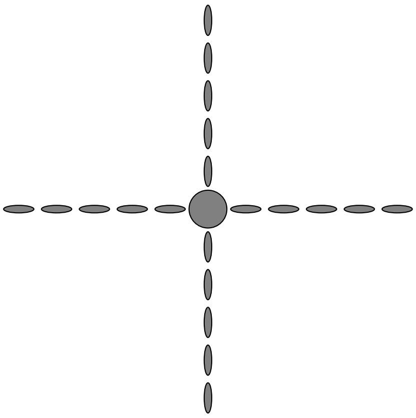


Figure C.23: Beugungsbild gekreuzter Drähte.

## Lösungsvorschläge

1. Sind die Drähte senkrecht zueinander ergibt sich in Näherung folgendes Beugungsbild (siehe Figure C.23).

2. Gemäß der Formel $mL\lambda = \text{konst.} = y_m \cdot a$ müssen für größere Spaltbreite $a$ die Abstände zu den Minima und Maxima abnehmen.

3. Die Mittelwerte betragen: $\bar{y}_m = \{0,010\text{ m}; 0,022\text{ m}; 0,032\text{ m}; 0,044\text{ m}\}$. Dann ist $\bar{y}_m = 0,027$ m. Die Spaltbreiten betragen demzufolge ($a = mL\lambda/y_m$): $a = \{63,4\ \mu\text{m}; 58,4\ \mu\text{m}; 61,4\ \mu\text{m}; 59,4\ \mu\text{m}\}$. Der Mittelwert aus den Spaltbreiten beträgt $a = 60,7\ \mu$m.

4. Die Messunsicherheit einer abhängigen Variablen (hier: Spaltbreite $a$) kann von mehreren gemessenen Variablen abhängen (hier: Wellenlänge des Laserlichtes, Abstand Spalt-Schirm, Abstand der Minima). Für die unterschiedlichen Größen müssen die Messunsicherheiten angegeben werden. Wir gehen zur Vereinfachung im Folgenden davon aus, dass die Wellenlänge fehlerfrei gemessen wurde. Im Weiteren wurde der Abstand Spalt-Schirm mit einer Genauigkeit von $\Delta L = 0,01$ m (kleinste Skaleneinheit) gemessen und die Minima mit einer Genauigkeit von $\Delta y_m = 0,001$ m (kleinste Skaleneinheit). Eine Methode zur Abschätzung des Gesamtfehlers ist das Gesetz der linearen Fehlerfortpflanzung. Nach dieser Methode wird der Gesamtfehler einer Funktion $y = y(x_1, x_2, \dots)$ wie folgt berechnet:

$$\Delta y = \left|\frac{\partial y}{\partial x_1}\right|\Delta x_1 + \left|\frac{\partial y}{\partial x_2}\right|\Delta x_2 + \dots$$

Hierbei sind die $x_1, x_2, \dots$ die gemessenen Variablen. Angewendet auf das obige Beispiel ergibt: $y = a, \Delta y = \Delta a, x_1 = L, x_2 = y_m, x_3 = \lambda, \Delta x_1 = \Delta L, \Delta x_2 = \Delta y_m, \Delta x_3 = 0$.

$$\Delta a = \left|\frac{m\lambda}{y_m}\right|\Delta L + \left|\frac{m\lambda L}{y_m^2}\right|\Delta y_m = \dots = 1,1\ \mu\text{m}.$$

Die Spaltbreite beträgt $a = (61 \pm 1)\ \mu$m.

# Experiment: Die Suche nach der wahren Form der DNA

In den 1940er Jahren rechnete die Forschungswelt damit, dass die Form der DNA gänzlich enthüllt würde. Anfang der 40er Jahre hatte man schon entdeckt, dass die DNA eine Kette ohne Abzweigung war, sodass nun nur noch der Aufbau der Kette erforscht werden musste. Das Experiment, welches zu der Erkenntnis geführt hat, dass die DNA eine Doppelhelix ist, wird im Folgenden nachgestellt.

Wesentlicher Aspekt des Experimentes ist die Interferenz an der DNA. Da die DNA viel zu klein ist, um sichtbares Licht an ihr zu beugen, verwenden Sie ein Modell. Dieses Modell sind zwei gekreuzte Drähte. Warum zwei gekreuzte Drähte eine geeignete Modellierung darstellen sehen sie in Figure C.24. In Figure C.24 ist die Seitenansicht einer Doppelhelix dargestellt. Der vergrößerte Ausschnitt zeigt den Bereich auf den die Strahlung trifft, die dort gebeugt wird.

Für die menschliche DNA wurde dieser Versuch mithilfe einer Röntgenquelle durchgeführt, da die Wellenlänge des sichtbaren Lichtes zu groß im Vergleich zur DNA ist. Es wird hier aus Sicherheitsgründen ein Laser im sichtbaren Bereich

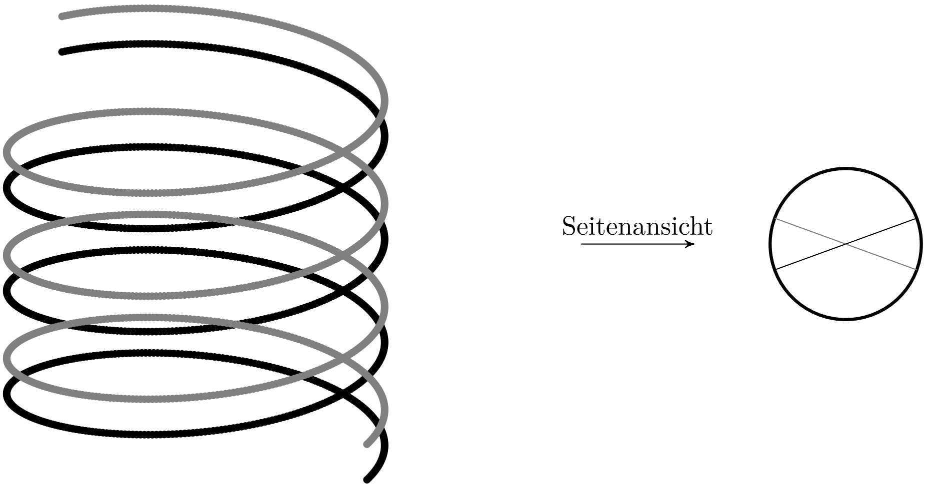


Figure C.24: Seitenansicht der DNA-Struktur.

des elektromagnetischen Spektrums genutzt. Darüber hinaus stellen wir die DNA in einem DNA-Modell dar, welches um einen Faktor von ca. 1000 größer als unsere eigene DNA ist.

### Material

- Laser (grün: $\lambda = 532$ nm oder rot: $\lambda = 650$ nm)
- DNA-Modell im Plexiglasquader
- weißer, matter Schirm (auf den Papier geklebt werden kann)
- Stativmaterial

**ACHTUNG: Richten sie den Laser niemals auf andere Personen oder reflektierende oder metallische Oberflächen. Richten sie den Laser immer fern von Durchgangswegen und schalten sie den Laser nur ein, wenn sie Werte aufnehmen. Achten sie weiter darauf nicht mit reflektierenden Gegenständen, wie Metallstiften oder Armbanduhren in den Strahl zu gelangen.**

### Aufgaben

1. Betrachten Sie das DNA-Modell im Plexiglas. Skizzieren Sie das erwartete Beugungsmuster, welches Sie auf dem Schirm erwarten, wenn man die Mitte des DNA-Modells mit einem Laser ausstrahlt. Schätzen Sie weiter die Dicke der einzelnen Drähte im DNA-Modell. Hinweis: Das Beugungsbild eines Spaltes der Breite d und das Beugungsbild eines Hindernisses (z.B. Draht) der Dicke d sind in guter Näherung identisch.
    - Holen Sie sich nun einen Laser vom Lehrerpult und legen Sie diesen auf den Holzblock. Stellen Sie nun das DNA-Modell im Plexiglas nahe an den Laserpointer. Achten Sie darauf, dass die Drähte sich in einem Punkt kreuzen.

- Stellen Sie den Schirm ca. einen Meter von der Probe entfernt auf, sodass das Beugungsbild auf diesen abgebildet wird.
- Schalten Sie den Laser ein, um ihn auf die Mitte des DNA-Modells auszurichten. Hinweis: Sie können die Neigung des Holzblockes mithilfe des Pappstreifens variieren und den Laserstrahl durch Drehen an der vorderen Kappe fokussieren und somit ein schärferes Bild bekommen. Schalten Sie den Laser auf Dauerbetrieb, indem sie den Knopf mithilfe des Klebestreifens gedrückt halten.

2. Zeichnen Sie das Beugungsmuster in geeigneter Weise nach, sodass sie die Orte der Minima und Maxima bestimmen können.

3. Füllen Sie die untenstehende Tabelle mithilfe der aufgenommenen Minima aus. Berechnen Sie anhand Ihrer Messwerte die Dicke der DNA-Stränge mithilfe der Formel: $d = n\lambda s/x_n$ , wobei n für die Ordnung des Minimums steht, $s$ für den Abstand von Schirm und DNA-Probe und xn für den Abstand vom $n$-ten Minimum zum zentralen Maximum (siehe Figure C.22).

4. In welchem Winkel stehen die einzelnen Stränge zueinander? Berechnen Sie den Winkel anhand des Bildes auf dem Schirm.

5. Vergleichen Sie kritisch Ihre Hypothese aus Aufgabe 1 mit Ihren berechneten Ergebnissen.

6. Stellen Sie auf der Grundlage Ihrer Berechnungen Vermutungen darüber an, wie ein DNA-Strang aussehen könnte. Haben Sie auch eine Idee wie es als 3D-Gebilde aussehen könnte? Erklären Sie, wie ein 2D-Modell aussehen könnte mit dem eine solche Struktur dargestellt würde. Wie könnte die dazugehörige Kette aussehen? Die Probe wurde hier mit einer Wellenlänge von $\lambda = 14 \cdot 10^{-12}$ m bestrahlt. Die Photoplatte (entspricht dem Schirm) stand $1,8$ cm von der Probe entfernt und der Abstand vom 3. Minimum zum Zentrum betrug etwa 2 cm. Berechnen sie die Dicke der DNA-Stränge. Beschreiben sie ihre Vorgehensweise.

7. Als Wissenschaftlerin/Wissenschaftler stehen Sie nun vor der Publikation Ihrer Ergebnisse. Schreiben sie einen Beitrag für eine wissenschaftliche Zeitschrift, in der Sie eine Form Ihrer fiktiven DNA-Probe vorschlagen und in der Sie den Aufbau dieser skizzieren.

# Fachwissenstest Strahlung

**Liebe Teilnehmende!**

Bitte beantworten Sie die folgenden Fragen zu Thema Strahlung. In den meisten Fällen haben Sie vor der jeweiligen Antwortalternative ein Kästchen, in welchem Sie einfach ein Kreuz für ihre Wahl setzen können. In anderen Fällen müssen Sie selbst zeichnerisch tätig werden.
Wenn Sie eine Antwort ändern möchten, streichen Sie Ihre alte Antwort einfach durch.
Weiterhin interessiert uns, wie sicher Sie sich in Ihrer Antwort fühlen. Kreuzen Sie dazu nach jeder Frage an, wie sicher Sie sich bei Ihrer Antwort fühlen
Bitte tragen Sie hier Ihren Teilnehmendencode ein:

**Viel Erfolg bei der Bearbeitung!**

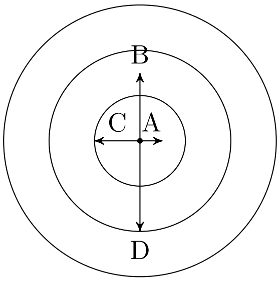
[INTERFERENZ_1] EM-Wellen verschiedener Quellen treffen in einem Punkt A aufeinander. Welche der folgenden Aussagen zur Überlagerung der Wellen im Punkt A ist richtig?

- Die Überlagerung findet nur dann statt, wenn die EM-Wellen im Punkt A dieselbe Phase haben.
- Die Überlagerung findet nur dann statt, wenn alle EM-Wellen dieselbe Wellenlänge haben, während ihre Amplituden nicht gleich sein müssen.
- Die Überlagerung findet nur dann statt, wenn alle EM-Wellen eine konstante Phasendifferenz im Punkt A besitzen.
- Die Überlagerung der EM-Wellen findet unabhängig von Phasendifferenz, Amplitude und Wellenlänge statt.

Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[DARSTELLUNG_1] Die folgende Abbildung zeigt eine einfache Kreiswelle einer bestimmten Wellenlänge $\lambda$. Kreuze die Abbildung an, in welcher die Wellenlänge durch den Pfeil richtig eingezeichnet ist?



Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[ABBILDUNG_1] Wie ändert sich das bestehende Interferenzmuster eines Einzelspaltes, wenn der Schirm eine halbe Wellenlänge vom Spalt weggeschoben wird?

- Maxima werden zu Minima und umgekehrt.
- Maxima und Minima werden schmaler.
- Maxima und Minima werden breiter.
- Maxima werden schmaler, während Minima breiter werden.
- Maxima werden breiter, während Minima schmaler werden.

Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[BEUGUNG_1] Abbildung A zeigt eine ebene Welle, die von links nach rechts verläuft und auf ein lichtundurchlässiges Hindernis trifft. In Abbildung B trifft die Welle auf einen Spalt mit den gleichen Abmessungen wie das vorherige Hindernis.
Welche der folgenden Aussagen trifft für die Intensitätsverteilungen auf einem Schirm, der in jeweils gleichen Abstand hinter dem Hindernis/Spalt positioniert ist, zu?

Abbildung 1

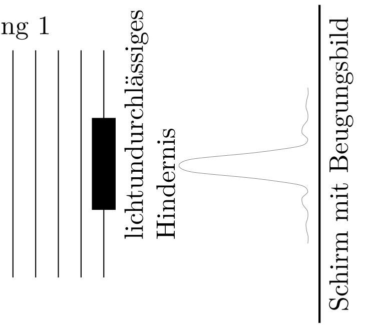
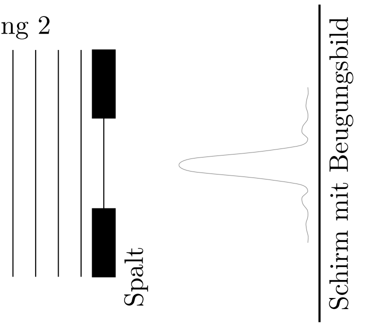


Abbildung 2



- Beide Graphen stellen die zugehörigen Intensitätsverteilungen qualitativ korrekt dar.
- Keiner der Graphen stellt die zugehörigen Intensitätsverteilungen qualitativ korrekt dar.

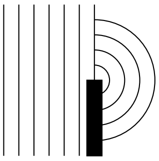
- Nur der Graph aus Abbildung A stellt die zugehörigen Intensitätsverteilungen qualitativ korrekt dar.
- Nur der Graph aus Abbildung B stellt die zugehörigen Intensitätsverteilungen qualitativ korrekt dar.

Wie sicher fühlen Sie sich bei Ihrer Antwort?

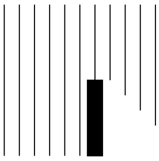
☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[ELEMENTARWELLE_1] Eine ebene Welle verläuft von links nach rechts und trifft auf eine scharfe Kante eines lichtundurchlässigen Objektes. Welche der folgenden Abbildungen gibt am besten die Form der Wellenfronten auf der rechten Seite des Objektes wieder?

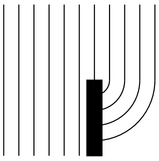
A



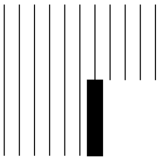
C



B



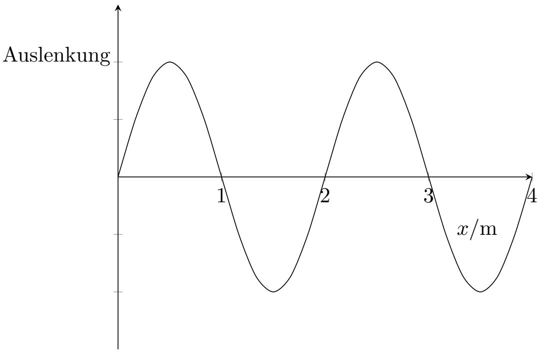
D



Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

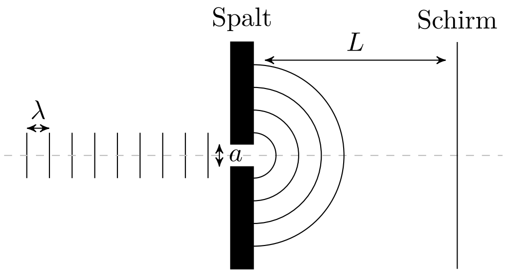
[DARSTELLUNG_2] In der folgenden Abbildung sehen Sie einen Teil einer EM-Welle. Bitte trage in das Feld die Wellenlänge der Welle ein. Die Wellenlänge beträgt … m.



Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[BEUGUNG_2] Im Folgenden trifft von links eine Welle auf einen Spalt. Welches Phänomen ist auf folgender Skizze dargestellt?



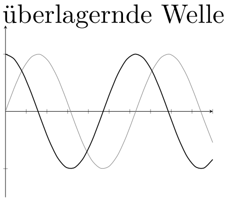
- Polarisation
- Brechung
- Interferenz/Beugung
- Dispersion

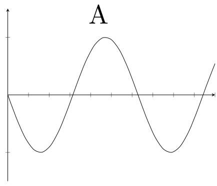
Wie sicher fühlen Sie sich bei Ihrer Antwort?

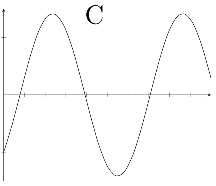
☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

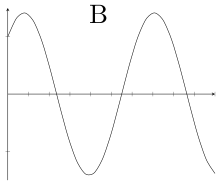
[INTERFERENZ_2] Zwei Wellen (dünn und dick gezeichnet) überlagern einander (siehe Abbildung). Welches ist die sich ergebende Welle.

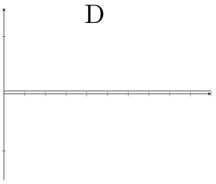
Sich überlagernde Wellen:




A


C

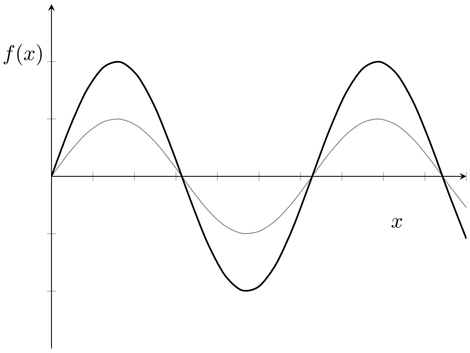

B


D

Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[INTERFERENZ_3] Zwei Wellen überlagern sich. Zeichnen Sie die resultierende Welle, die sich ergibt, wenn sich die dünn gezeichnete sowie die dick gezeichnete Welle überlagern.



Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[INTERFERENZ_4] Was geschieht bei konstruktiver Interferenz?

- Amplituden nehmen zu
- Wellenlängen nehmen zu
- Frequenzen nehmen zu
- Phasen gleichen sich an

Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

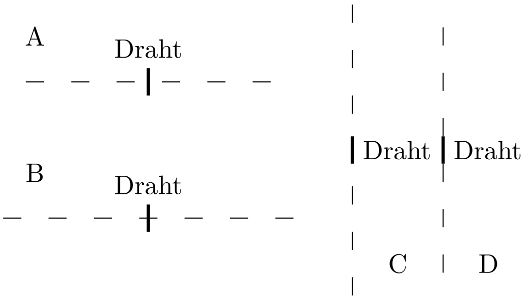
[SPEKTRUM_1] Was unterscheidet (unter anderem) sichtbares Licht von Mikrowellen?

- Mikrowellen können nicht ohne Elektrizität erzeugt werden, sichtbares Licht schon.
- Die Wellenlänge sichtbaren Lichtes ist kleiner, als die Wellenlänge von Mikrowellen.
- Mikrowellen breiten sich schneller aus, als sichtbares Licht.
- Mikrowellen breiten sich wellenförmig aus, während sichtbares Licht sich gradlinig ausbreitet.

Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[BEUGUNG_3] Welche Skizze beschreibt das Interferenzbild eines senkrechten Drahtes am ehesten? Hierbei sind dunkle Streifen Stellen hoher Intensität (Verstärkung).



Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

[ELEMENTARWELLE_2] Die dunklen Punkte sind Quellen von Elementarwellen. Zeichnen Sie in Abbildung A und Abbildung B jeweils zwei resultierende Wellenfronten ein.

Abbildung A:

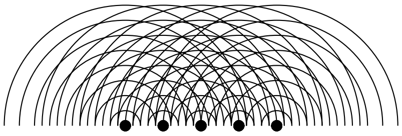
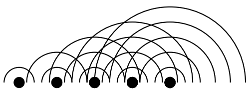


Abbildung B:



Wie sicher fühlen Sie sich bei Ihrer Antwort?

☐ sehr sicher ☐ eher sicher ☐ eher unsicher ☐ sehr unsicher

Table C.2: Item statistics for CK test in study 3.

| | Time 1 ($\alpha_1 = 0.71$) | | | | Time 2 ($\alpha_2 = 0.46$) | | | |
|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | $\alpha_{(-i)}$[a] | $r_{ij}$ | *M* | *SD* | $\alpha_{(-i)}$ | $r_{ij}$ |
| INTERFERENZ_1.c | 0.52 | 0.51 | 0.72 | 0.20 | 0.89 | 0.32 | 0.46 | 0.08 |
| DARSTELLUNG_1.c | 0.56 | 0.51 | 0.67 | 0.17 | 0.85 | 0.36 | 0.46 | 0.09 |
| ABBILDUNG_1.c | 0.19 | 0.40 | 0.71 | 0.19 | 0.44 | 0.51 | 0.33 | 0.05 |
| BEUGUNG_1.c | 0.30 | 0.47 | 0.70 | 0.19 | 0.63 | 0.49 | 0.52 | 0.10 |
| ELEMENTARWELLE_1.c | 0.33 | 0.48 | 0.69 | 0.18 | 0.37 | 0.49 | 0.36 | 0.06 |
| DARSTELLUNG_2.c | 0.78 | 0.42 | 0.68 | 0.17 | 0.89 | 0.32 | 0.40 | 0.06 |
| BEUGUNG_2.c | 0.67 | 0.48 | 0.64 | 0.15 | 0.85 | 0.36 | 0.51 | 0.10 |
| INTERFERENZ_2.c | 0.56 | 0.51 | 0.65 | 0.16 | 0.85 | 0.36 | 0.44 | 0.08 |
| INTERFERENZ_4.c | 0.63 | 0.49 | 0.68 | 0.17 | 1.00 | 0.00 | 0.44 | 0.07 |
| SPEKTRUM_1.c | 0.56 | 0.51 | 0.68 | 0.17 | 0.74 | 0.45 | 0.41 | 0.06 |
| BEUGUNG_3.c | 0.33 | 0.48 | 0.71 | 0.19 | 0.56 | 0.51 | | |

[a] $\alpha_{(-i)}$ refers to the internal consistency (Cronbach's $\alpha$) for the whole scale without the current item. $r_{ij}$ refers to the discriminatory power of the item.

## Appendix D

# Materials study 4

Table D.1: Overview of measures at time 1 with group differences and gender differences.[b]

| | Treatment | | | | Control | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | female | | male | | female | | male | | $F_{\mathrm{Ge}}{}^{a}$ | $p$ | $F_{\mathrm{Gr}}$ | $p$ | $F_{\mathrm{Ge \times Gr}}$ | $p$ |
| Sense of belonging | 4.56 | 0.59 | 4.89 | 0.41 | 4.03 | 0.92 | 4.39 | 0.60 | 5.03 | $< .05$ | 6.75 | $< .05$ | 0.00 | .95 |
| Expectancy physics | 4.48 | 0.93 | 4.51 | 1.06 | 4.50 | 0.94 | 4.45 | 1.48 | 0.00 | .97 | 0.00 | .96 | 0.01 | .91 |
| Support by teachers | 3.38 | 0.89 | 3.91 | 0.96 | 3.10 | 1.01 | 4.00 | 0.67 | 5.43 | $< .05$ | 0.13 | .72 | 0.36 | .55 |
| Support by parents | 3.16 | 1.12 | 3.09 | 1.05 | 2.90 | 1.46 | 2.13 | 0.99 | 0.32 | .57 | 2.19 | .15 | 0.84 | .37 |
| Support by friends | 2.09 | 0.76 | 2.94 | 1.16 | 2.14 | 0.81 | 2.93 | 1.42 | 7.51 | $< .01$ | 0.01 | .94 | 0.01 | .93 |
| Science peer relations | 3.30 | 1.46 | 4.69 | 1.18 | 3.43 | 1.24 | 4.50 | 1.51 | 11.06 | $< .01$ | 0.00 | .97 | 0.13 | .72 |
| Possible science self | 5.13 | 0.77 | 4.99 | 0.96 | 5.43 | 0.80 | 5.60 | 0.86 | 0.17 | .69 | 2.20 | .15 | 0.28 | .60 |
| Age | 16.71 | 0.68 | 16.81 | 0.92 | 16.42 | 0.71 | 17.19 | 0.44 | 1.42 | .24 | 0.00 | .95 | 1.62 | .21 |
| Competition achievement | 29.77 | 6.93 | 32.94 | 7.33 | 30.79 | 5.77 | 28.70 | 10.46 | 0.77 | .38 | 0.29 | .59 | 1.10 | .30 |
| Entity mind set | 2.56 | 1.06 | 2.54 | 1.08 | 2.62 | 1.01 | 2.20 | 1.26 | 0.12 | .73 | 0.10 | .75 | 0.29 | .59 |
| Incremental mind set | 4.71 | 0.71 | 4.87 | 0.78 | 4.67 | 0.67 | 4.87 | 1.32 | 0.50 | .48 | 0.01 | .93 | 0.01 | .94 |
| Study aspiration (physics) | 60.53 | 32.94 | 67.06 | 31.62 | 82.00 | 14.19 | 69.60 | 23.20 | 0.00 | .98 | 1.68 | .20 | 0.89 | .35 |
| Socioeconomic background | 3.87 | 1.06 | 4.06 | 1.58 | 3.43 | 1.69 | 2.50 | 1.00 | 0.00 | .98 | 3.98 | .05 | 1.39 | .25 |

[a] One-way ANOVA was used to determine mean differences for the samples.

[b] Note that due to multiple comparisons, only large values for the $F$ statistic (that relate to theoretical prediction) should be interpreted. Note that the overall gist of the differences can be replicated with a Bayesian modelling approach, except that science peer relations, and peer support do not show such a high gender effect. Maybe this comes from the fact that the normality assumption in the ANOVA is untenable.

Table D.2: Estimates multilevel models with covariates (scaled) for sense of belonging and expectancy of success.

| | Sense of belonging | | | Expectancy of success | | |
|---|---|---|---|---|---|---|
| Variable | $b^*$ | $SE(b^*)$ | 95% CI | $b^*$ | $SE(b^*)$ | 95% CI |
| Intercept | 4.45 | 0.14 | [4.17,4.73] | 4.44 | 0.31 | [3.82,5.06] |
| Time | 0.00 | 0.04 | [-0.08,0.08] | 0.03 | 0.05 | [-0.07,0.13] |
| Group (control) | -0.69 | 0.19 | [-1.07,-0.31] | -0.25 | 0.44 | [-1.13,0.63] |
| Gender (male) | 0.57 | 0.19 | [0.19,0.95] | 0.09 | 0.43 | [-0.77,0.95] |
| Support by teachers | 0.16 | 0.09 | [-0.02,0.34] | 0.09 | 0.21 | [-0.33,0.51] |
| Support by parents | 0.05 | 0.09 | [-0.13,0.23] | 0.12 | 0.20 | [-0.28,0.52] |
| Support by friends | 0.00 | 0.10 | [-0.2,0.2] | 0.08 | 0.23 | [-0.38,0.54] |
| Science peer relations | -0.26 | 0.09 | [-0.44,-0.08] | -0.22 | 0.22 | [-0.66,0.22] |
| Possible science self | 0.28 | 0.09 | [0.1,0.46] | 0.36 | 0.20 | [-0.04,0.76] |
| Socioeconomic background | -0.06 | 0.09 | [-0.24,0.12] | -0.12 | 0.20 | [-0.52,0.28] |
| Competition achievement | -0.12 | 0.09 | [-0.3,0.06] | 0.08 | 0.20 | [-0.32,0.48] |
| Time × Group (control) | 0.10 | 0.05 | [0,0.2] | 0.03 | 0.08 | [-0.13,0.19] |
| Time × Gender (male) | -0.01 | 0.05 | [-0.11,0.09] | 0.07 | 0.07 | [-0.07,0.21] |
| Time × SST | -0.03 | 0.03 | [-0.09,0.03] | -0.10 | 0.04 | [-0.18,-0.02] |
| Time × SSP | 0.00 | 0.02 | [-0.04,0.04] | 0.00 | 0.04 | [-0.08,0.08] |
| Time × SSF | -0.03 | 0.03 | [-0.09,0.03] | 0.03 | 0.04 | [-0.05,0.11] |
| Time × SPR | 0.04 | 0.03 | [-0.02,0.1] | 0.01 | 0.04 | [-0.07,0.09] |
| Time × PSS | -0.04 | 0.02 | [-0.08,0] | 0.00 | 0.03 | [-0.06,0.06] |
| Time × SES | -0.02 | 0.02 | [-0.06,0.02] | 0.00 | 0.04 | [-0.08,0.08] |
| Time × Punkte | -0.03 | 0.02 | [-0.07,0.01] | -0.04 | 0.03 | [-0.1,0.02] |
| Var(Inter) | 0.11 | | | 0.89 | | |
| Var(Slope) | 0.01 | | | 0.02 | | |
| Corr. | -0.14 | | | -0.76 | | |
| $R^2$ | 0.08 | | | 0.27 | | |

Table D.3: Correlation table for situational interest subscales.

| Variable | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| 1 Situational interest: task (2) | 3.76 | 0.66 | - | .67*** | .43 | .37 | .53* | .18 | .19 |
| 2 Situational interest: task (3) | 3.67 | 0.69 | | - | .62*** | .50 | .42 | -.03 | .48 |
| 3 Situational interest: task (5) | 3.92 | 0.56 | | | - | .47 | .40 | -.13 | .18 |
| 4 Situational interest: group (2) | 4.21 | 0.55 | | | | - | .49 | .25 | .06 |
| 5 Situational interest: group (5) | 4.28 | 0.51 | | | | | - | .26 | .32 |
| 6 Situational interest: instructor (2)[a] | 4.82 | 0.29 | | | | | | - | -.03 |
| 7 Situational interest: instructor (5)[a] | 4.80 | 0.34 | | | | | | | - |

[a] Note that correlations with instructor are essentially meaningless since values of instructor have a very small range (ceiling effect).

Table D.4: 2-way (2×2)-ANOVA table for situational interest with gender (and group).

| | Treatment | | | | Control | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | female | | male | | female | | male | | | | | | | |
| Variable | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | $F_{\mathrm{Ge}}$ | *p* | $F_{\mathrm{Gr}}$ | *p* | $F_{\mathrm{Ge}\times\mathrm{Gr}}$ | *p* |
| Situational interest: group (2) | 4.20 | 0.47 | 4.21 | 0.63 | | | | | 0.00 | .96 | | | | |
| Situational interest: group (5) | 4.40 | 0.49 | 4.19 | 0.52 | | | | | 1.48 | .23 | | | | |
| Situational interest: instructor (2) | 4.78 | 0.37 | 4.87 | 0.17 | | | | | 0.71 | .41 | | | | |
| Situational interest: instructor (5) | 4.71 | 0.35 | 4.87 | 0.33 | | | | | 1.81 | .19 | | | | |
| Situational interest: task (2) | 3.80 | 0.56 | 3.58 | 0.74 | 4.11 | 0.61 | 3.75 | 0.76 | 1.86 | .18 | 1.21 | .28 | 0.08 | .77 |
| Situational interest: task (3) | 3.54 | 0.53 | 3.69 | 0.58 | 3.80 | 1.00 | 3.83 | 1.01 | 0.19 | .66 | 0.75 | .39 | 0.07 | .79 |
| Situational interest: task (5) | 3.97 | 0.51 | 3.92 | 0.54 | 4.05 | 0.70 | 3.58 | 0.66 | 0.80 | .38 | 0.30 | .58 | 1.22 | .28 |

Table D.5: Modelling the effects from design elements of the seminar program on the slope for sense of belonging.

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| | $b^*$ | $SE(b^*)$ | $b^*$ | $SE(b^*)$ | $b^*$ | $SE(b^*)$ | $b^*$ | $SE(b^*)$ |
| Intercept | -0.75 | 0.24 | -0.56 | 0.17 | -0.57 | 0.17 | -0.44 | 0.07 |
| Gender (male) | 0.4 | 0.36 | 0 | 0.02 | | | | |
| Situational interest: task | 0.08 | 0.03 | 0.06 | 0.02 | 0.06 | 0.02 | 0.06 | 0.02 |
| Situational interest: group | 0.01 | 0.04 | 0.04 | 0.02 | 0.04 | 0.02 | 0.05 | 0.02 |
| Situational interest: instructor | 0.08 | 0.06 | 0.03 | 0.04 | 0.03 | 0.04 | | |
| Gender (male) × Sit. int.: task | -0.04 | 0.04 | | | | | | |
| Gender (male) × Sit. int.: group | 0.04 | 0.05 | | | | | | |
| Gender (male) × Sit. int.: instructor | -0.09 | 0.08 | | | | | | |
| $R^2_{\text{adj}}$ | 0.48 | | 0.49 | | 0.51 | | 0.51 | |

[a] $F$-tests between the models (from full to restricted) yield: $F_{12}(\Delta df = -3) = 0.74, p = .54$; $F_{23}(\Delta df = -1) = 0.07, p = .79$; $F_{34}(\Delta df = -1) = 0.78, p = .38$; $F_{45}(\Delta df = -2) = 17.69, p < .001$. Note that model 6 is the only-intercept model.

Table D.6: Logistic regression for dropout from intervention and further participation in Physics Olympiad (treatment group).

| | $b^*$ | $SE(b^*)$ | $OR$ | $z$ | $p$ |
|---|---|---|---|---|---|
| (Intercept) | 0.63 | 0.65 | 1.88 | 0.97 | .33 |
| Gender | -0.68 | 1.01 | 0.51 | -0.67 | .50 |
| Support by teachers | -0.4 | 0.52 | 0.67 | -0.77 | .44 |
| Support by parents | 0.6 | 0.57 | 1.82 | 1.05 | .29 |
| Support by friends | -0.57 | 0.58 | 0.56 | -0.99 | .32 |
| Science peer relations | 1.13 | 0.65 | 3.1 | 1.75 | .08 |
| Possible science self | -0.17 | 0.49 | 0.84 | -0.35 | .73 |
| Socioeconomic background | -0.87 | 0.55 | 0.42 | -1.59 | .11 |
| Competition achievement | 0.02 | 0.51 | 1.02 | 0.04 | .97 |
| Situational interest | -1.21 | 1.34 | 0.3 | -0.9 | .37 |

Table D.7: Logistic regression for dropout from intervention and further participation in Physics Olympiad (control group).

| | $b^*$ | $SE(b^*)$ | $OR$ | $z$ | $p$ |
|---|---|---|---|---|---|
| (Intercept) | 0.08 | 0.61 | 1.09 | 0.14 | .89 |
| Science peer relations | -0.27 | 0.69 | 0.76 | -0.4 | .69 |
| Competition achievement | 0.47 | 0.64 | 1.6 | 0.73 | .47 |
| Situational interest | -0.5 | 0.8 | 0.61 | -0.62 | .53 |

# Learning materials study 4

## Experiment: Ein winziger Elektromotor

Mit einfachsten Alltagsgegenständen könnt ihr einen faszinierenden kleinen Elektromotor herstellen. Dies ist deine Aufgabe! Nutzt dazu die folgenden Materialien:

- 1x AA-Batterie
- 1x elektrisch leitfähige Schraube
- 1x starke (Neodym-)Magnet (es ist wichtig, dass der Magnet stark ist. Solltet ihr keinen Magneten zu Hause haben, fragt einfach in eurer Schule nach. Ansonsten kann man auch recht preisgünstig mehrere starke Magnete über Internet kaufen)
- 1x Duplo-Schokoriegel (alternativ geht auch ein ca. 10 cm langes Kabel - auf Isolation achten)

### Aufgabe

Besorgt euch die entsprechenden Materialien und bastelt den Elektromotor. Wenn ihr einen funktionsfähigen Motor habe (um den Spaß nicht zu verderben, solltet ihr davon absehen im Internet nachzusehen), dann nehmt ein kurzes Video mit dem funktionsfähigen Motor auf. Schreibt dann einen kurzen Text, in dem ihr euren Erklärungsvorschlag für den Elektromotor präsentiert.

## Lösungvorschlag

Auf Ihrem Platz finden Sie eine Batterie, einen starken Magneten, eine Schraube sowie einen Schokoladenriegel mit einer teilweise leitenden Verpackung.

Überlegt euch eine Möglichkeit mit diesen Materialien einen Elektromotor zu bauen.

Das Alupapier kann als Leiter für den rechts abgebildeten Versuchsaufbau verwendet werden. Hält man das eine Ende des Papiers an den einen Pol der Batterie und das andere an die Seite des Magneten, so beginnt sich die Schraube mit dem Magneten zu drehen. Dieser so genannte Unipolar- oder Monopolarmotor lässt sich auch auf andere Weise realisieren.

## Impulssatz

Aus den Newton'schen Grundgesetzen der Mechanik kann man einen weiteren fundamentalen Erhaltungssatz der Mechanik ableiten: Den Impulserhaltungssatz[1]. Hierzu betrachte man allgemein zwei Körper (siehe Figure D.2). Diese können als Massepunkte aufgefasst werden. Der Einfachheit halber (aber ohne Verletzung der Allgemeinheit) reduzieren wir das Problem auf den eindimensionalen Fall: Die beiden Massepunkte bewegen sich auf einer Geraden.

---

[1] Herleitung angelehnt an leifiphysik.de.

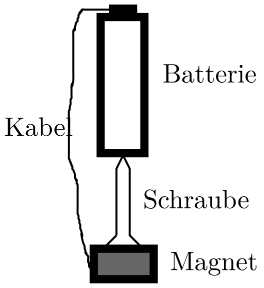


Figure D.1: Grafische Darstellung einer Realisierung eines Elektromotors mit den gegebenen Materialien.

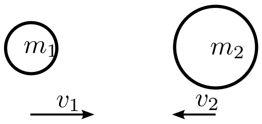


Figure D.2: Zwei Massepunkte kollidieren miteinander.

Eine dritte Annahme besteht darin anzunehmen, dass die Beschleunigungen während des Stoßes der beiden Körper konstant seien und keine äußeren Beschleunigungen auf die Massen wirken.

### Aufgabe und Lösung

Im Moment der Kollision: Stellt die 3. Newton'sche Axion (Actio gleich Reaction) für diesen Fall auf.

Es gilt

$$-F_{12} = F_{21}. \tag{D.1}$$

### Aufgabe und Lösung

Für den gleichen Moment: Stellt das 2. Newton'sche Axiom (Kraftgesetz) auf. Ersetzt die Beschleunigung (mit der Annahme konstanter Beschleunigung) durch $\Delta v/\Delta t$ und multipliziert die erhaltene Gleichung mit $\Delta t$. Was sagt euch die erhaltene Gleichung?

Newton 2 eingesetzt in Gleichung (D.1) ergibt:

$$-m_1 \cdot a_1 = m_2 \cdot a_2.$$

Unter der Annahme konstanter Beschleunigung kann man schreiben:

$$-m_1 \cdot \frac{\Delta v_1}{\Delta t} = m_2 \cdot \frac{\Delta v_2}{\Delta t}.$$

$\Delta t$ kürzt sich raus und es bleibt:

$$\begin{aligned} -m_1 \cdot \Delta v_1 &= m_2 \cdot \Delta v_2 \\ -m_1 \cdot (v_1' - v_1) &= m_2 \cdot (v_2' - v_2). \end{aligned}$$

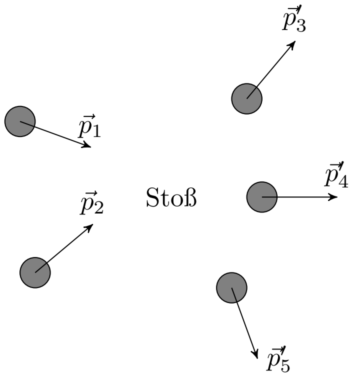


Figure D.3: Grafische Veranschaulichung des Impulssatzes.

Die Differenz $(v' - v)$ bedeutet hierbei die Veränderung der Geschwindigkeit eines Körpers von vor zu nach dem Stoß. Nach Umstellen folgt:

$$m_1 \cdot v_1 + m_2 \cdot v_2 = m_1 \cdot v_1' + m_2 \cdot v_2'.$$

Das ist der Impulserhaltungssatz für eine Dimension. Auf der linken Seite steht der Gesamtimpuls des abgeschlossenen Systems (zwei Massepunkte) vor dem Stoß. Auf der rechten Seite steht der Gesamtimpuls des abgeschlossenen Systems nach dem Stoß. Auch beim Impulssatz ist es deshalb unabdingbar, das System genau zu definieren.

## Steckbrief Impuls und Impulssatz

Definition Impuls: Besitzt ein Körper eine Masse $m$ und eine Geschwindigkeit $\vec{v}$, so ist dessen Impuls definiert als

$$\vec{p} = m \cdot \vec{v}.$$

$$\text{Formelzeichen:}p \qquad \text{Einheit:}[p] = \text{kg} \cdot \frac{\text{m}}{\text{s}} = \text{N} \cdot \text{s}$$

Definition Impuls(erhaltungs)satz: In einem abgeschlossenen System ist die vektorielle Summe der Impulsvektoren vor der Wechselwirkung gleich der vektoriellen Summe der Impulsvektoren nach der Wechselwirkung: $\vec{p_1} + \vec{p_2} = \vec{p_3}' + \vec{p_4}' + \vec{p_5}'$ (siehe Figure D.3).

## Aufgaben Impulssatz

### Aufgabe Mensch im Boot[2]

Ein Mensch mit der Masse $m = 50$ kg steht in einem Boot mit der Masse $m = 150$ kg, das im Wasser ruht (siehe Figure D.4). Der Mensch geht nun mit der Geschwindigkeit $0,75$ m $\text{s}^{-1}$ - vom Wasser aus betrachtet - im Boot nach rechts (positive Richtung). Gib an, wie sich das Boot verhält.

---

[2] Aus: leifiphysik.de.

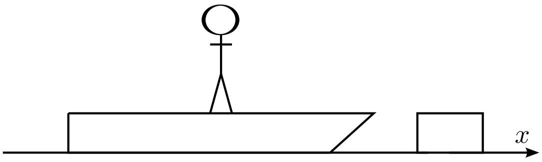


Figure D.4: Skizze Aufgabe Mensch im Boot.

1. Berechne die Geschwindigkeit des Bootes relativ zum Wasser.
2. Berechne die Geschwindigkeit des Menschen relativ zum Boot.
3. Der Mensch bleibt wieder stehen. Wie verhält sich das Boot?

### Lösung Mensch im Boot

1. Das Boot bewegt sich aufgrund des Impulserhaltungssatzes nach links (negative x-Richtung). Berechnung der Bootsgeschwindigkeit $u_B$ relativ zum Wasser mit Hilfe des Impulserhaltungssatzes: Da die Summe aller Impulse vor dem Abdrücken gleich der Summe aller Impulse nach dem Abdrücken ist, gilt

$$\begin{aligned} 0 &= m_B \cdot u_B + m_M \cdot u_M \\ \Rightarrow u_B &= -\frac{m_J}{m_B} \cdot u_M. \end{aligned}$$

Einsetzen der gegebenen Werte liefert $u_B = -\frac{50\text{ kg}}{150\text{ kg}} \cdot 0,75\text{ m s}^{-1} = -0,25\text{ m s}^{-1}$. Berechnung der Geschwindigkeit $u_M*$ des Menschen relativ zum Boot: Die Relativgeschwindigkeit des Systems Boot zum Wasser ist $u_{B,W} = -0,25\text{ m s}^{-1}$; somit gilt

$$\begin{aligned} u_M = u_{B,W} + u_M* \Leftrightarrow u_M* &= u_M - u_{B,W} \\ &\Rightarrow 0,75\text{ m s}^{-1} - (-0,25\text{ m s}^{-1}) = 1,0\text{ m s}^{-1}. \end{aligned}$$

2. Das Boot muss auch wieder zum Stehen kommen. Es handelt sich um ein abgeschlossenes System, auf das keine äußeren Kräfte wirken. Somit muss der Gesamtimpuls erhalten bleiben. Da dieser vorher Null war, muss er nachher auch Null sein. Da der ruhende Junge keinen Impuls hat, darf auch das Boot keinen Impuls haben.

### Aufgabe Prinzip des Raketenantriebs[3]

Auf einer horizontalen Ebene steht eine Frau auf einem Wagen, der reibungsfrei beweglich ist (Figure D.5). Frau und Wagen haben zusammen die Masse $m_E$. Zusätzlich befinden sich auf dem Wagen $N$ Pflastersteine (Treibstoff), so dass die Gesamtmasse $m_A$ ist. Die Frau wirft nun die Steine in horizontaler Richtung nach hinten, so dass die Relativgeschwindigkeit der Steine bezüglich des Wagens (der Rakete) $v_{\text{rel}}$ beträgt (Ausstoßgeschwindigkeit). Zahlenbeispiel: $m_A = 250\text{ kg}; \mathrm{m_E} = 100\text{ kg}; \mathrm{N} = 3; \mathrm{v_{rel}} = -10\text{m s}^{-1}; \Delta\mathrm{m} = \frac{\mathrm{m_E} - \mathrm{m_A}}{\mathrm{N}} = -50\text{ kg}$.

---

[3] Aus: leifiphysik.de.

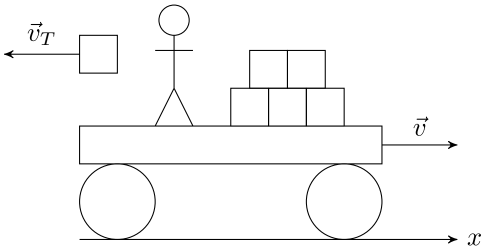


Figure D.5: Modellhafter Raketenantrieb (hier dargestellt mit $N = 6$ Pflastersteinen).

1. Überlegt euch den Zusammenhang zwischen der Geschwindigkeit $v_{\text{rel}}$, der Geschwindigkeit $v_T$ des Geschosses nach dem Stoß und der Geschwindigkeit des Wagens (Rakete) $v$.
2. Berechnet die Geschwindigkeit $v_1$ des Wagens nach dem ersten Ausstoß.
3. Berechnet nun auch die Geschwindigkeiten des Wagens $v_2$ und $v_3$ nach dem zweiten und dritten Ausstoß.
4. Die Geschwindigkeitszunahme des Wagens nach dem 1. Ausstoß sei $\Delta v_{10}$. Die Geschwindigkeitszunahme nach dem 2. Ausstoß $\Delta v_{21}$, nach dem 3. Ausstoß $\Delta v_{32}$. Warum wird die Geschwindigkeitszunahme der Rakete von Ausstoß zu Ausstoß immer größer?

**Lösung Prinzit des Raketenantriebs**

1. $v_{\text{rel}}$ ist die Relativgeschwindigkeit von Wagen und ausgestoßenem Treibstoff. Es gilt

$$v_{\text{rel}} = v_T - v. \tag{D.2}$$

Raketengeschwindigkeit (in Bezug zum Boden) nach dem Ausstoß: $v = 3 \text{ m s}^{-1}$, Treibstoffgeschwindigkeit (in Bezug zum Boden) nach dem Ausstoß: $v_T = -7 \text{ m s}^{-1}$, Relativgeschwindigkeit: $v_{\text{rel}} = -7 \text{ m s}^{-1} - 3 \text{ m s}^{-1} = -10 \text{ m s}^{-1}$. Beachte hierbei, dass Geschwindigkeiten in $+x$-Richtung positiv, Geschwindigkeiten in $-x$-Richtung negativ gezählt werden.

2. Erster Ausstoß: Der Wagen (die Rakete) bewegt sich vor dem 1. Ausstoß nicht: Wir bezeichnen mit

$$\begin{aligned}
v_{T,1} &:\text{Geschwindigkeit des Treibstoffes nach dem 1. Ausstoß}\\
v_0 &:\text{Geschwindigkeit der Rakete zu Beginn (hier } v_0 = 0 \text{ m)}\\
v_1 &:\text{Geschwindigkeit der Rakete nach dem 1. Ausstoß}\\
\Delta m_T &:\text{ausgestoßene Treibstoffmasse}\\
\Delta m &:\text{Änderung der Raketenmasse; } \Delta m = -\Delta m_T
\end{aligned}$$

Da die Summe der Impulse vorher gleich der Summe der Impulse nachher sein muss, gilt

$$m_{\text{A}} \cdot v_0 = \Delta m_{\text{T}} \cdot v_{\text{T},1} + (m_{\text{A}} + \Delta m) \cdot v_1$$

mit Gleichung (D.2) und $\Delta m_T = -\Delta m$ ergibt sich

$$\begin{aligned} m_\mathrm{A} \cdot v_0 &= -\Delta m \cdot (v_\mathrm{rel} + v_1) + (m_\mathrm{A} + \Delta m) \cdot v_1 \\ m_\mathrm{A} \cdot (v_1 - v_0) &= \Delta m \cdot v_\mathrm{rel} \end{aligned}$$

Bezeichnen wir die (relative) Geschwindigkeitsänderung $v_1 - v_0$ mit $\Delta v_{10}$, so ergibt sich

$$\Delta v_{10} = \frac{\Delta m}{m_\mathrm{A}} \cdot v_\mathrm{rel} \Rightarrow \Delta v_{10} = \frac{-50\mathrm{kg}}{250\mathrm{kg}} \cdot \left(-10\frac{\mathrm{m}}{\mathrm{s}}\right) = 2,0\frac{\mathrm{m}}{\mathrm{s}}$$

3. Zweiter Ausstoß:

$$(m_\mathrm{A} + \Delta m) \cdot v_1 = \Delta m_\mathrm{T} \cdot v_{\mathrm{T},2} + (m_\mathrm{A} + 2 \cdot \Delta m) \cdot v_2$$

Analog zum ersten Ausstoß ergibt sich

$$\Delta v_{21} = \frac{\Delta m}{m_\mathrm{A} + \Delta m} \cdot v_\mathrm{rel} \Rightarrow \Delta v_{21} = \frac{-50\mathrm{kg}}{200\mathrm{kg}} \cdot \left(-10\frac{\mathrm{m}}{\mathrm{s}}\right) = 2,5\frac{\mathrm{m}}{\mathrm{s}}$$

Da die Rakete vor dem Ausstoß schon die Geschwindigkeit $2,0$ m s$^{-1}$ besaß, hat sie nach dem 2. Ausstoß die Geschwindigkeit $4,5$ m s$^{-1}$. Für den 3. Ausstoß folgt: Da auch hier die Summe der Impulse vorher gleich der Summe der Impulse nachher sein muss, gilt

$$(m_\mathrm{A} + 2 \cdot \Delta m) \cdot v_2 = \Delta m_\mathrm{T} \cdot v_{\mathrm{T},3} + (m_\mathrm{A} + 3 \cdot \Delta m) \cdot v_3$$

und schließlich

$$\Delta v_{32} = \frac{\Delta m}{m_\mathrm{A} + 2 \cdot \Delta m} \cdot v_\mathrm{rel} \Rightarrow \Delta v_{32} = \frac{-50\mathrm{kg}}{150\mathrm{kg}} \cdot \left(-10\frac{\mathrm{m}}{\mathrm{s}}\right) = 3,3\frac{\mathrm{m}}{\mathrm{s}}$$

Da die Rakete vor dem Ausstoß schon die Geschwindigkeit $4,5$ m s$^{-1}$ besaß, hat sie nach dem 3. Ausstoß die Geschwindigkeit $7,8$ m s$^{-1}$.

4. Der Geschwindigkeitszuwachs wird bei jedem Ausstoß größer, da die zu beschleunigende Masse des Wagens (der Rakete) abnimmt.

[...]

## Physikalische Repräsentationen und Problemlösen

Das Besondere an der Physik ist die Darstellung von Wissen in unterschiedlichen Repräsentationsformen. Die Transformation zwischen unterschiedlichen Repräsentationsformen ist demzufolge eine wichtige Kompetenz und unabdingbar für erfolgreiches physikalisches Problemlösen. Ein Modell zur Beschreibung unterschiedlicher Repräsentationsformen und deren Zusammenwirken stammt von James Greeno (1989).

Greeno stellt fest, dass eine häufig angewendete Strategie im Problemlösen darin besteht, dass auf der symbolischen Ebene nach Entsprechungen in der Problembeschreibung gesucht wird (auch: "plug-and-chug"-Methode oder "formula-based approach" genannt). Das bedeutet, dass man beispielsweise ein Wort liest (z.B.: Kraft) und dann automatisch nach Formeln sucht, die eben diesen

Table D.8: Greeno's Konzeptualisierung des wissenschaftlichen Problemlösens.

| Domäne | Beschreibung | Ebene | Beispiel |
|---|---|---|---|
| Konkret | Physikalische Objekte und Prozesse/Ereignisse | a | Wagen, schiefe Ebene, Rolle |
| | | b | Flaschenzug |
| Modell | Modelle der Realität und Abstraktionen | a | Vektoren |
| | | b | Vektordiagramme |
| Abstrakt | Konzepte, Gesetze und Prinzipien | a | Masse, Beschleunigung, Geschwindigkeit |
| | | b | Newton 2 ($F = ma$) |
| Symbolisch | Sprache und Algebra | a | Worte und Symbole ($E, v, a$) |
| | | b | Sätze und Gleichungen ($E = mgh, F = ma, \dots$) |

Wort beinhalten. Diese Strategie führt zwangsläufig zu inkorrekten Ergebnissen, denn die wichtigen Repräsentationsformen "Modell" und "Abstrakt" (siehe Table D.8) werden nicht berücksichtigt. Häufig resultiert diese Strategie darin, dass das Problem mit ungeeigneten Annahmen und Voraussetzungen gelöst wird.

Wie bereits im Online-Training angedeutet, besteht eine sinnvollere Strategie darin, zunächst das (physikalische) Problem genau zu beschreiben und zu verstehen. Dazu gehört die geeignete Repräsentation des Problems, z.B. als Skizze. Wenn man das Problem geeignet darstellt, dann hat man es oft sehr viel leichter dieses auch zu lösen. In dieser Station werdet ihr an einer exemplarischen Aufgabe die genaue Problembeschreibung trainieren.

### Aufgabe Schwingender Balken:[4]

Ein Balken der Länge $l$ und der Masse $M$ hängt an der Decke, siehe Abbildung. Ein Stück Knete der Masse $m$ kommt mit der Geschwindigkeit $v$ von links auf den Balken zugeflogen. Nach der Kollision klebt die Knete am Balken genau im Mittelpunkt des Balkens.

Wie groß muss die Geschwindigkeit der Knete sein, dass der Balken (mit Knete) zu schwingen beginnt und genau horizontal zum Stillstand kommt, bevor er dann wieder nach unten schwingt?

Nutzt bei eurer Lösung das Problemlöseschema, das im Online-Training präsentiert wurde. Geht bei der Lösung auf folgende Punkte speziell ein:

- Erstellt eine grafische Darstellung des Problems.
- Welche physikalischen Prinzipien wendet ihr zur Lösung dieser Aufgabe an? (Hilfekarte)

---

[4] Angeregt aus: W. J. Leonard, R. J. Dufresne, and J. P. Mestre, Using qualitative problem-solving strategies to highlight the role of conceptual knowledge in solving problems, Am. J. Phys. 64, 1495 (1996).

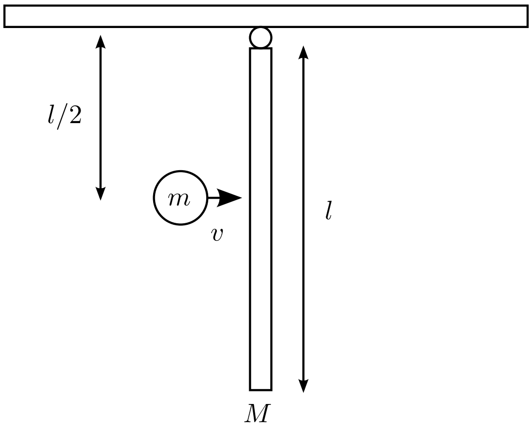


Figure D.6: Darstellung des Problems.

- Warum dürft ihr diese Prinzipien anwenden?

Nachdem ihr sicher seid, das Problem verstanden und qualitativ (ohne Formeln) beschrieben zu haben, versucht es zu lösen.

### Hilfekarte

Die Aufgabe scheint auf den ersten Blick recht kompliziert. Ihr werdet aber sehen, dass ihr mit geeigneten Annahmen diese Aufgabe verhältnismäßig einfach lösen könnt.

Es ist klar, dass es sich bei dem Vorgang um ein Problem aus dem Bereich Mechanik handelt. Es wird demzufolge etwas mit Kraft, Impuls und Energie zu tun haben. Da das Brett drehbar aufgehängt ist, bekommt man ebenso den Eindruck, dass das Drehmoment eine Rolle spielt. Doch muss es so kompliziert sein? Eine geeignete Darstellung des Problems könnte folgendermaßen aussehen (siehe Figure D.6).

### Lösung Schwingender Balken[5]

### Annahmen und qualitative Betrachtung:

- Wir nehmen an, dass es sich bei dem Stoß um einen ideal inelastischen Stoß handelt. Hierfür gilt der Impulserhaltungssatz.

- Der Stoß erfolgt instantan (d.h. in sehr kurzer Zeit). Mit dieser Annahme stellen wir sicher, dass nach dem ersten Auftreffen keine Kraft durch die Masse mehr auf den Balken wirkt.

- Nach dem inelastischen Stoß wirkt auf den ”neuen Stab” nur die Gewichtskraft. Diese wirkt der Bewegung des ”neuen Stabs” entgegen.

- Wir vernachlässigen Reibung (sowohl Luftreibung als auch Reibung durch die Scharniere o.ä.)

---

[5] Dank gilt Stefan Petersen für die zentrale Hinweise zur Lösung der Aufgabe.

**Anwendbare Prinzipien:**

- Energieerhaltungssatz:
  - Zustand 1: kurz vor dem Stoß
  - Zustand 2: gewünschter Endzustand (”neuer Stab” in Horizontale)

Der Drehimpulserhaltungssatz liefert:

$$mv\frac{l}{2} = I_S\omega + m\omega\left(\frac{l}{2}\right)^2$$

Das Trägheitsmoment des Stabes beträgt $I_S = \frac{1}{12}Ml^2 = \frac{1}{4}M\left(\frac{l}{2}\right)^2$. Die kinetische Rotationsenergie direkt nach dem inelastischen Stoß beträgt:

$$E_{\text{kin}} = \frac{1}{2}\left(I_S + m\left(\frac{l}{2}\right)^2\right)\omega^2.$$

Diese muss gleich der potentiellen Energie sein, die notwendig ist, um den Stab in die Horizontale zu bewegen:

$$E_{\text{kin}} = \Delta E_{\text{pot}} = (M+m)g\frac{l}{2}.$$

Es folgt:

$$\frac{1}{2}\left(I_S + m\left(\frac{l}{2}\right)^2\right)\omega^2 = (M+m)g\frac{l}{2}.$$

Ersetzt man nun die Winkelgeschwindigkeit $\omega$ durch $v/\frac{l}{2}$. Drückt man nun die Winkelgeschwindigkeit durch die Geschwindigkeit aus, ergibt sich:

$$\omega = \frac{m}{I_S + m\left(\frac{l}{2}\right)^2}\frac{l}{2}v.$$

Dies eingesetzt ergibt:

$$\begin{aligned} v^2 &= \frac{M+m}{m}\left(I_S + m\left(\frac{l}{2}\right)^2\right)g\frac{4}{l} \\ \Rightarrow v &= \sqrt{\frac{M+m}{m^2}\left(\frac{M}{4} + m\right)gl}. \end{aligned}$$

# Raumfahrt

Die Raumfahrt ist ein wichtiges Thema in der Physik. Es gäbe unzählige spannende Dinge über die Raumfahrt zu lernen. In dieser Station wollen wir uns auf Phänomene beziehen, die im Zusammenhang mit der Mechanik, genauer: den Newton’schen Gesetzen und dem Impulssatz stehen.

Ein spannendes mechanisches Problem ist die Betrachtung der Bewegung einer Rakete. Wir beschränken uns dazu auf den zunächst einfachsten Fall, der einstufigen Rakete (siehe Figure D.7). Das meiste, was eine Rakete mit sich führt, ist Treibstoff (häufig Wasserstoff und Sauerstoff).

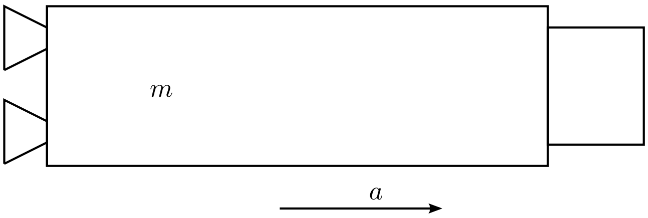


Figure D.7: Eine beschleunigende einstufige Rakete.

Im Folgenden geht es darum die Bewegung einer Rakete zu verstehen. Eine zentrale Frage in diesem Zusammenhang ist, wie groß die Geschwindigkeit $v$ der Rakete bei Brennschluss (Ende des Treibstoffes) ist. Die Bewegung der Rakete ist ein physikalisches Problem. Wie ihr dies in den vorigen Seminaren gelernt habt, ist der erste Schritt zur Lösung eines physikalischen Problems die genaue Beschreibung, Definition und grafische Darstellung des Problems.

### Aufgabe und Lösung

Die Herausforderung der Problemdarstellung nimmt euch FigureD.8 zu Teilen ab.

- Nutzt diese Abbildung und definiert das Problem der startenden Rakete so genau es geht. Legt dabei alle relevanten Variablen fest.
- Mit welchen physikalischen Prinzipien würdet ihr das Problem lösen und wie geht ihr bei der Lösung vor?

Eine Rakete besitze die Gesamtmasse $m$. Diese setzt sich zusammen aus der Masse des Treibstoffes, der Nutzlast sowie der Masse der Rakete (ohne Treibstoff). Das Besondere bei der Bewegung einer Rakete ist, dass ein Großteil der Masse $m$ Treibstoff ist. Aus diesem Grund kann man die Veränderung der Masse einer Rakete bei der Fortbewegung nicht vernachlässigen. Anders ist dies bei der Bewegung eines PKW. Für einen PKW ist es eine gute Näherung, die Masse des PKW während der Bewegung als konstant anzunehmen. Die Masse des Treibstoffes des PKW im Verhältnis zur Gesamtmasse des PKW ist vernachlässigbar. Für die Rakete gilt das allerdings nicht mehr. Aus diesem Grund ist die Beschreibung der Bewegung einer Rakete physikalisch eine besondere Herausforderung.

Figure D.8 zeigt die Grundsituation der Bewegung einer einstufigen Rakete[6]. Die Rakete habe zum Zeitpunkt $t$ eine Geschwindigkeit $v(t)$. Durch den Ausstoß des Treibstoffen der Masse $\Delta m$ mit der Geschwindigkeit $v_T$ wird die Rakete nach dem Rückstoßprinzip beschleunigt. Folgende Annahmen sind für das im Folgenden betrachtete Raketenmodell wichtig:

- Geschwindigkeiten nach rechts werden positiv gezählt.
- Die Austrittsgeschwindigkeit des Treibstoffes über die Zeit ist konstant ($v_T$ =konst.).

---

[6] Die Herleitung der Raketengleichung geht auf den russischen Mathematiker Ziolkowski zurück. Die hier verwendete Herleitung ist eng angelehnt an die Herleitung auf leifiphysik.de

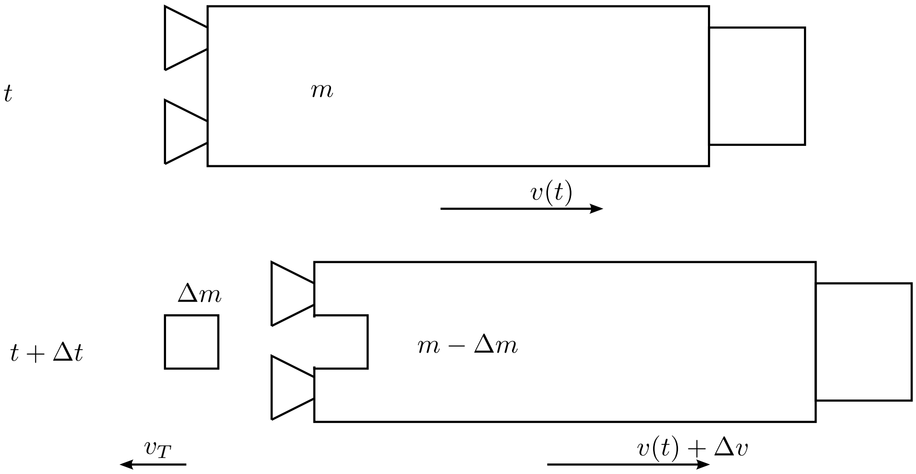


Figure D.8: Problemdarstellung der Bewegung einer Rakete zu den ersten beiden Zeitpunkten.

Für die Lösung des Problems kann nun das zweite Newton'sche Axiom in seiner allgemeinen Form verwendet werden: Eine Kraft $F$ bewirkt die Änderung des Impulses eines Objektes

$$F = \frac{\Delta p}{\Delta t}. \tag{D.3}$$

Wenn nun die Änderungen infinitesimal klein sind, geht der Differenzenquotient in den Differentialquotient über:

$$F = \frac{\Delta p}{\Delta t} \to F = \frac{\mathrm{d}p}{\mathrm{d}t} = \frac{\mathrm{d}(mv)}{\mathrm{d}t} = m\frac{\mathrm{d}v}{\mathrm{d}t} + v\frac{\mathrm{d}m}{\mathrm{d}t}. \tag{D.4}$$

Der Treibstoffausstoß verursacht eine Impulsänderung, $\Delta p$, der Rakete. Überprüft nun eure Problembeschreibung. Der Treibstoffausstoß verursacht eine Impulsänderung, $\Delta p$, der Rakete.

### Aufgabe und Lösung

Drücke die Impulsänderung, $\Delta p$, der Rakete durch die von dir identifizierten Größen aus. Hinweise:

- $\Delta p = p(t + \Delta t) - p(t)$
- Größen: $m, v, v_T, \Delta m, \Delta v$, mit $v_{rel} = v + \Delta v + v_T$.

$$\begin{aligned}
\Delta p &= p(t + \Delta t) - p(t) \\
&= [(m - \Delta m) \cdot (v + \Delta v) + \Delta m \cdot (-v_\mathrm{T})] - m \cdot v \\
&= [m \cdot v + m \cdot \Delta v - \Delta m \cdot v - \Delta m \cdot \Delta v - \Delta m \cdot v_\mathrm{T}] - m \cdot v \\
&= m \cdot \Delta v - \Delta m \cdot v - \Delta m \cdot \Delta v - \Delta m \cdot v_\mathrm{T} \\
&= m \cdot \Delta v - \Delta m \cdot \underbrace{(v + \Delta v + v_\mathrm{T})}_{v_\mathrm{rel}}
\end{aligned}$$

### Aufgabe und Lösung

Leitet euren Ausdruck nach der Zeit ab: $\Delta p/\Delta t = \ldots$. Versucht den Ausdruck zu interpretieren. Überprüft dazu beispielsweise die Einheiten der Summanden, um zu wissen, um welche physikalische Größen es sich handelt.

$$F_{\mathrm{A}} = \frac{\Delta p}{\Delta t} = \frac{m \cdot \Delta v - \Delta m \cdot v_{\mathrm{rel}}}{\Delta t} = m \cdot \frac{\Delta v}{\Delta t} - v_{\mathrm{rel}} \cdot \frac{\Delta m}{\Delta t}$$

Lässt man nun $\Delta t$ immer kleiner werden, so ergibt sich folgender Ausdruck:

$$\begin{aligned} F_{\mathrm{A}} &= m \cdot \frac{dv}{dt} - v_{\mathrm{rel}} \cdot \frac{dm}{dt} \Leftrightarrow \\ m \cdot \frac{dv}{dt} &= v_{\mathrm{rel}} \cdot \frac{dm}{dt} + F_{\mathrm{A}} \end{aligned}$$

Definiere nun die Schubkraft als: $F_{\mathrm{Schub}} := v_{\mathrm{rel}} \cdot \frac{\mathrm{d}m}{\mathrm{d}t}$ und ersetze diesen Ausdruck in der Gleichung. Dann erhältst du die Bewegungsgleichung der Rakete.

### Aufgabe und Lösung

Interpretiere die erhaltene Bewegungsgleichung. Von welchen Kräften hängt nun die Beschleunigung (Geschwindigkeit) der Rakete ab?

Die Bewegungsgleichung der Rakete (nach Ziolkowski) lautet:

$$m \cdot \frac{dv}{dt} = F_{\mathrm{Schub}} + F_{\mathrm{A}}. \tag{D.5}$$

Die Beschleunigung der Rakete d$v$/d$t$ hängt von der Schubkraft und von äußeren Kräften (z.B. der Gravitationskraft) ab, die in der vorigen Betrachtung außer Acht gelassen wurden.

### Aufgabe und Lösung

Integriere die Bewegungsgleichung, um die Geschwindigkeit der Rakete beim Brennschluss, $v_B$, zu erhalten. Nimm dabei an, dass Treibstoff nur im Intervall von $0 \leq t \leq t_B$ ausgestoßen wird, dass die Relativgeschwindigkeit, $v_{\mathrm{rel}}$, während der Brennzeit konstant ist und dass der Massenstrom $\frac{\mathrm{d}m}{\mathrm{d}t}$ der ausgestoßenen Gase konstant ist. Nimm weiterhin an, dass die Rakete nur eine Stufe hat und der Start im Gravitationsfeld der Erde stattfindet ($F_A = -m \cdot g$), wobei $g$ als konstant angenommen werden darf. Der Luftwiderstand darf vernachlässigt werden.

Einsetzen und Umformen ergibt dann:

$$m \cdot \frac{dv}{dt} = v_{\mathrm{rel}} \cdot \frac{dm}{dt} - m \cdot g \Leftrightarrow \frac{dv}{dt} = v_{\mathrm{rel}} \cdot \frac{dm}{m \cdot dt} - g \Leftrightarrow dv = v_{\mathrm{rel}} \cdot \frac{dm}{m} - g \cdot dt$$

Im Mathematikunterricht habt ihr vielleicht schon das bestimmte oder unbestimmte Integral der Funktion $\int x^{-1} \mathrm{d}x$ gelernt. Dieses ist $\int x^{-1} \mathrm{d}x = \ln x$. Das erscheint plausibel, denn umgekehrt gilt, dass die Ableitung der ln-Funktion gleich $x^{-1}$ ist.

Es folgt die Lösung der Raketengleichung zu

$$v_\mathrm{B} = v_\mathrm{rel} \cdot \ln\left(\frac{m_0}{m_\mathrm{B}}\right) - g \cdot t_\mathrm{B}.$$

Hierbei ist $m_0$ die Masse zum Zeitpunkt $t = 0$ s.

## Anwendung der Raketengleichung (aus: leifiphysik.de)

### Aufgabe und Lösung: Flugkörper auf stabiler Bahn

Damit ein Flugkörper die Erde auf einer stabilen Bahn umkreisen kann, muss er eine minimale Höhe von 160 km haben. Ein solcher Körper bewegt sich auf einer solchen Bahn mit ca. $7,8$ km/s. Die Bewegung auf einem niedrigeren Niveau wäre aufgrund des dort herrschenden Luftwiderstandes nicht mehr möglich. Dieser Widerstand muss auch beim Aufstieg eines Raumschiffes durch die Erdatmosphäre überwunden werden. Die Rakete sollte also mindestens Endgeschwindigkeit von $9,0$ km/s erreichen. Wie groß ist die entsprechende Ausstoßgeschwindigkeit der Verbrennungsgase, falls der Massenquotient 11 ist? Hinweis: Geht hierbei vom Optimalfall aus, in dem keine Gravitationskraft wirkt.

Im Optimalfall gilt die Gleichung: $v_B = v_\mathrm{rel} \cdot \ln(\frac{m_0}{m_B})$. Das Massenverhältnis beträgt 11 und die Endgeschwindigkeit muss $v_B = 9$ km/s betragen. Mit diesen Angaben folgt eine Ausstoßgeschwindigkeit von

$$v_\mathrm{rel} = \frac{v_B}{\ln(11)} = 3,8 \text{ km s}^{-1}.$$

### Aufgabe und Lösung: Space Shuttle

Die Hauptmotoren des Space Shuttle verbrennen ein Gemisch aus flüssigem Wasserstoff und Sauerstoff, die Gasausstoßgeschwindigkeit beträgt ca. $4,6$ km $\mathrm{s}^{-1}$. Das Verhältnis von Anfangs- und Endmasse ist ca. $3,5$. Könnte ein Shuttle allein mit seinen Hauptmotoren eine Erdumlaufbahn erreichen? Hinweis: Geht hierbei vom Optimalfall aus, in dem keine Gravitationskraft wirkt.

Nein, denn

$$v_B = v_\mathrm{rel} \cdot \ln 3,5 = 5,8 \text{ km s}^{-1} < 9 \text{ km s}^{-1}.$$

Weitere spannende Aufgaben findet ihr auf leifiphysik.de.

# Die kosmischen Geschwindigkeiten

Auf der Erdoberfläche beobachten wir, dass ein Objekt, das wir mit einer Geschwindigkeit $v$ werfen, einer konstanten Fallbeschleunigung durch die Erdanziehung ausgesetzt ist. Daher folgt es einer Parabelbahn, bis es auf ein Hindernis wie den Erdboden trifft.

Entfernt man sich weit genug von der Erdoberfläche (in der Größenordnung des Erdradius $R = 6400$ km, also mindestens ein paar tausend Kilometer), so ist die Erdanziehungskraft jedoch nicht mehr konstant. Es gilt dann das Gravitationsgesetz für eine abstandsabhängige Fallbeschleunigung $g(r)$

$$g(r) = \gamma \frac{M}{r^2}$$

Dabei ist $M = 6 \cdot 10^{24}$ kg die Erdmasse und $\gamma = 6,7 \cdot 10^{-11}$ m$^3$ kg$^{-1}$ s$^{-2}$ die Gravitationskonstante. Die potentielle Energie eines Objektes der Masse $m$ im Erdgravitationfeld ist

$$E_G(r) = -\gamma \frac{Mm}{r}$$

Die potentielle Energie steigt also mit zunehmendem Abstand immer weiter an und erreicht im Grenzwert für einen unendlich großen Abstand $r$ den Wert null.

### Aufgaben und Lösungen

a) Berechne mit dieser Formel die potentielle Energie einer Tafel Schokolade (100 g) auf der Erdoberfläche.

b) Die Schokoladentafel soll jetzt so schnell geworfen werden, dass sie die Erde in der Nähe der Erdoberfläche ($g = const. = 9,81$ m s$^2$) umrundet ohne herunterzufallen. Verwende das Kräftegleichgewicht zwischen Zentrifugalkraft $F_Z = mv^2/r$ und Gravitationskraft, um die dafür notwendige Geschwindigkeit zu berechnen. Diese Geschwindigkeit heißt erste Kosmische Geschwindigkeit.

c) Hat die Schokolade eine höhere als in b) berechnete Geschwindigkeit, ist die Bahn kein Kreis, sondern eine Ellipse. Erreicht die Schokoladentafel im Grenzfall die sogenannte zweite Kosmische Geschwindigkeit, wird aus der elliptischen Bahn eine Parabel und die Schokoladentafel kann dem Gravitationsfeld der Erde entfliehen (sie kommt also nicht wie auf einer elliptischen Bahn zurück). Setze zur Berechnung der zweiten Kosmischen Geschwindigkeit die Summe aus oben angegebener potentieller Energie und kinetischer Energie gleich null (also gerade gleich der übrigen potentielle Energie im Unendlichen).

a) Die potentielle Energie berechnet sich zu:

$$E_{\text{pot}} = -\gamma \frac{Mm}{r} = -6,7 \cdot 10^{-11} \text{ m}^3 \text{ kg}^{-1} \cdot \frac{6 \cdot 10^{24} \text{ kg} \cdot 0,1 \text{ kg}}{6,400 \cdot 10^3 \text{ m}} = -6,28 \text{ MJ}.$$

b) Die (berühmte) erste kosmische Geschwindigkeit lautet:

$$\begin{aligned} F_Z &= F_G \\ \Rightarrow m\frac{v^2}{r} &= \gamma \frac{Mm}{r^2} \\ \Rightarrow v &= +\sqrt{\gamma \frac{M}{r}} \end{aligned}$$

Mit den entsprechenden Werten eingesetzt folgt:

$$v = \sqrt{6,7 \cdot 10^{-11} \text{ m}^3 \text{ kg}^{-1} \cdot \frac{6 \cdot 10^{24} \text{ kg}}{6,400 \cdot 10^3 \text{ m}}} = 7,93 \text{ km s}^{-1}.$$

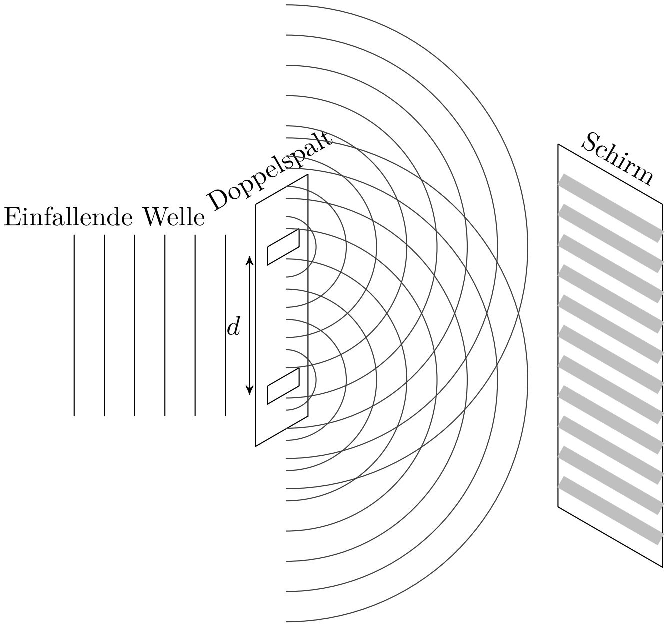


Figure D.9: Schematische Darstellung des Doppelspaltes mit einfallender Welle und Beugungsmuster auf dem Schirm.

c) Die (ebenso berühmte) zweite kosmische Geschwindigkeit berechnet sich zu:

$$\begin{aligned} E_{\text{pot}} + E_{\text{kin}} &= 0 \text{ J} \\ \Rightarrow -6,28 \text{ MJ} + \frac{m}{2}v^2 &= 0 \text{ J} \\ \Rightarrow v &= +\sqrt{\frac{2 \cdot 6,28 \text{ MJ}}{0,1 \text{ kg}}} = 11,2 \text{ km s}^{-1}. \end{aligned}$$

# Interferenz am Doppelspalt[7]

Auf dem Arbeitsblatt "Die Interferenz am Einzelspalt" wurden die Bedingungen für Maxima und Minima im Beugungsbild des Einzelspaltes mit dem huygensschen Prinzip hergeleitet. Eine ähnliche Situation ergibt sich, wenn man den sogenannten Doppelspalt betrachtet. Selbstverständlich kann auch beim Doppelspalt das Huygenssche Prinzip zum Verständnis zu Rate gezogen werden.

Der Doppelspalt besteht, wie der Name dies sagt, aus zwei Einzelspalten, die parallel zueinander angeordnet sind (siehe Figure D.9). Auf diese beiden Spalten trifft dann kohärentes Licht. Kohärent bedeutet, dass die Phasen der Wellen der beiden Spalten, eine konstante Phasenbeziehung zueinander haben. Das bedeutet, dass ein über die Zeit konstantes Beugungsbild auf dem Schirm, der sich hinter dem Doppelspalt befindet, entsteht.

Anders als beim Einzelspalt treffen wir folgende Annahme: Der Abstand der beiden Spalte $d$ sei sehr viel größer als die Breite eines einzelnen Spaltes. Deshalb nehmen wir an, dass jeweils nur eine einzige Elementarwelle durch einen

---

[7] Angelehnt an Tipler (2004).

Spalt geht (die Herleitung funktioniert auch mit nicht so strengen Annahmen). Diese beiden Elementarwellen überlagern einander. Eine solche Überlagerung haben Sie auf dem Arbeitsblatt "Interferenz und Beugung Elektromagnetischer Strahlung" kennengelernt. Nun ist man erneut interessiert an der mathematischen Herleitung der Orte, an denen maximale Verstärkung auf dem Schirm auftritt (weiße Streifen). Diese Herleitung führen Sie unter Anleitung selber durch:

Figure D.10 zeigt den Doppelspalt von oben. Dort dargestellt sind zwei Lichtstrahlen, die sich am gleichen Ort auf dem Schirm treffen und dort interferieren. Am Doppelspalt haben diese beiden Lichtwellen die gleiche Phase. Allerdings legen beide Strahlen einen unterschiedlich langen Weg bis zum Schirm zurück, sodass diese auf dem Schirm mit einer Phasendifferenz zueinander auftreffen.

### Aufgaben

1. Drücken Sie den Wegunterschied der beiden Strahlen zueinander durch $d$ und $\theta$ aus, wenn diese auf dem Schirm detektiert werden.
2. Finden Sie eine Bedingung dafür, dass auf dem Schirm Maxima entstehen. Denken Sie zurück an die Aufgabe beim Einzelspalt.
3. Finden Sie ein geometrische Beziehungen zwischen $L$, $y$ und $\theta$.
4. Drücken Sie die Abstand des $m$-ten Maximums ($m \in \mathbb{N}$) vom Mittelpunkt des Schirmes $y_m$ durch alle anderen messbaren Größen aus. Hinweis: Machen Sie eine Kleinwinkelnäherung ($\sin\theta = \tan\theta = \theta$).
5. Berechnen Sie den Abstand der ersten drei Maxima $y_m$ für $m = 1, 2, 3$ vom Zentrum des Schirms. Das Laserlicht habe eine Wellenlänge von $\lambda = (650 \pm 20)$ nm, der Abstand Doppelspalt-Schirm beträgt $L = (1,000 \pm 0,001)$ m und die Spaltbreite $d = 0,1$ mm (ohne Fehler). Schätzen Sie den Fehler ab, indem Sie jeweils die größten, sowie kleinsten möglichen Werte (z.B. $L_{min} = 0,999$ m und $L_{max} = 1,001$ m) in die Gleichung einsetzen.
6. Leiten Sie eine analoge Beziehung für die Minima her.

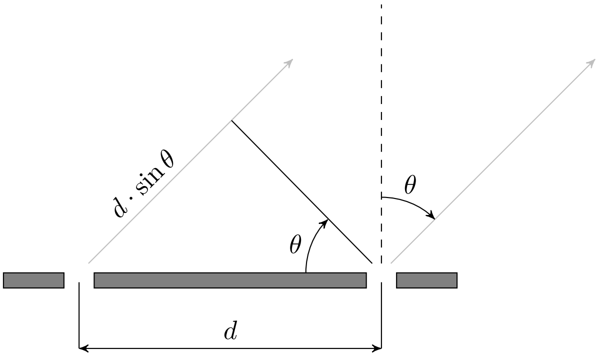
### Lösungsvorschlag

In der Aufgabe wird der ideale Doppelspalt behandelt. Beim idealen Doppelspalt kann man davon ausgehen, dass die Spaltbreite gegenüber dem Spaltabstand ($d$) vernachlässigbar klein ist. Dann kann man davon ausgehen, dass an jedem Spalt genau eine Elementarwelle ausgesendet wird.

1. Der Wegunterschied wird geometrisch bestimmt. Aus der Lupenansicht (Abbildung D.10) erkennt man, dass der untere Strahl einen Weg von $d \sin\theta$ mehr zurücklegt. Damit beträgt die Wegdifferent der beiden Strahlen am Schirm: $\Delta d = d \sin\theta$. Der Winkel $\theta$ habe einen Definitionsbereich von $-90° \leq \theta \leq 90°$. Die Phase $\Delta$ einer Welle ist das Argument in der Sinusfunktion: $\psi(x,t) = \psi_0 \cdot \sin(kx + \omega t + \varphi) : \Delta = kx + \omega t + \varphi$.

2. Maxima entstehen bei konstruktiver Interferenz zweier Wellen. Das bedeutet, dass Wellenberg (Wellental) auf Wellenberg (Wellental) trifft. Wenn

Nahansicht des Spaltes:



Von entfertem Standpunkte:

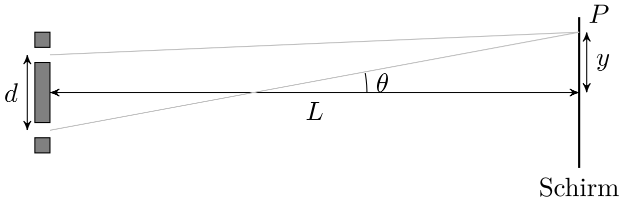


Figure D.10: Darstellung des Doppelspaltes aus der Nahsicht sowie aus der Ferne.

Table D.9: Ergebnisse Doppelspalt.

| | $y_{min}$ [cm] | $y_m$ [cm] | $y_{max}$ [cm] |
|---|---|---|---|
| $m = 1$ | $0,63$ | $0,65$ | $0,67$ |
| $m = 2$ | $1,26$ | $1,30$ | $1,34$ |
| $m = 3$ | $1,89$ | $1,95$ | $2,01$ |

wir von zwei monochromatischen, kohärenten Wellen ausgehen, dann lautet die Bedingung: $\Delta d = m\lambda$, mit $m \in \mathbb{N}$.

3. Im Folgenden nutzt man das Wissen um die Geometrie der Anordnung (im Experiment messbar) aus. Unter der Annahme, dass $L \gg d$ ($L$ ist sehr viel größer als $d$), lässt sich der Winkel $\theta$ als $\tan\theta = y/L$ und (siehe Lupenansicht) als $\sin\theta = \Delta d/d$ schreiben.

4. Da $L$ sehr viel größer als $d$ ist, betrachten wir nur kleine Winkel für $\theta$. Bei kleinen Winkeln für $\theta$ (bis ca. 5°) haben die Sinusfunktion und die Tangensfunktion nahezu die gleichen Funktionswerte, nämlich $\theta$ (Hinweis: Für die Kleinwinkelnäherung gilt $\sin\theta \sim \tan\theta \sim \theta$). Damit können wir die vorigen Gleichungen gleichsetzen und erhalten folgenden Ausdruck:

$$\tan\theta = y/L = \sin\theta = \Delta d/d \tag{D.6}$$

$$\Rightarrow \frac{y}{L} = \frac{\Delta d}{d}. \tag{D.7}$$

Die Maxima entstehen in den Abständen $y_m$ vom Mittelpunkt des Schirmes. Hierzu wird $\Delta d$ in der Gleichung durch die entsprechenden Bedingungen ersetzt:

$$y = \frac{\Delta d}{d} \cdot L = \frac{m\lambda}{d} \cdot L.$$

5. Man nutze: $y = m\lambda/dL$ und erhalte die Ergebnisse in Table D.9.

6. Für den Fall, dass auf dem Schirm Minima auftreten, gilt folgende Bedingung für den Wegunterschied der beiden Wellen: $\Delta d = (m + 1/2) \cdot \lambda$. Dies eingesetzt in Gleichung D.7 ergibt:

$$y = \frac{\Delta d}{d} \cdot L = \left(m + \frac{1}{2}\right) \cdot \frac{\lambda}{2} \cdot L.$$

# Physikalisches Problemlösen: Wie löse ich physikalische Probleme?

### Ablaufschema für physikalisches Problemlösen

Viele Alltagsprobleme können mit Hilfe der Physik und Mathematik beschrieben und gelöst werden. Doch wie kann man die Lösung eines physikalischen Problems am besten angehen? Eine erste Kategorisierung physikalischer Probleme erfolgt anhand der verschiedenen fachlichen Themengebiete. Beispielsweise sind Bewegungen von Alltagsobjekten (Ball, Fahrzeuge) häufig der Mechanik zuzuordnen. Geht es um Temperaturen und Wärmekraftmaschinen (Verbrennungsmotor) sind die Probleme dem Gebiet der Wärmelehre zuzuordnen. Bei Strömen, Spannungen und Schaltkreisen handelt es sich um Probleme aus dem Bereich der E-Lehre usw.

Physikalische Probleme haben dabei eine immer wiederkehrende Struktur. Die zunehmende Arbeit mit physikalischen Problemen gibt Sicherheit und Erfahrung, sodass die Probleme immer schneller und zielführender gelöst werden können. Der Mathematiker Alan Schoenfeld hat ein Ablaufschema vorgeschlagen, anhand dessen man solche Probleme lösen kann.[8] Es zahlt sich aus ein solches Ablaufschema zu erlernen und bei der Bearbeitung physikalischer Probleme anzuwenden. Mit der Zeit verinnerlicht man die Abläufe. Dann gelingt das Lösen vieler physikalischer Probleme auch ohne viel Aufwand. Doch wie läuft das Problemlösen ab (siehe Table D.10)?

Der Prozess des physikalischen Problemlösens sei an einem Beispiel erläutert. Stellt euch vor, ihr begegnet folgendem Problem: Wenn ein Stein vom oberen Ende eines Brunnens fallen gelassen wird, hört man nach der Zeit $t_W = 2$ s das Auftreffen des Steines auf der Wasseroberfläche. Die physikalische Intuition drängt hierbei die Frage auf, wie groß die Strecke von der Oberkante des Brunnens bis zur Wasseroberfläche ist. Bereits die Fragestellung ist ein erster Schritt des Problemlösens, nämlich die Identifikation eines Problems. In der folgenden Tabelle sind fünf immer wiederkehrende Schritte dargestellt, die dabei helfen, ein physikalisches Problem sicher zu lösen (Table D.10).

### Aufgabe Brunnentiefe

Nicht jeder Schritt muss bei jeder Problemlösung vollständig ausformuliert werden. Mit zunehmender Übung werden gerade die ersten Schritte oft zumindest teilweise automatisch durchgeführt. Man weiß insbesondere, dass Schülerinnen und Schüler, die das Problemlösen bereits sicher beherrschen, eher unterfordert sind mit diesen Problemlöseabläufen und häufig wenig Sinn darin sehen. Diese Problemlöseschema richten sich insbesondere an diejenigen, die ihre Fähigkeiten im Problemlösen gerade entwickeln und noch nicht so viel Erfahrung mit dem Lösen physikalischer Probleme haben.

Zur Veranschaulichung der einzelnen Schritte wenden wir dieses Schema nun auf das obenstehende Problem an: Wenn ein Stein vom oberen Ende eines Brunnens fallen gelassen wird, hört man nach der Zeit $t_W = 2$ s das Auftreffen des Steines auf der Wasseroberfläche.

### 1. Visualisierung des Problems (Übersetze die Worte des Problems in eine visuelle Darstellung)

:

- Zeichne eine Skizze der Situation (oder mehrere)
- Finde die bekannten und unbekannten Größen des Problems und Beschränkungen dieser Größen
- Formuliere die Frage

---

[8] Schoenfeld, Alan (1985): Mathematical Problem Solving. San Diego, CA: Academic Press. Es gibt auch noch andere Vorgehensweisen, die aber alle sehr ähnlich zueinander sind. Das vorliegende Schema ist entnommen aus: Heller, Patricia; Keith, Ronald; Anderson, Scott (1992): Teaching Problem Solving through cooperative grouping. Part 1: Group versus individual problem solving. In: American Journal of Physics 60 (7), S. 627–636.

Table D.10: Ablaufschema zum physikalischen Problemlösen

| Schritt | Beschreibung |
|---|---|
| 1: Visualisierung des Problems | Übersetze die Worte des Problems in eine visuelle Darstellung<br>• Zeichne eine Skizze der Situation (oder mehrere)<br>• Finde die bekannten und unbekannten Größen des Problems und Beschränkungen dieser Größen<br>• Formuliere die Frage<br>• Finde die grundlegende Herangehensweise an das Problem – Welche Konzepte und Prinzipien sind angemessen für diese Situation (z.B. Newtons Grundgesetz, Energieerhaltung, . . . ) |
| 2: Beschreibung des Problems in physikalischer Weise | Übersetze die Skizze in eine physikalische Beschreibung des Problems:<br>• Nutze die gefundenen Prinzipien und Konzepte, konstruiere damit neue Diagramme und Koordinatensysteme für jedes Objekt zu interessierenden Zeitpunkten (z.B. Vektordiagramme)<br>• Finde Symbole für die bekannten und unbekannten Größen (z.B. $v$ für die Geschwindigkeit)<br>• Lege die Zielgröße symbolisch fest (z.B. finde $v_0$ so, dass $h_m > 10$ m) |
| 3: Planen einer Lösung | Übersetze die physikalische Beschreibung in eine mathematische Beschreibung des Problems:<br>• Beginne mit den gefundenen Konzepten und Prinzipien in Gleichungsform (z.B. $\sum_i F_i = ma, \dots$ )<br>• Wende die Prinzipien systematisch an jedem Objekt und jeder Wechselwirkung in der physikalischen Beschreibung an<br>• Füge Gleichungen für die Beschränkungen hinzu (z.B. $v_0 = 0\,\mathrm{m\,s^{-1}}$, Anfangsgeschwindigkeit verschwindet)<br>• Arbeite rückwärtsgerichtet von der Zielgröße bis du sicher bist, dass du genug Information hast, das Problem zu lösen (du musst die gleiche Anzahl an unabhängigen Gleichungen haben, wie du unbekannte Größen hast!)<br>• Lege die mathematischen Schritte fest, um dein Gleichungssystem zu lösen (z.B. stelle Gleichung (1) nach $x$ um und setze in Gleichung (2) ein) |
| 4: Ausführung des Lösungsplanes | Führe deinen Lösungsplan in eine Reihe von mathematischen Operationen über:<br>• Nutze die Regeln der Algebra, um einen Ausdruck zu erhalten, in dem die Zielgröße auf der linken Gleichungsseite steht und alle anderen bekannten Größen auf der rechten Seite<br>• Ersetze die Größen durch ihre Werte, sodass du einen arithmetischen Ausdruck für die Zielvariable erhältst |
| 5: Kontrolle der Lösung | Bestimme, ob deine Lösung Sinn ergibt:<br>• Ist die Lösung komplett?<br>• Ist das Vorzeichen korrekt und physikalisch sinnvoll, und stimmt die Einheit?<br>• Passt die Größenordnung deines Ergebnisses? |

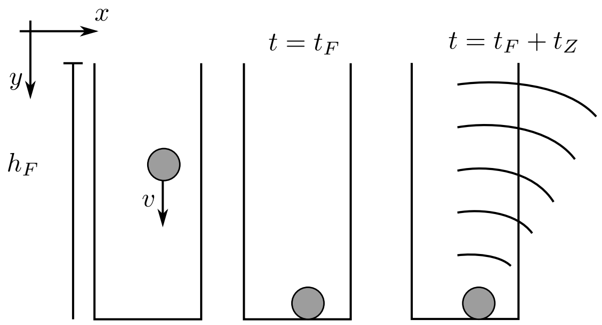


Figure D.11: Darstellungen zur Brunnentiefe.

- Finde die grundlegende Herangehensweise an das Problem – Welche Konzepte und Prinzipien sind angemessen für diese Situation (z.B. Newtons Grundgesetz, Energieerhaltung, . . . )

Schematische Darstellung des Problems zu drei wichtigen Zeitpunkten (siehe Figure D.11). Grundlegende Prinzipien sind:

- Eindimensionale Betrachtung der Bewegung
- Bewegungsgesetze der Mechanik (beschleunigte Bewegung sowie gleichförmige Bewegung)

Sodass sich folgende Fragen ergeben:

- Gegeben der gemessenen Zeit vom Loslassen des Objektes bis zur Registrierung des Aufschlages auf der Wasseroberfläche, wie groß ist die Strecke von der Oberkante des Brunnens bis zur Wasseroberfläche?
- Teilfrage: Was ist die "wirkliche" Fallzeit?

**2. Beschreibung des Problems in physikalischer Weise (Übersetze die Skizze in eine physikalische Beschreibung des Problems)**

- Nutze die gefundenen Prinzipien und Konzepte, konstruiere damit neue Diagramme und Koordinatensysteme für jedes Objekt zu interessierenden Zeitpunkten (z.B. Vektordiagramme)
- Finde Symbole für die bekannten und unbekannten Größen (z.B. $v$ für die Geschwindigkeit)
- Lege die Zielgröße symbolisch fest (z.B. finde $v_0$ so, dass $h_m > 10$ m)

Die Bewegung des Objektes (Weg-Zeit-Gesetz für den freien Fall) sieht folgendermaßen aus (links in Figure D.12). Die Bewegung des Schalls vom Ort des Aufschlags zum Ohr sieht folgendermaßen aus (rechts Figure D.12)).

- Die wahrgenommene Zeit setzt sich zusammen aus $t_W = t_F + t_Z$. Dabei sind $t_F$ die Zeit des "wirklichen" Falls und $t_Z$ die Zeit, die der Schall zurück benötigt.

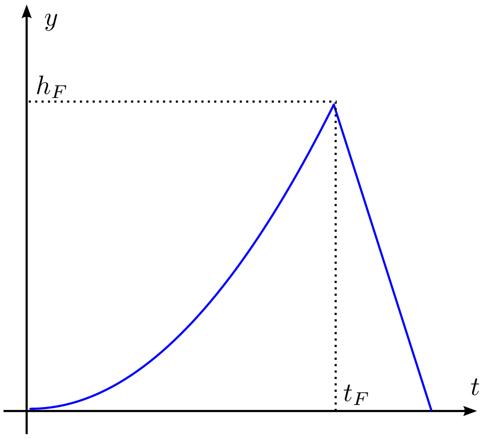


Figure D.12: Darstellungen zur Brunnentiefe.

- $g$ ist die Erdbeschleunigung ($9,81$ m s$^{-2}$) und $v$ ist die Schallgeschwindigkeit in Luft ($340$ m s$^{-1}$).
- Gesucht ist $h_F$.

### 3. Planen einer Lösung (Übersetze die physikalische Beschreibung in eine mathematische Beschreibung des Problems)

- Beginne mit den gefundenen Konzepten und Prinzipien in Gleichungsform (z.B. $\sum_i F_i = ma, \dots$)
- Wende die Prinzipien systematisch an jedem Objekt und jeder Wechselwirkung in der physikalischen Beschreibung an
- Füge Gleichungen für die Beschränkungen hinzu (z.B. $v_0 = 0$ m s$^{-1}$, Anfangsgeschwindigkeit verschwindet)
- Arbeite rückwärtsgerichtet von der Zielgröße bis du sicher bist, dass du genug Information hast, das Problem zu lösen (du musst die gleiche Anzahl an unabhängigen Gleichungen haben, wie du unbekannte Größen hast!)
- Lege die mathematischen Schritte fest, um dein Gleichungssystem zu lösen (z.B. stelle Gleichung (1) nach $x$ um und setze in Gleichung (2) ein)

Die Bewegungsgleichungen für die zwei Teilbewegungen lauten für die gleichmäßig beschleunigte Bewegung: $y = \frac{g}{2} \cdot t^2 + v_0 \cdot t + y_0$ und für die gleichförmige Bewegung $y' = v' \cdot t' + y'_0$. Hierbei gelten folgende Randbedingungen für die beschleunigte Bewegung: $y = h_F; v_0 = 0$ m s$^{-1}$; $y_0 = 0$ m; $t = t_F \rightarrow t_F = t_W - t_Z$. Für die gleichförmige Bewegung gilt: $y' = 0$ m$t' = t_Z$; $s'_0 = h_F$; $v' = -v$. Es gibt nun 2 Gleichungen für 2 Unbekannte ($t_F$ und $h_F$). Damit ist das Gleichungssystem prinzipiell lösbar. Eine Gleichung wird nach $t_Z$ umgestellt, sodass $t_Z$ in der anderen Gleichung substituiert wird. Daraus kann dann $h_F$ berechnet werden.

### 4. Ausführung des Lösungsplanes (Führe deinen Lösungsplan in eine Reihe von mathematischen Operationen über)

- Nutze die Regeln der Algebra, um einen Ausdruck zu erhalten, in dem die Zielgröße auf der linken Gleichungsseite steht und alle anderen bekannten Größen auf der rechten Seite
- Ersetze die Größen durch ihre Werte, sodass du einen arithmetischen Ausdruck für die Zielvariable erhältst

Zunächst werden die Randbedingungen ersetzt. Damit folgen zwei Gleichungen: $h_F = \frac{g}{2}(t_W - t_Z)^2$ und $0 = -v \cdot t_Z + h_F$. Der Rest ist Algebra:

$$\begin{aligned} h_F &= v \cdot t_Z \rightarrow t_Z = \frac{h_F}{v} \\ h_F &= \frac{g}{2} \cdot \left(t_W - \frac{h_F}{v}\right)^2 \\ h_F &= \frac{\left(\sqrt{2gt_W v + v^2} \cdot |v| + gt_W v + v^2\right)}{g} \end{aligned}$$

Nun können die Werte eingesetzt werden:

$$h_F = \frac{\left(\sqrt{2 \cdot 9,81 \text{ m s}^{-2} \cdot 2 \text{ s} \cdot 340 \text{ m s}^{-1} + (340 \text{ m s}^{-1})^2} \cdot 340 \text{ m s}^{-1} + 9,81 \text{ m s}^{-2} \cdot 2 \text{ s} \cdot 340 \text{ m s}^{-1} + (340 \text{ m s}^{-1})^2\right)}{9,81 \text{ m s}^{-2}}$$

$$h_F = 18,5 \text{ m}.$$

### 5. Kontrolle der Lösung (Bestimme, ob deine Lösung Sinn ergibt)

- Ist die Lösung komplett?
- Ist das Vorzeichen korrekt und physikalisch sinnvoll, und stimmt die Einheit?
- Passt die Größenordnung deines Ergebnisses?

$t_Z$ konnte ersetzt werden und $h_F$ konnte durch bekannte Größen dargestellt werden. So konnte die tatsächliche Strecke von Brunnenoberkante bis Wasseroberfläche gefunden werden. In unserem Problem ist die Koordinatenachse nach unten orientiert. Damit ist der positive Wert sinnvoll. Man kann sich überlegen, dass die maximale Strecke gleich $h = \frac{g}{2} \cdot t^2 = 19,62$ m sein kann. Das Ergebnis muss etwas kleiner sein, da das Objekt nicht die gesamte Zeit gefallen ist. Die Größenordnung des Ergebnisses scheint demzufolge nicht übertrieben groß oder klein.

### Aufgaben

1. Du hilfst einer Freundin in eine neue Wohnung einzuziehen. Ein Umzugskarton wiegt 50 kg und muss zunächst umgestellt werden, um Platz für eine Couch zu machen. Du bist größer als der Karton, sodass du heruntergreifst und den Karton in einem Winkel von 50° zur Horizontalen schiebst.

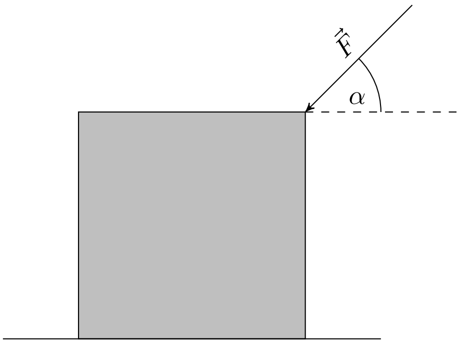


Figure D.13: Seitenansicht der Kiste.

Der Haftreibungskoeffizient zwischen Karton und Boden ist $0,50$ und der Gleitreibungskoeffizient zwischen Karton und Boden ist $0,30$. Wenn du die kleinstmögliche Kraft aufwenden möchtest, wie viel Kraft müsstest du gerade aufwenden, um den Karton zu schieben (siehe Figure D.13).

2. Um die Höhe der Aussichtsetage eines hohen Gebäudes zu bestimmen, stellt sich eine Person im Aufzug auf eine Personenwaage. Vor dem Anfahren zeigt diese 75 kg an. Beim Anfahren zeigt die Waage $8,5 \pm 0,25$ s lang 66 kg an. Anschließend verzeichnet die Waage für $26 \pm 0,25$ s wieder 75 kg. Schließlich zeigt die Waage für $9,5 \pm 0,25$ s ein Gewicht von 84 kg an. Dann hält der Aufzug. Welche Höhe wurde während der Fahrt zurückgelegt und in welcher Höhe befindet sich demnach die Aussichtsetage, wenn der Ausstieg des Fahrstuhls 25 m über dem Boden liegt? Schätze den Fehler der bestimmten Höhe ab.[9]

**Lösungsvorschlag**

1. Grundlegende Prinzipien: Vektorzerlegung einer Kraft, Konzept Haftreibung sowie Gleitreibung, Frage: Welche Kraft ist minimal notwendig, sodass sich die Kiste gerade bewegt, d.h. dass die Haftreibung überwunden wird?

Die angreifende Gesamtkraft kann in ihre x- sowie y-Komponente zerlegt werden. Alle auf die Box angreifenden Kräfte können dann wie folgt dargestellt werden (Abbildung D.14). Gesucht ist $\vec{F}_{min}$.Die Kraftkomponenten $F_x$ und $F_y$ bestimmen sich aus der Gesamtkraft $\vec{F}$ folgendermaßen:

$$|F_x| = \cos\alpha|F|, \text{sowie}|F_y| = \sin\alpha|F|. \tag{D.8}$$

Die Betrag-Striche werden im Folgenden weggelassen. Es genügt den Betrag von $F$ zu bestimmen, denn die Richtung ist durch den Winkel vorgegeben. Die Gleit- und Haftreibungskräfte bestimmen sich zu:

$$F_{Haft} = \mu_H \cdot F_N \tag{D.9}$$

$$(F_{Gleit} = \mu_{Gl} \cdot F_N) \tag{D.10}$$

---

[9] Aufgaben adaptiert aus: Heller, Patricia; Keith, Ronald; Anderson, Scott (1992): Teaching Problem Solving through cooperative grouping. Part 1: Group versus individual problem solving. In: American Journal of Physics 60 (7), S. 627–636.

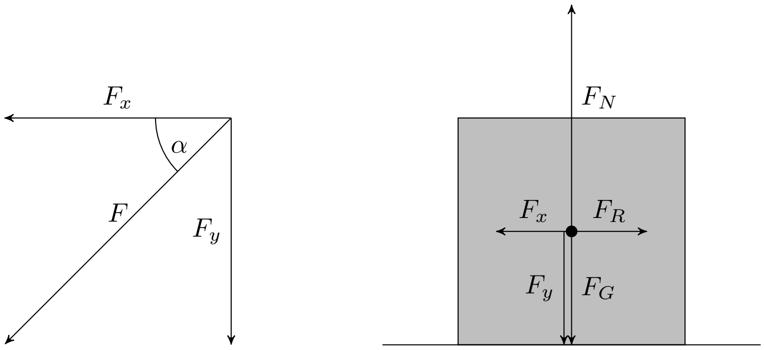


Figure D.14: Schematische Darstellung der angreifenden Kräfte.

In Richtung $y$-Achse wirkt neben der Gravitationskraft zusätzlich die $y$-Komponente $F_y$ der Gesamtkraft. $F_N$ ergibt sich zu:

$$F_N = F_G + F_y = mg + F_y. \tag{D.11}$$

Die Kraft $F_x$ in $x$-Richtung muss gerade die Haftreibungskraft überwinden. Dabei gilt: $F_x \geq F_H$. Wir haben drei Gleichungen für zwei Unbekannte ($F$ und $F_N$). Das Gleichungssystem ist lösbar. Nun kann man Gleichung D.11 in Gleichung D.10 einsetzen und dann mit Gleichung D.8 gleichsetzen, um $F$ zu berechnen.

$$\begin{aligned} F_H &= \mu_H \cdot F_N = \mu_H \cdot (mg + F_y) \\ F_x \geq F_H \Rightarrow \cos\alpha F &= \mu_H \cdot (mg + F_y) = \mu_H \cdot (mg + \sin\alpha F) \\ \cos\alpha F - \mu_H \sin\alpha F &= \mu_H mg \\ \Rightarrow F &= \frac{\mu_H mg}{\cos\alpha - \mu_H \sin\alpha}. \end{aligned}$$

Werte einsetzen ergibt:

$$F = \frac{0,3 \cdot 50\ \text{kg}9,81\ \text{m s}^{(}-2)}{\cos 50^\circ - 0,3 \sin 50^\circ} = 356,3\ \text{N}.$$

Der Betrag von F ist positiv. Das ist sinnvoll. Weiterhin gilt: Die Gewichtskraft einer 50 kg Masse beträgt 500 N. Wenn man unter einem Winkel von 0° zur Horizontalen schiebt, ergibt sich eine erforderliche Kraft von $0,5 \cdot 500$ N= 250 N und $0,3 \cdot 500$ N= 150 N. Da man bei einem Winkel größer 0° auch Kraft auf die Unterlage auswirkt und damit die Reibungskräfte erhöht, scheinen die berechneten Kräfte zumindest in dem Sinne sinnvoll, dass sie größer als diese parallele Kraft sind.

### Aufgabe Seifenblasendicke[10]

Eine senkrechte Seifenblasenschicht wird horizontal mit einer Natriumlampe (Wellenlänge 589 nm) bestrahlt, und die Reflektion des Lichtes wird beobachtet.

---

[10] Übernommen aus IPhO Aufgabensammlung.

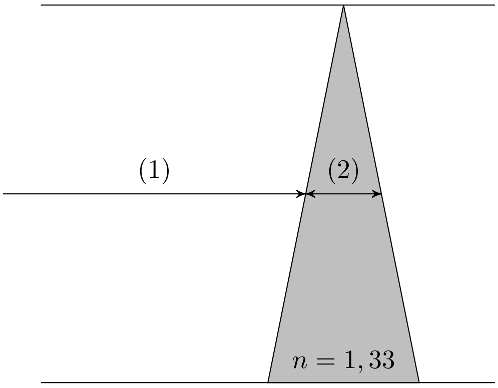


Figure D.15: Seitenansicht der Seifenblasenschicht.

Das obere Ende der Schicht ist so dünn, dass kein Licht reflektiert wird und die Schicht dort schwarz erscheint. Unterhalb des oberen Endes erscheinen fünf helle Streifen, der fünfte am unteren Ende der Schicht. Bestimmen sie die Dicke der Seifenblasenschicht am unteren Ende. Verwenden sie für den Brechungsindex von Wasser den Wert $1,33$.

**Hinweiskarte**

- Finden Sie zunächst einen passenden Ansatz: Es handelt sich um ein Problem der Interferenz (siehe Seminar 1: Interferenz an dünnen Schichten)
- Es interferieren zwei Teilstrahlen miteinander. Zum einen der an der am vorderen Ende der Seifenblasen reflektierte und zum anderen der Teilstrahl, der einen Weg durch die Seife zurücklegt und dann am hinteren Ende der Seifenblase reflektiert wird.
- Beachten Sie: Der vordere Strahl erfährt einen Phasensprung von $\lambda/2$, da er am festen Ende reflektiert wird.
- Helle Streifen entstehen durch konstruktive Interferenz. D.h. konstruktive Interferenz ist die Bedingung für den Wegunterschied. Bei konstruktiver Interferenz muss der Wegunterschied gerade dem natürlichen Vielfachen eine ganzen Wellenlänge betragen.

**Lösungsvorschlag**

In der Abbildung ist die Geometrie der Aufgabe seitlich dargestellt. Eine Seifenblasenschicht wird von einem Laserstrahl (1) angeleuchtet (siehe Abbildung D.15). Die Seifenblasenschicht wird durch die Gravitationskraft nach unten hin dicker. Gesucht ist nun die Dicke am Ort des 5. Maximums.

Bei der Aufgabe handelt es sich um ein Interferenzproblem. An der Grenzschicht Luft-Seife wird ein Teil des einfallenden Lichts reflektiert, ein anderer Teil des Lichts tritt in die Seife ein. Dieser zweite Teil des Lichts wird dann am anderen (hinteren) Ende der Seifenblasenschicht reflektiert. Aus diesem Grund überlagern sich am Punkt (1) zwei Strahlen, die einen Wegunterschied aufweisen. Der Strahl (2), der in die Seife eintritt legt einen größeren optischen Weg zurück, als geometrischen. Der geometrische Weg beträgt einfach $2 \cdot d(y)$. Da aber die Ausbreitungsgeschwindigkeit in Seife um geringer ist als in Luft, arbeitet man mit einem größeren Weg: $2d(y) \cdot n$.

Da Strahl (1) an einem festen Ende (Brechnungindex $n$ von Seife ist größer als der von Luft) reflektiert wird, erfährt dieser einen Phasensprung um $\lambda/2$ ($\pi$) bei der Reflexion. Dies muss für den Phasenunterschied der beiden Wellen noch mit berücksichtigt werden. Der Wegunterschied in einer Höhe $y$ beträgt demnach: $\Delta = 2d(y) \cdot n - \lambda/2$.

Um helle Strahlen zu erhalten (konstruktive Interferenz), muss der Wegunterschied der beiden Wellen gerade: $\Delta = m\lambda$, mit $m \in \mathbb{N}$ sein. Setzt man die Gleichungen für den Wegunterschied gleich, erhält man: $2d(y) \cdot n - \lambda/2 = m\lambda$. Aus der Aufgabenstellung geht hervor, dass es sich um das 5. Maximum am Boden handelt. D.h. m=5. Nach umstellen und einsetzen ergibt sich: $d(y) = (5\lambda + \lambda/2)/2n = 9\lambda/4n \sim 9,96 \cdot 10^{-7}$ m.

### Aufgaben Text Quantenwelten[11]

In seinem Buch "Die verborgene Wirklichkeit" beschriebt der Physiker Brian Greene (Professor für Physik an der Columbia Universität) moderne Theoriegebäude der Physik und deren Zusammenhang zu sogenannten Multiversen. Unter anderem geht es um die Multiversen-Interpretation in der Quantenphysik. Sie finden im Folgenden einen Auszug aus dem Text, in dem er auf den Hintergrund der Quantenmechanik eingeht.

### Abschnitt 1:

1. Stellen Sie anhand des Textes die zentralen Positionen von „klassischer" Mechanik und der Quantenrevolution gegenüber. In ihrer Gegenüberstellung sollten die Konzepte „Vergangenheit und Zukunft" sowie „Zufall und Wahrscheinlichkeit" aufgegriffen werden.

2. Warum ist die „klassische" Mechanik trotzdem weit verbreitet und findet Anwendung? Was ist ein Grund dafür, dass die Quantenmechanik nicht mehr bezweifelt wird?

3. Welches ist die Kernaussage des Gedankenexperimentes mit den 100 Schachteln mit Elektronen, das Brian Greene auf S. 240 entwickelt?

### Abschnitt 2: Das Rätsel der Alternativen

4. Welches der folgenden Beugungsbilder hatte man beim Davisson-Germer-Versuch erwartet? ($y$-Achse: Intensität, $x$-Achse: Position auf Schirm). Hinweis: Die Höhe der Intensitätsmaxima sei außer Acht gelassen.

5. Skizziere das Beugungsbild, welches tatsächlich beobachtet wurde.

---

[11] Text aus: Greene, Brian: Die verborgene Wirklichkeit, S. 239 - 247.

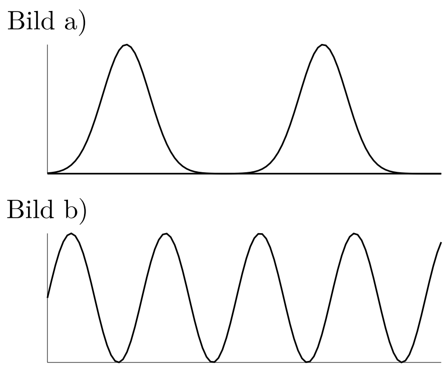


Figure D.16: Mögliche Beugungsbilder.

### Abschnitt 3: Quantenwellen

6. Welche Schlussfolgerung über die Natur von Elektronen lässt das Beugungsbild des Davisson-Germer-Versuches zu? Warum?
7. Benenne die konkreten Belege, die Max Born dazu veranlasste, Teilchen mit einer Wahrscheinlichkeitswelle zu assoziieren.
8. Wie muss man sich die Bewegung eines Teilchens demzufolge vorstellen?
9. Gedankenexperiment: Stell Dir vor auf einen Spalt wie in Abbildung 8.4 (S. 247) würde immer einzeln ein Elektron geschossen. Offensichtlich würde das Elektron dann kein anderes Teilchen haben, mit dem es interferieren kann. Wenn man die „Landestellen" der einzelnen Elektronen auf dem Schirm aufsummiert über die Zeit, welches Beugungsbild würde sich ergeben? Bild a) oder Bild b) aus Aufgabe 4? Warum?
10. Kann man bei Kenntnis der Geschwindigkeit und weiterer wichtiger Parameter den Ort des Elektrons aus Aufgabe 9), das auf den Beugungsschirm fliegt, exakt vorhersagen.

### Lösungsvorschläge Quantenwelten

1. Table D.11 zeigt eine Gegenüberstellung von klassischer Mechanik und Quantenmechanik.

2. Für die Bewegung großer Objekte (wie Planeten) liefert die klassische Mechanik gute Vorhersagen. Es gibt seit den 80 Jahren der Beforschung kein einziges Experiment oder keine einzige Beobachtung, die die Aussagen der Quantenmechanik widerlegt.

3. Da die hundert Personen trotz exakt gleichem Aufbau die Elektronen an jeweils anderen Positionen messen, kann man schlussfolgern, dass der Ausgang eines einzelnen Experimentes nicht vorausgesagt werden kann. Man kann lediglich die Wahrscheinlichkeit angeben, das Elektron an einer bestimmten Position zu detektieren.

4. Erwartet hat man ein Intensitätsbild wie Figure D.16, Bild a).

5. Tatsächlich erhielt man ein Intensitätsbild wie Figure D.16, Bild b).

Table D.11: Gegenüberstellung klassische Mechanik und Quantenmechanik.

| | ”klassische” Mechanik | Quantenmechanik |
|---|---|---|
| Vergangenheit und Zukunft | In der klassischen Mechanik geht man davon aus, dass man aus der Kenntnis ”wie die Dinge heute stehen” die Vergangenheit oder Zukunft berechnen kann. Nur die Komplexität der Gleichungen verhindert, dass man nicht alles voraussagen kann. | Auch die Kenntnis aller Parameter (Ort, Geschwindigkeit, Masse, . . . ) von Teilchen ermöglicht keine exakte Vorhersage der Zukunft. In der Quantenmechanik werden Wahrscheinlichkeiten vorhergesagt (Schrödingergleichung). |
| Zufall und Wahrscheinlichkeit | So etwas wie Zufall gibt es für Naturprozesse nicht. Alles kann bei entsprechende genauer Kenntnis der Parameter (Ort, Masse, . . . ) genau vorhergesagt werden. | Der Ausgang von Versuchen folgt einer Wahrscheinlichkeitsverteilung. Den Ausgang eines einzigen Experiments kann man nicht voraussagen |

6. Da ein Beugungsbild nur bei Öffnung beider Spalte auftritt, kann man schlussfolgern, dass Elektronen von dem anderen Spalt auf irgendeine Art etwas ”wissen”. Das Beugungsbild deutet stark darauf hin, dass es sich bei Elektronen um Wellen handeln muss, denn ein solches Beugungsbild ist beispielsweise aus Interferenzversuchen mit Licht bekannt.

7. Max Born kombinierte die Anhaltspunkte unterschiedlicher Versuche. Zum einen wusste man aus dem skizzierten Elektronenexperiment mit den hundert Versuchsleitern, dass man bei der Beschreibung der Ausbreitung von Elektronen auf Wahrscheinlichkeiten zurückgreifen muss. Die strenge Voraussagbarkeit der klassischen Mechanik gilt für Elektronen nicht. Zum anderen zeigt das Davisson-Germer-Experiment, dass Elektronen Welleneigenschaften zeigen. Als Schlussfolgerung sagte Born, dass sich eine Wahrscheinlichkeitswelle im Raum ausbreitet, die das Verhalten (bspw. Ort) von Elektronen beschreibt.

8. Um die Bewegung zu beschreiben greift man auf die Ausbreitung der Wahrscheinlichkeitswelle zurück. An Orten, an denen die Wahrscheinlichkeitswelle groß ist, befindet sich das Teilchen mit hoher Wahrscheinlichkeit. Dort, wo die Wahrscheinlichkeitswelle gleich Null ist, besteht keine Chance das Teilchen anzutreffen. Die Ausbreitung eines Teilchens ist dann die Ausbreitung einer Wahrscheinlichkeitswelle im Raum.

9. Schießt man Elektronen auf einen Doppelspalt erhält man ein Beugungsbild wie in Figure D.16, Bild b) dargestellt. Dieses Beugungsbild entsteht auch, wenn die Elektronen einzeln auf den Doppelspalt geschossen werden. Warum ist das so? Wie im Rahmen der Quantenmechanik beschrieben, werden Elektronen durch eine Wahrscheinlichkeitswelle beschrieben. Diese Wahrscheinlichkeitswelle durchsetzt beide Spalte. Damit ”weiß” das Elektron von beiden Spalten und ist zur Interferenz mit sich selbst fähig, sodass ein Beugungsbild eines Doppelspaltes entsteht.

10. Nein, das kann man nicht. Elektronen bewegen sich gemäß ihrer Wahrscheinlichkeitswelle. Damit sind sie Quantenmechanische Objekte. In der ersten Aufgaben haben wir aber festgestellt, dass die Quantenmechanik nur Wahrscheinlichkeiten für Orte vorgibt, nie aber exakt einen Ort voraussagt.

# Die Übersetzung der Welt in Symbole – Problemrepräsentation in der Physik

*A picture is worth a thousand words*

— (idiom)

In der letzten Einheit habt ihr ein Problemlöseschema kennengelernt und dieses auf zwei Aufgaben angewendet. Was beim physikalischen Problemlösen häufig passiert, ist, dass man die ersten Schritte des Problemlöseprozesses überspringt, da man meint das Problem schon in- und auswendig zu kennen. Dann beginnt man mit Dingen wie Gegeben und Gesucht und arbeitet die mathematischen Schritte im Weiteren ab. Dieses Vorgehen ist im Allgemeinen nicht sinnvoll und oft problematisch. Es konnte gezeigt werden, dass besonders die ersten beiden Phasen des Problemlöseprozesses (Visualisierung und Beschreibung des Problems) stark dazu beitragen wie gut man das Problem lösen kann. Kleine Fehler im Verständnis und der Darstellung des Problems lösen dann eine Kettenreaktion an Fehlern aus, sodass man das Problem nicht mehr lösen kann. Es ist häufig ganz entscheidend, dass man geeignete Repräsentationsformen für ein Problem findet. Dann sollte man die grundlegenden Prinzipien identifizieren und erst dann mit der Mathematik beginnen.

Ihr kennt viele Problemrepräsentationen aus verschiedenen Bereichen. Zum Beispiel sind Schaltskizzen in der E-Lehre typische Repräsentationsformen, die ihr häufig verwendet. Die folgenden Repräsentationsformen sind weitere Beispiele für zentrale Repräsentationsformen in der Physik: Skizze, Vektordiagramm, Graph, Feldlinien, mathematische Gleichung und Äquipotentiallinien. Die verschiedenen Repräsentationsformen sind nicht immer klar voneinander zu trennen (beispielsweise kann eine Skizze auch als Vektordarstellung gesehen werden), jedoch adressieren spezifische Repräsentationsformen auch spezifische Klassen von physikalischen Problemen. Wie einige dieser Repräsentationsformen mit verschiedenen physikalischen Problemen zusammenhängen, soll im Folgenden kurz dargestellt werden. In der Aufgabe zu den Repräsentationen werden ihr sehen, wie wichtig das Verständnis und die Darstellung eines physikalischen Problems ist.

1. Grundsätzlich sollte man ein Problem in eine Skizze übersetzen. Hierbei verwendet man bereits zahlreiche Annahmen und Reduktionen, die dann den Problemlöseprozess einfacher oder schwerer machen können. Denkt zurück an das erste Seminar zur elektromagnetischen Strahlung. Dort habt ihr einen Versuch zur Interferenz von Strahlung behandelt. Der Aufbau dieses Versuches in der Realität sieht folgendermaßen aus (C.7). Ein Laserpointer (links) beleuchtet eine Probe und auf dem Schirm (rechts) wird das Beugungs- oder Interferenzbild abgebildet. Das Problem kann man experimentell bearbeiten oder theoretisch lösen. Als theoretisches Problem könnte man fragen, wie weit das erste Beugungsmaximum vom zentralen Maximum entfernt ist. Nun muss man dieses Problem reduzieren, da im Foto zu viele unwichtige Informationen gegeben sind. Wir entscheiden uns für die Draufsicht (2-dimensional, Abbildung C.3) und markieren wichtige gegebene oder messbare Größen. Diese Skizze hat noch nicht den höchsten Abstraktionsgrad (die Nähe von Repräsentation und Foto) erreicht, aber sollte bereits helfen wichtige Aspekte zu erkennen. Beispielsweise wird deutlich, dass Geometrie eine wichtige Rolle spielen

Table D.12: Newtonsche Axiome.

| | |
|---|---|
| 1. Axiom (Trägheitsgesetz) | Ein Körper verharrt im Zustand der Ruhe oder der gleichförmigen Bewegung, solange sich die auf ihn einwirkenden Kräfte ausgleichen. |
| 2. Axiom (Kraftgesetz) | Wirkt eine Kraft $F$ auf einen Körper der Masse $m$, so wird dieser mit der Beschleunigung $a$ beschleunigt. Diese einfache Definition gilt nur bei konstanter Masse. Allgemeiner lautet das 2. Axiom, dass die Kraft gleich der Änderung des Impulses ist. |
| 3. Axiom (Wechselwirkungsgesetz) | Für jede Kraft existiert eine gleich große, aber entgegengesetzt gerichtete Gegenkraft („Actio = Reactio“). |

wird. Zur einfachen Lösung der Interferenz muss man die gerechtfertigte Annahme machen, dass a sehr viel kleiner ist als s ($a \ll s$), um dann weitere Vereinfachungen durchführen zu dürfen. Diese Annahme ist zur Lösung des Problems sehr wichtig, da man sich sonst in mathematischen Betrachtungen verfängt.

2. Vektordarstellungen treten dann auf, wenn man Wechselwirkungen betrachtet. Denkt zum Beispiel an die Aufgabe ”Umzugskiste”. Bei dieser Aufgabe war gefragt, welche Kraft man aufwenden muss, um einen Umzugskarton vorwärts zu schieben. Die angreifende Kraft nimmt dabei einen Winkel von $\alpha = 50°$ mit der horizontalen ein. Auch dieses Problem sollte man zunächst in eine Skizze übersetzen, um daraus dann ein Vektordiagramm zu erstellen. Den ersten Schritt lassen wir hier aus und gehen gleich zum Vektordiagramm über. Mit seinem physikalischen Wissen erschließt man sich, dass in jedem Fall die Gravitationskraft, dass eine Reibungskraft wirkt und dass man Kräfte in ihre Komponenten entlang der Koordinatenachsen zerlegen kann.

# Mechanik mit den Newton’schen Axiomen

Der englische Physiker Isaac Newton hat im 17. Jh. die Grundlagen für unser heutiges Verständnis der (klassischen) Mechanik gelegt. Newton war auch ein Experte in Farbenlehre und kämpfte für seine Korpuskeltheorie des Lichts (die gewisse Ähnlichkeit zu den Lichtquanten des 20. Jh. hat), doch seine größten Verdienste für die Physik sind im Gebiet der Mechanik zu verzeichnen. Mit drei Axiomen (lat. ”Lehrsätze”) legt Newton eine Theorie vor, die es uns ermöglicht die Ursachen für Bewegungen von Objekten (Dynamik) zu verstehen und die Bewegung der Objekte vorherzusagen. Diese drei Axiome lauten (siehe Table D.12).

Historisch betrachtet waren diese Erkenntnisse revolutionär. Aristoteles beispielsweise beschreibt ”erzwungene Bewegungen” als solche, zu deren Aufrechterhaltung es einer Kraft bedarf. Er nahm an, dass die Ruhe der ”Normalzustand” ist und alle anderen Bewegungen Krafteinwirkungen bedürfen. Diese Vorstellung wurde mit Newtons Axiomen komplett verändert. Newton erkannte, dass im Universum ohne Reibung ein Körper seinen Bewegungszustand ohne äußere Krafteinwirkung beibehält. Nun wurde die gleichförmige Bewegung der ”Normalzustand” (mit dem Spezialfall der Ruhe). Um die gleichförmige Bewegung zu ändern bedarf es einer Krafteinwirkung (1. Axiom).

Obwohl das Beherrschen dieser drei Axiome das Grundrüstzeug für Physikerinnen und Physiker ist, entwickeln Schulen Wissen um die Newton’schen Axiome oft nur unzureichend[12]. Es bedarf der kontinuierlichen Übung und Erfahrung mit Aufgaben, sodass man diese Prinzipien verinnerlicht und ”im Schlaf” anwenden kann. Die Arbeit an diesen Konzepten lohnt sich deshalb in jedem Fall zum soliden Verständnis der Physik. Wie man mit Newton’schen Gesetzen an physikalische Probleme herangeht, beleuchten wir im Folgenden aus zwei sich ergänzenden Perspektiven. Zum einen schauen wir uns (1) eine Strategie an mit der man sicherer Probleme bearbeitet, die Kräfte und die Newton’schen Gesetze beinhalten (besonders Newton 2). Anschließend werfen wir (2) einen Blick auf die sehr empfehlenswerte Physikseite leifiphysik.de[13]. Dort werden anhand von Beispielen verschiedene Kontexte vorgestellt, in welchen die Newton’schen Gesetze eine Rolle spielen.

## Strategie zur Analyse von Problemen zur Newton’schen Mechanik

Für die Newton’schen Mechanik gibt es eine Strategie der Problembeschreibung, die die Lösung der Probleme vereinfacht. Hierfür wurde ein Schema vorgeschlagen.[14] Dieses Schema ist sehr allgemein und abstrakt. Der Vorteil dieses Schemas ist, dass es auf die zentralen Aspekte bei den Problemen der Newton’schen Mechanik fokussiert und man nicht von der Formel erschlagen wird. Denn ohne die richtige Anwendung hilft die Formel nicht.

In vielen Fällen muss man bei Problemen, die man mit den Newton’schen Gesetzen bearbeitet, die Formel $\vec{F}_{tot} = m \cdot \vec{a}$ verstehen und korrekt anwenden. Dazu bestimmt man zunächst die Masse m und die Beschleunigung $\vec{a}$ des interessierenden Objektes. Diese Größen setzt man dann ins Verhältnis zu allen Kräften, die auf das Objekt wirken. Hat man einen dieser Aspekte inkorrekt beschrieben, führt die Anwendung der Newton’schen Gesetze zu Fehlern. Selbst erfahrene Studierende haben bei dieser Bestimmung große Schwierigkeiten. Besonders, wenn Probleme mehrere Systeme beinhalten, wird es schnell unübersichtlich und man muss einen kühlen Kopf bewahren und systematisch vorgehen. Frühe und kontinuierliche Übung mit diesen Aufgaben zahlt sich später aus. Das Schema besteht aus 5 Schritten, die voneinander abhängen, aber wenn möglich in der aufgeführten Reihenfolge durchgeführt werden sollen. Bei der Lösung Newton’scher Probleme kann wie folgt vorgegangen werden:

---

[12] Hestenes, David; Wells, Malcolm; Swackhamer, Gregg (1992): Force Concept Inventory. In: The Physics Teacher 30, S. 141–158.

[13] Auf dieser Seite könnt ihr auch noch genauer nachlesen, was konzeptionell hinter den Newton’schen Gesetzen steckt: http://www.leifiphysik.de/mechanik/kraft-und-bewegungsanderung#Kraft%20und%20Beschleunigung.

[14] Der folgende Text und die Aufgabe ist angelehnt an: Reif, F. (1995): Millikan Lecture 1994. Understanding and teaching important thought processes. In: American Journal of Physics 63 (1), S. 17–31.

1. Separation und Identifikation der Systeme: Komplexe Probleme sollten stets in verschiedene Systeme zerlegt werden. Diese zeichnen sich zumeist durch verschiedene Objekte und Wechselwirkungen aus.
2. Bestimmung der beschleunigten Masse: Welche Masse wird jeweils beschleunigt?
3. Bewegungsanalyse (Geschwindigkeiten und Beschleunigungen): Neben den Kräften ist es sehr wichtig alle Wechselwirkungen des Systems zu beschreiben. Dies ist erforderlich, da die Newton'schen Gesetze den Zusammenhang zwischen Kräften (Wechselwirkungen) und Bewegungen beschreiben. Die Bewegungsanalyse stellt einen sehr wichtigen Schritt zur Überprüfung des Ergebnisses dar. Es kann geprüft werden, ob die Richtung der Beschleunigung mit der Richtung der Gesamtkraft übereinstimmt.
4. Bestimmung aller Wechselwirkungen: Vor der Analyse der Kräfte sollten alle wechselwirkenden Objekte identifiziert werden. Große Reichweite: Wechselwirkende Objekte? Kräfte auf das System (z.B. Gravitation); Kontaktkräfte: Sich-berührende Objekte (markiere und benenne die Kontakte für jeden Kontakt unterschiedlicher Objekte. Der Kontakt unterschiedlicher Objekte wird hier stets nur an einer Stelle betrachtet.), Kräfte auf das System
5. Komponentenzerlegung

An der folgenden Aufgabe kann das verdeutlicht werden. Einige Schwierigkeiten werden an dieser Aufgabe deutlich. Zum Beispiel ist die Identifikation der Systeme eine mitunter große Herausforderung sowie die Analyse der Kontaktkräfte.

### Aufgabe

Eine Kiste der Masse $m$ rutscht mit vernachlässigbarer Reibung entlang einer ruhenden Rampe, die sich auf einer Waage befindet. Die Rampe hat die Masse $M$ und deren Oberfläche schließt mit der Horizontalen einen Winkel $\theta$ ein. Welches Gewicht zeigt die Waage an?

Selbsttest: Versuche die Aufgabe gerne selbst zu analysieren (Skizzen, Prinzipien) und zu beschreiben. Auf der nächsten Seite findest du einen Lösungsvorschlag.

### Lösungsvorschlag

**Problembeschreibung:** Die Kiste bewegt sich beschleunigt die Rampe hinunter. Durch die Kiste und die Rampe wirkt auf die Waage eine Gewichtskraft. Gesucht ist die Normalkraft (Gewichtskraft), die auf die Waage wirkt.

**Separation und Identifikation der Systeme:** Es liegen zwei Massen vor: die Kiste (oben) und die Rampe (unten) (siehe Figure D.17). Beachte, dass Vektoren fett gedruckt sind. Das ist eine übliche Darstellung in einigen Lehrbüchern.

**Bestimmung der Masse:** Die Masse $m$ wird entlang der Rampe mit der Beschleunigung $a$ beschleunigt. Durch die Reibungskraft $F_R$ wird die Rampe der Masse $M$ nicht beschleunigt. **Bewegung (Geschwindigkeit und Beschleunigung):** Nur die Kiste bewegt sich die Rampe hinab. Die Rampe bewegt sich nicht. **Bestimmung aller Wechselwirkungen:** Große Reichweite: Auf die

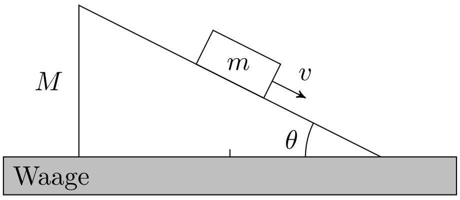


Figure D.17: Darstellung des Problems.

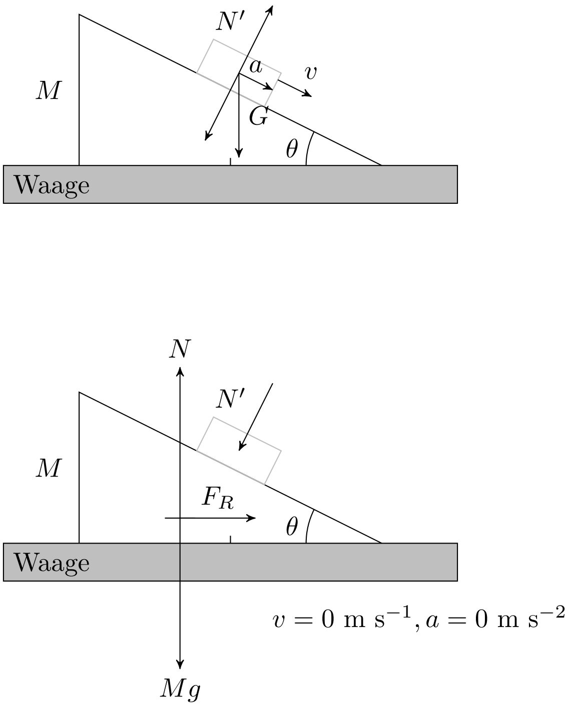


Figure D.18: Darstellung des Problems.

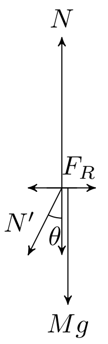


Figure D.19: Komponentendarstellung der Vektoren.

Kiste und die Rampe wirkt die Gravitationskraft; Kontaktkräfte: Die Kontaktkraft (Gleitreibung) zwischen Kiste und Rampe kann vernachlässigt werden. Zwischen Rampe und Waage wirkt eine Kontaktkraft (Haftreibung) entgegen der durch die Kiste hervorgerufenen Bewegung. Häufig wird die Reibungskraft der Rampe auf die Waage vergessen. **Komponenten:** Die Normalkraft $N$, die die Waage aufbringt, setzt sich zusammen aus der vertikalen Komponente der Normalkraft $N'$, die die Rampe wegen der Kiste aufbringt und der Gewichtskraft der Rampe. Die Reibungskraft $F_R$ kompensiert die horizontale Komponente der Kraft.

**Mathematische Ausführung:** Für die Normalkraft Kiste-Rampe folgt:

$$N' = \cos\theta F_G = \cos\theta mg$$

Weiter folgt für die Normalkraft Rampe-Waage:

$$N = \cos\theta N' + Mg = (\cos^2\theta m + M)g.$$

## Kontexte der Newton'schen Gesetze

Mit Hilfe des zweiten Newton'schen Gesetzes sind wir nun in der Lage, die Bewegung eines Körpers in der Zukunft vorherzusagen. Dazu müssen wir außer dem jetzigen Ort und der jetzigen Geschwindigkeit des Körpers wissen, ...

... welche Kräfte auf den Körper jetzt und in der Zukunft wirken, in welche Richtung diese Kräfte wirken und wie groß diese Kräfte sind

... wie groß die Masse des Körpers jetzt und in der Zukunft ist.

Kennen wir nämlich alle auf den Körper wirkenden Kräfte, so können wir zuerst einmal vektoriell die resultierende Kraft $\vec{F}_{res}$ auf den Körper ermitteln:

$$\vec{F}_{res} = \vec{F}_1 + \vec{F}_2 + \ldots$$

Nach dem zweiten Newton'schen Gesetz können wir bei konstanter Masse dann den Beschleunigungsvektor $\vec{a}$ bestimmen:

$$\vec{F}_{res} = m \cdot \vec{a} \Leftrightarrow \vec{a} = \frac{\vec{F}_{res}}{m}.$$

Dann müssen wir drei Fälle unterscheiden:

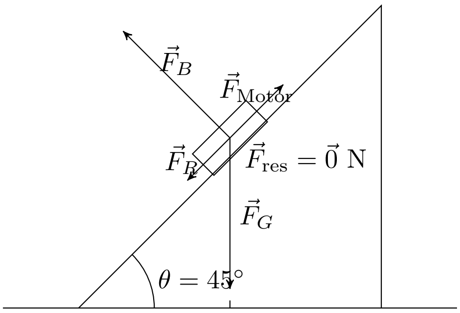


Figure D.20: Auto auf Hang.

1. Fall: Der Beschleunigungsvektors ist konstant der Nullvektor: $\vec{a} = \vec{0}$: Ist der Betrag des Beschleunigungsvektors Null, d.h. wird der Körper gar nicht beschleunigt, so bewegt sich der Körper jetzt und in der Zukunft gleichförmig weiter. Wir können somit alle Bewegungsgesetze der gleichförmigen Bewegung nutzen und sowohl den Ort als auch die Geschwindigkeit des Körpers in der Zukunft vorhersagen.

2. Fall: Der Beschleunigungsvektors ist konstant (in Richtung und Betrag), aber nicht Null: $\vec{a}$ =const.: Ist der Beschleunigungsvektor in Richtung und Betrag konstant, d.h. wird der Körper konstant beschleunigt oder verzögert, so bewegt sich der Körper jetzt und in der Zukunft gleichmäßig beschleunigt weiter. Wir können somit alle Bewegungsgesetze der gleichmäßig beschleunigten Bewegung nutzen und sowohl den Ort als auch die Geschwindigkeit des Körpers vorhersagen.

3. Der Beschleunigungsvektors ist nicht konstant: Ist der Beschleunigungsvektor nicht konstant, so bewegt sich der Körper (ungleichmäßig) beschleunigt weiter. Dies ist z.B. dann der Fall, wenn die resultierende Kraft und/oder die Masse des Körpers nicht konstant ist. Ein typisches Beispiel hierfür ist der Start einer Rakete: Bei zunehmender Höhe wird die Schwerkraft auf die Rakete immer kleiner und auch die Masse der Rakete wird durch den Treibstoffausstoß immer kleiner. Solche ungleichmäßig beschleunigten Bewegungen sind in einigen Fällen mit Mitteln der Universitätsmathematik lösbar, allgemein aber alle mit Hilfe des Computers berechenbar. Eine Einführung in die dabei benutzte sogenannte Methode der kleinen Schritte und eine Vorstellung der dabei benutzten Modellbildungs-Software findest du an anderer Stelle auf LEIFIphysik.

### Beispiele für die Anwendung der oben besprochenen Strategie

**Beispiel 1:** Ein Auto fährt mit eingeschaltetem Motor und konstanter Geschwindigkeit einen Hang hinauf (siehe Figure D.20). Wenn wir den Luftwiderstand des Autos vernachlässigen, so wirken während dieser Bewegung im Wesentlichen vier Kräfte auf das Auto:

- die senkrecht zur Erdoberfläche gerichtete konstante Gewichtskraft $\vec{F}_G$
- die senkrecht zum Hang schräg nach oben gerichtete konstante Kraft des Bodens $\vec{F}_B$

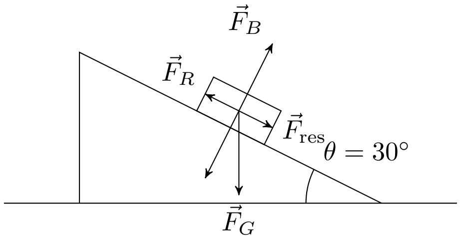


Figure D.21: Auto auf Hang.

- die entgegen der Bewegungsrichtung gerichtete konstante Reibungskraft $\vec{F}_R$
- die in Bewegungsrichtung gerichtete Motorkraft $\vec{F}_{Motor}$

Durch Vektoraddition erhält man die resultierende Kraft $\vec{F}_{res}$, die in diesem Fall $\vec{0}$ beträgt - auf das Auto wirkt also keine resultierende Kraft. Vernachlässigen wir nun die Verkleinerung der Masse des Autos durch den Verbrauch von Treibstoff, so bleibt die Masse des Autos wieder konstant. Somit ist der Beschleunigungsvektor $\vec{a} = \vec{0}$ m s$^{-2}$, so dass sich das Auto gleichförmig den Hang hinauf bewegt.

Zahlenbeispiel (im hier vorliegenden eindimensionalen Fall werden die Vektoren zu Skalaren): $F_G = 10000$ N,$F_B = 7071$ N,$F_R = 2500$ N,$F_Motor = 9571$ N; durch Vektoraddition ergibt sich $F_{res} = 0$ N und mit $m = 1000$ kg:

$$a = \frac{F_{res}}{m} \Rightarrow a = \frac{0 \text{ N}}{1000kg} = 0 \text{ m s}^{-2}.$$

**Beispiel 2:** Ein Auto rollt mit ausgeschaltetem Motor einen Hang hinab (siehe Figure D.21). Wenn wir wieder den Luftwiderstand des Autos vernachlässigen, so wirken während dieser Bewegung im Wesentlichen drei Kräfte auf das Auto:

- die senkrecht zur Erdoberfläche gerichtete konstante Gewichtskraft $\vec{F}_G$
- die senkrecht zum Hang schräg nach oben gerichtete konstante Kraft des Bodens $\vec{F}_B$
- die entgegen der Bewegungsrichtung gerichtete konstante Reibungskraft $\vec{F}_R$

Durch Vektoraddition erhält man die konstante resultierende Kraft $\vec{F}_{res}$, die in Bewegungsrichtung des Autos zeigt. Da das Auto keinen Treibstoff verbraucht, bleibt die Masse des Autos ebenfalls konstant. Somit ist der Beschleunigungsvektor $\vec{a}$ in Betrag und Richtung konstant in Bewegungsrichtung des Autos, so dass sich das Auto gleichmäßig beschleunigt den Hang hinunter bewegt.

Zahlenbeispiel (im hier vorliegenden eindimensionalen Fall werden die Vektoren zu Skalaren): $F_G = 10000$ N,$F_B = 8660$ N,$F_R = 2500$ N; durch Vektoraddition ergibt sich $F_{res} = 2500$ N und mit $m = 1000$ kg:

$$a = \frac{F_{res}}{m} \Rightarrow a = \frac{2500 \text{ N}}{1000kg} = 2,5 \text{ m s}^{-2}.$$

**Beispiel 3:** Ein Auto rollt mit ausgeschaltetem Motor auf einer ebenen Fläche. Wenn wir wieder den Luftwiderstand des Autos vernachlässigen, so wirken während dieser im Wesentlichen drei Kräfte auf das Auto:

- die senkrecht zur Erdoberfläche gerichtete konstante Gewichtskraft $\vec{F}_G$
- die senkrecht zum Hang schräg nach oben gerichtete konstante Kraft des Bodens $\vec{F}_B$
- die entgegen der Bewegungsrichtung gerichtete konstante Reibungskraft $\vec{F}_R$

Durch Vektoraddition erhält man die konstante resultierende Kraft $\vec{F}_{res}$, die nun entgegen der Bewegungsrichtung des Autos zeigt. Hinweis: Kraft- und/oder Beschleunigung entgegen der Bewegungsrichtung verdeutlicht man oft durch ein Minuszeichen vor dem Kraft- und/oder Beschleunigungsbetrag. Da das Auto wieder keinen Treibstoff verbraucht, bleibt die Masse des Autos ebenfalls konstant. Somit ist der Beschleunigungsvektor $\vec{a}$ in Betrag und Richtung konstant entgegen der Bewegungsrichtung des Autos, so dass sich das Auto gleichmäßig verzögert (gebremst) auf der ebenen Fläche bewegt.

Zahlenbeispiel (im hier vorliegenden eindimensionalen Fall werden die Vektoren zu Skalaren): $F_G = 10000$ N,$F_B = 8660$ N,$F_R = 2500$ N; durch Vektoraddition ergibt sich $F_{res} = (-)2500$ N und mit $m = 1000$ kg:

$$a = \frac{F_{res}}{m} \Rightarrow a = \frac{(-)2500 \text{ N}}{1000kg} = (-)2,5 \text{ m s}^{-2}.$$

## Das Lösen physikalischer Probleme mit Energie und Kraft

### Das Lösen physikalischer Probleme mit Energie und Kraft[15]

Neben den Newton'schen Gesetzen ist ein zweites wichtigstes Prinzip in der Mechanik der Energieerhaltungssatz (EES). Das Wissen um den EES ermöglicht es uns, verschiedene Problemstellungen zu lösen. Es ist meist nicht besonders schwierig anzugeben, dass Anfangsenergie gleich der Endenergie ist. Es wird allerdings schwierig, wenn man auch begründen soll, warum man den EES bei bestimmten Problemen anwenden darf, bei anderen aber nicht. Genau das werdet ihr in der folgenden Einheit vertiefen.

Generell gilt, in einem mechanischen System auf der Erde liegt Energie als potentielle Energie (Energie bezüglich der Position im Gravitationsfeld der Erde) und kinetische Energie (Energie bezüglich der Translationsbewegung des Schwerpunktes und der Rotation um diesen) vor (Spannenergie sei für den Moment vernachlässigt). Die Gesamtenergie eines abgeschlossenen Systems ist die Summe aus potentieller Energie und kinetischer Energie. Abgeschlossen

---

[15] Angelehnt an: Oman, R., & Oman, D. How to solve Physics Problems. McGraw-Hill Education, 1997.

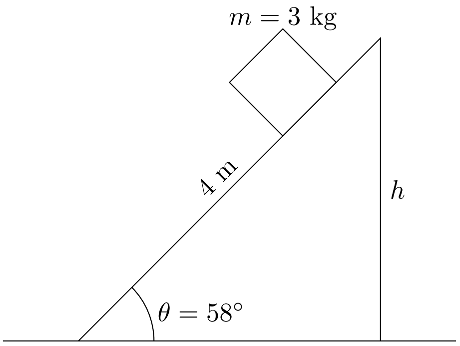


Figure D.22: Kiste auf schiefer Ebene.

meint, dass beispielsweise keine Kräfte "von außen" wirken. Nur dann bleibt die Gesamtenergie des Systems erhalten. Kräfte "von außen" wären beispielsweise Reibungskräfte und alle anderen Kräfte, die am System Arbeit leisten. Kräfte, die nicht "von außen" wirken sind beispielsweise konservative Kräfte wie die Gravitationskraft. Diese Kräfte haben ein Potential und es gilt, dass man bei Rückkehr an den gleichen Ort auch wieder die gleiche Energie hat.

Ein einfaches Beispiel ist die schiefe Ebene ohne Reibung. Gesucht ist die Geschwindigkeit der Kiste am unteren Ende der schiefen Ebene (siehe Abbildung D.22).

Die Aufgabe kann einfach gelöst werden durch Anwendung des EES. Nach Betrachtung der Energien in zwei (beliebig wählbaren) Punkten, kann man Aussagen über das Verhalten des Systems treffen. Man wählt hierbei die Punkte, über die hinreichend viel bekannt ist. Zustand 1 ist dabei der Ausgangszustand der Kiste. An diesem Punkt weiß man, dass die Geschwindigkeit der Kiste Null ist, sodass die Kiste nur potentielle Energie besitzt. Als zweiten Zustand nimmt man geeigneter Weise denjenigen, der die gesuchte Größe zum gesuchten Zeitpunkt enthält. Das ist in diesem Fall das untere Ende der schiefen Ebene. Mit den bekannten Zusammenhängen für die kinetische und potentielle Energie folgt für Zustand 1: $E_{\text{pot}} = mgh$ und für den Zustand 2: $E_k in = m/2v^2$. Die Endgeschwindigkeit ist damit $v = \sqrt{2gh}$, wobei $h$ durch $\sin 58°\dot{4}, 0$ m ersetzt werden kann.[16]

Die Gesamtenergie dieses Systems wäre im Übrigen nicht erhalten, wenn beispielsweise eine Reibungskraft vorhanden wäre, wobei ein Teil der Energie in Bewegung der kleinsten Bestandteile der Bahn und der Kiste umgewandelt würde (sprich die Bahn und die Kiste würden sich leicht erwärmen). Ebenso wäre die Gesamtenergie nicht erhalten, wenn die Kiste zusätzlich an einer Feder hängen würde und man die Feder nicht als Teil des abgeschlossenen Systems betrachtet (siehe Abbildung D.23). Dann ist die Masse m am Anfang in Ruhe und hat nur potentielle Energie. Lässt man diese los, wandelt sich die potentielle Energie in kinetische Energie und Spannenergie der Feder, bis die Kiste an einem Punkt zum Stillstand kommt. An diesem Punkt setzt sich die Gesamtenergie aus potentieller Energie und Spannenergie zusammen. Da die Spannenergie

---

[16] Der Nullpunkt der Höhe ist bei der Position des Mittelpunktes des Kastens am unteren Ende der Ebene gewählt. Eine andere Festlegung führt nicht zu einem anderen Ergebnis (potentielle Energie ist nur bis auf additive Konstante festgelegt).

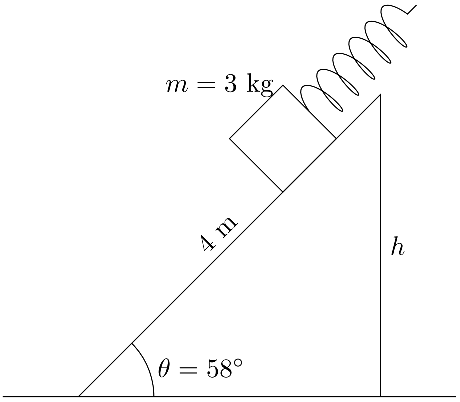


Figure D.23: Kiste auf schiefer Ebene.

aber nicht als Teil des „abgeschlossenen Systems“ betrachtet wird, würde man potentielle Energie im Zustand 1 mit potentieller Energie im Zustand 2 gleichsetzen. Die potentielle Energie im Zustand 2 ist allerdings geringer, sodass der EES nicht gilt. Es ist demzufolge auch eine Frage der Systemdefinition, ob der EES angewendet werden darf oder nicht.

Nun kennt ihr prinzipiell zwei Methoden, um einfache physikalische Probleme der Mechanik zu lösen. Das sind der Kraftansatz (der im Wesentlichen auf Newtons zweitem Grundgesetz basiert) und der EES. Wenn ihr physikalische Probleme bearbeitet, müsst ihr euch für einen dieser beiden Ansätze entscheiden. Der folgende Abschnitt soll euch bei der Auswahl helfen.

### EES und Kraftansatz

Bei vielen Problemen kann man den EES oder den Kraftansatz zu Hilfe nehmen. Beispielsweise kann man die schiefe Ebene von oben sowohl mit Kraftansatz als auch mit Energieansatz berechnen:

**Kraftansatz:** Annahmen: Gleichförmig beschleunigte Bewegung sowie Bewegungsgesetze:

$$\begin{aligned} v &= a \cdot t + v_0 \\ s &= \frac{a}{2} t^2 + v_0 \cdot t + s_0. \end{aligned}$$

2. Newton’sches Gesetz: $F = m \cdot a$.

Problemrepräsentation (siehe Figure D.24). Lösungsplan:

- Berechnung der Hangabtriebsbeschleunigung

- Aus Bewegungsgesetzen die Zeit substituieren und die Endgeschwindigkeit berechnen.

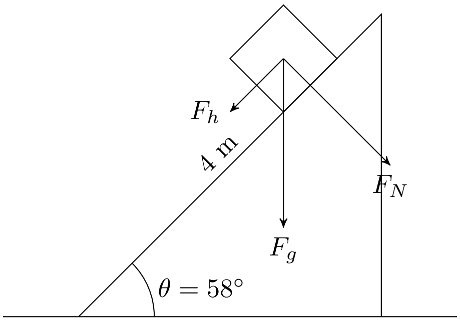


Figure D.24: Kiste auf schiefer Ebene.

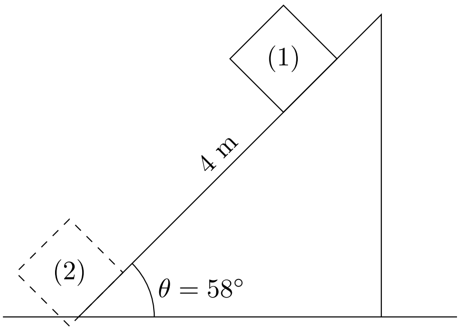


Figure D.25: Kiste auf schiefer Ebene.

Ausführung:

$$\begin{aligned} ma_H = \sin 58° \cdot mg \rightarrow a_H &= \sin 58° \cdot g \\ t &= \frac{v}{a} \\ s &= \frac{a}{2}\left(\frac{v}{a}\right)^2 = \frac{v^2}{2a} \\ v &= \sqrt{2as} = \sqrt{2 \sin 58° gs}. \end{aligned}$$

**EES:** Annahmen: Es wirken nur konservative Kräfte (d.h. Kräfte, die auch ein Potential haben). EES gilt:

$$E_{kin_1} + E_{pot_1} = E_{kin_2} + E_{pot_2}$$

Problemrepräsentation (siehe Figure D.25). Lösungsplan:

- Bestimmung von $h$
- Bestimmung der mechanischen Energien in Zustand 1 und Zustand 2
- Gleichsetzen der Energien und Umstellen nach $v$

Ausführung:

$$h = \sin 58^\circ \cdot s$$

Zustand 1:

$$E_{kin} = 0 \text{ J}; E_{pot} = mgh$$

Zustand 2:

$$\begin{aligned} E_{kin} &= \frac{m}{2}v^2; E_{pot} = 0 \text{ J} \\ \Rightarrow mgh &= \frac{m}{2}v^2 \\ v &= \sqrt{2gh} = \sqrt{2\sin 58^\circ gs}. \end{aligned}$$

Die Ergebnisse der beiden Ansätze stimmen erwartungsgemäß überein. Insbesondere in Fällen, in denen die Beschleunigung nicht konstant ist, kann eine Lösung mit Hilfe des Energieerhaltungssatzes deutlich einfacher sein.

### Aufgabe Objekt im Gravitationsfeld

Ein Objekt bewegt sich im Gravitationsfeld eines sehr schweren, kugelförmigen Körpers mit einer Masse m. Anfangs hat es einen Abstand von 6000 km von dessen Mittelpunkt und kommt dann auf einen Abstand von 3000 km. Wenn das Objekt anfangs in Ruhe war, wie groß ist die Geschwindigkeit bei der Entfernung 3000 km?

### Lösung Objekt im Gravitationsfeld

**Kraftansatz:** Annahmen: Ungleichförmig beschleunigte Bewegung; Bewegungsgesetze

Sehr schwierig lösbar.

**EES:** Es wirken nur konservative Kräfte (d.h. Kräfte, die auch ein Potential haben). EES gilt!

Strategie: Energie in Zustand 1 und Zustand 2 bestimmen. Energien gleichsetzen und $v$ bestimmen

Ausführen:

Zustand 1:

$$E_{kin} = 0 \text{ J}; E_{pot} = \frac{\gamma m M}{r_1}$$

Zustand 2:

$$\begin{aligned} E_{kin} &= \frac{m}{2}v^2; E_{pot} = \frac{\gamma m M}{r_2} \\ \Rightarrow \frac{\gamma m M}{r_1} &= \frac{\gamma m M}{r_2} + \frac{m}{2}v^2 \\ \Rightarrow v &= \sqrt{2\gamma M\left(\frac{1}{r_2} - \frac{1}{r_1}\right)} \end{aligned}$$

Nun seid ihr gerüstet für die folgenden Aufgaben im Online-Training. Legt bei den Aufgaben besonderen Wert darauf, dass ihr begründet, warum ihr bestimmte Prinzipien (EES, Newton 2, ...) zur Lösung des Problems nutzen dürft.

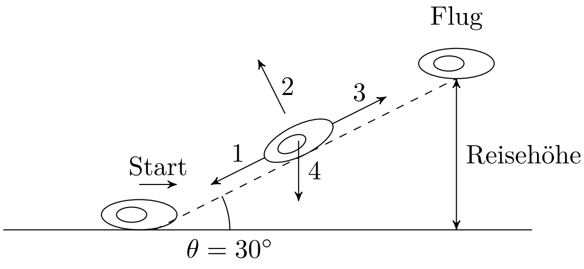


Figure D.26: Skizze zum Aufstieg des Flugzeugs. Hierbei sind 1: Reibungskraft, 2: Hubkraft, 3: Schubkraft, 4: Gewichtskraft.

Ihr solltet euch bei der Lösung am Problemlöseschema orientieren, welches wir im anderen Training eingeführt haben.

### Aufgabe Flugzeug

Eines Morgens, als du auf den Unterrichtsbeginn wartest, liest du einen Artikel über Flugzeugsicherheit. Dieser Artikel betont die Bedeutung von Materialermüdung in aktuellen Flugzeugunglücken. Materialermüdung resultiert aus der Beugung von Bauteilen in Reaktion auf die Kräfte, die auf das Flugzeug wirken, besonders während des Starts und der Landung. Der Bericht nutzt ein Beispielflugzeug mit einer Masse von 75 t und einer Take-Off Geschwindigkeit von 320 km $h^{-1}$. Dieses steigt in einem Winkel von 30° mit konstanter Beschleunigung auf eine Reisehöhe von 10 km mit einer Geschwindigkeit von 800 km $h^{-1}$. Die Turbinen geben einen Schub von 546 kN durch Zurückstoßen der Luft. Der Artikel erklärt dann weiter, dass ein Flugzeug fliegt, weil die Luft eine nach oben gerichtete Kraft auf die Tragflächen ausübt (Hubkraft), die senkrecht zur Flügeloberfläche ist. Du weiß, dass die Luftreibung eine ebenso wichtige Kraft ist, die in entgegengesetzter Richtung zur Geschwindigkeit des Flugzeugs wirkt. Der Artikel bezeichnet diese Kraft als Luftreibungskraft. Obwohl die Reporterin schreibt, dass die Materialermüdung auf die Hubkraft und auf die Luftreibungskraft zurückzuführen sind, gibt sie an keiner Stelle die Größe dieser Kraft an. Glücklicherweise enthält der Artikel genügend Informationen diese zu berechnen. Führe auf dem Weg zur Berechnung dieser Kräfte die gelb unterlegten Felder in dem Problemlöseschema aus. (Hinweis: Nimm an, dass die Masse des Flugzeugs bei dieser Aufgabe konstant bleibt.)

### Lösung Flugzeug

*Visualisierung des Problems:* siehe Figure D.26.

Grundlegende Prinzipien: Zerlegung von Kräften in ihre Vektorkomponenten, Gesetze der gleichmäßig beschleunigten Bewegung. Frage: Wie groß sind die Reibungskraft sowie die Hubkraft. Beschreibung des Problems in physikalischen Begriffen: siehe Figure D.27.

Welche Ziffern entsprechen den folgenden Größen (Definition siehe unten)? (Lösung siehe Figure D.28). Lege die Zielgröße symbolisch fest (z.B. finde $v_0$ so, dass $h_m > 10$ m): Gesucht sind R und H.

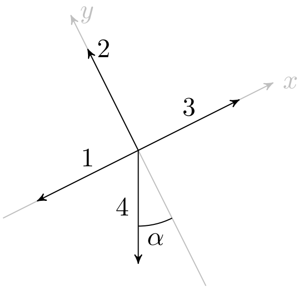


Figure D.27: Skizze zum Aufstieg des Flugzeugs. Hierbei sind 1: $R$, 2: $H$, 3: $S$, 4: $G$.

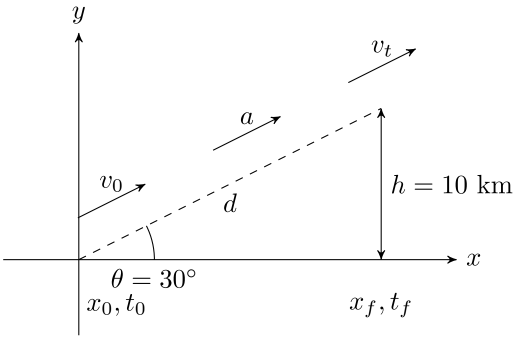


Figure D.28: Schematische Grafik zum Aufstieg des Flugzeugs.

*Planen einer Lösung:* Komponenten der Gewichtskraft: $G_x = \cos\alpha G, G_y = \sin\alpha G$. Kräftegleichgewicht in x-Richtung (Achtung, es werden zwei Koordinatensysteme verwendet):

$$\sum_i F_{y_i} = ma_y \tag{D.12}$$

$$H - G_y = H - \cos\alpha G = 0 \qquad H \text{ gesucht.} \tag{D.13}$$

$$\sum_i F_{x_i} = ma_x \tag{D.14}$$

$$-R - G_x + S = -R - \sin\alpha G + S = ma_x \qquad a_x \text{ unbekannt, } R \text{ gesucht.} \tag{D.15}$$

Bewegungsgesetze:

$$\begin{aligned} a_x &= \frac{v_f - v_0}{t_f - t_0} && t_f \text{ unbekannt.} \\ \bar{v} &= \frac{v_f + v_0}{2} && \bar{v} \text{ unbekannt.} \\ \bar{v} &= \frac{d}{t_f - t_0} && d \text{ unbekannt.} \\ \sin\alpha &= \frac{h}{d} \end{aligned}$$

Füge Gleichungen für die Beschränkungen hinzu (z.B. $v_0 = 0$ m s°, Anfangsgeschwindigkeit verschwindet): $t_0 = 0$ s. Arbeite nun rückwärtsgerichtet von der Zielgröße bis du sicher bist, dass du genug Information hast, das Problem zu lösen (du musst die gleiche Anzahl an unabhängigen Gleichungen haben, wie du unbekannte Größen hast!) Lege die mathematischen Schritte fest, um dein Gleichungssystem zu lösen (z.B. stelle Gleichung (1) nach x um und setze in Gleichung (2) ein): Die Hubkraft kann mittels der Gleichung D.13 berechnet werden. Anhand der Bewegungsgesetze kann $a_x$ berechnet werden (4 Gleichungen, 3 Unbekannte) und in Gleichung D.15 eingesetzt werden (2 Gleichungen für 2 Unbekannte).

*Ausführung des Lösungsplanes:* Die Hubkraft ergibt sich zu:

$$H = \cos\alpha G = \cos\alpha mg = \cos 30° \cdot 75 \text{ t} \cdot 9,81 \text{ m s}^{-2} = 637 \text{ kN.}$$

$$\begin{aligned} \frac{v_f + v_0}{2} &= \frac{d}{t_f - t_0} = \frac{\frac{h}{\sin\alpha}}{t_f - t_0} \\ \Rightarrow t_f &= \frac{\frac{2h}{\sin\alpha}}{v_f - v_0} = \frac{2h}{\sin\alpha(v_f + v_0)} \\ a_x &= \frac{v_f - v_0}{t_f} = \frac{(v_f - v_0)(v_f + v_0)}{2h}\sin\alpha \end{aligned}$$

Einsetzen in Gleichung D.15 ergibt:

$$\begin{aligned} -R - \sin\alpha mg + S &= m\frac{(v_f - v_0)(v_f + v_0)}{2h}\sin\alpha \\ \Rightarrow R &= S - \sin\alpha mg - m\frac{(v_f - v_0)(v_f + v_0)}{2h}\sin\alpha, \end{aligned}$$

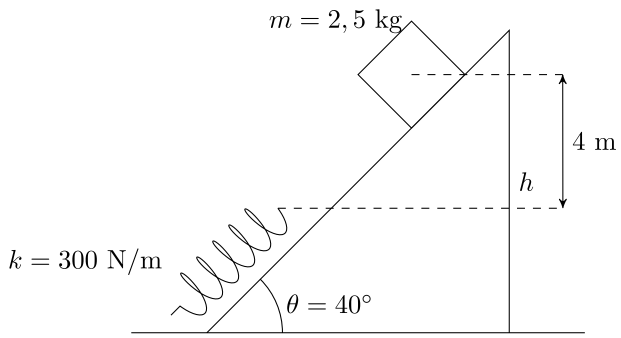


Figure D.29: Kiste auf schiefer Ebene.

und nach Einsetzen der Werte folgt

$$\begin{aligned} R =& 546 \text{ kN} - \sin 30° \cdot 75 \text{ t} \cdot 9,81 \text{ m s}^{-2} - 75 \text{ t}\cdot \\ & \frac{(800/3,6 \text{ m s}^{-1} - 320/3,6 \text{ m s}^{-1})(800/3,6 \text{ m s}^{-1} + 320/3,6 \text{ m s}^{-1})}{2 \cdot 10000 \text{ m}} \sin 30° \\ =& - 100 \text{ kN}. \end{aligned}$$

*Kontrolle der Lösung:* Das Vorzeichen sowie die Größenordnung der Hubkraft scheinen sinnvoll. Die Hubkraft sollte etwas geringer sein als die Gewichtskraft, denn ein Teil der Gewichtskraft wird von der Schubkraft kompensiert. Das Vorzeichen der Reibungskraft ist richtig. Die Reibungskraft muss in jedem Fall kleiner sein als die Schubkraft. Auch diese Bedingung ist erfüllt.

### Aufgabe Kiste[17]

Ein kleiner Kasten der Masse $m = 2,5$ kg befindet sich am oberen Ende einer geneigten Ebene (siehe Abbildung D.29). Nach dem Loslassen rutscht er die Ebene hinunter. Die Reibung darf dabei vernachlässigt werden. Berechne die maximale Kompression der Feder, wenn der Kasten auf diese draufrutscht. Der Kasten darf als Punktmasse angenommen werden (d.h., dessen Länge und Höhe sei vernachlässigbar klein).

Nutze, wo du es für sinnvoll hältst, bei deiner Lösung das Problemlöseschema, das im Online-Training präsentiert wurde. Gehe bei der Lösung auf folgende Punkte speziell ein:

1. Welche physikalischen Prinzipien wendest du zur Lösung dieser Aufgabe an? (Hinweiskarte)

2. Warum darfst du diese Prinzipien anwenden?

Zusatz: Was passiert aus physikalischer Sicht nachdem die Masse am niedrigsten Punkt angelangt ist? Beschreibe.

---

[17] Aufgabenidee aus: Oman, Robert; Oman, Daniel (1997): How to solve physics problems: McGraw-Hill Education.

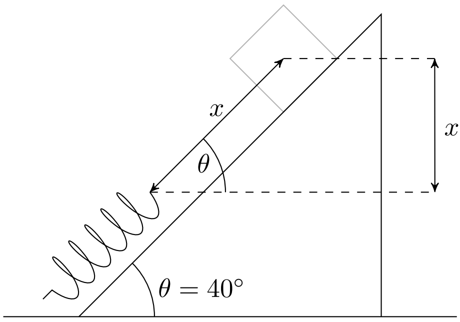


Figure D.30: Kiste auf schiefer Ebene, mit $m$... Masse ($2,5$ kg), $k$... Federkonstante (300 N/m), $h$... Höhe (4 m), $\alpha$ ... Winkel der schiefen Ebene (40°), $x$ ... Kompression der Feder, $x'$... Projektion von $x$ auf die vertikale Achse.

**Lösung Kiste**

Bei der Aufgabe handelt es sich um ein typisches Problem, welches mit dem Energieerhaltungssatz (EES) gelöst werden kann. *Visualisierung des Problems:* Wie stark wird die Feder komprimiert? (Länge), Prinzipien: Energieerhaltungssatz; Herangehensweise: Betrachtung von Extremzuständen: Energie im Zustand 1 (Masse befindet sich in maximaler Höhe) und Zustand 2 (Masse hat die Feder maximal komprimiert, Masse ruht dadurch und Masse besitzt eine geringere Höhe, siehe Figure D.30); Gleichsetzen der Zustände liefert eine Gleichung zur Berechnung der Kompression. Durch geometrische Überlegungen muss weiterhin die Kompression in Komponenten zerlegt werden. *Beschreibung des Problems in physikalischer Weise:* Zur Lösung des Problems wird der Energieerhaltungssatz (EES) verwendet. Der EES darf angewendet werden, wenn wir die Masse und die Feder als abgeschlossenes System betrachten. Es wirkt keine externe Kraft (z.B. Reibungskraft), die Arbeit am System verrichtet. Aus der Geometrie wird weiterhin die Kompression sowie die Höhendifferenz berechnet. Hierzu können die Gesetze der Trigonometrie genutzt werden. Die Zielgröße ist $x$.

*Planen einer Lösung:* Energie im Zustand 1 beträgt:

$$E_1 = E_{pot} = mg(h + x'). \tag{D.16}$$

Energie im Zustand 2 beträgt:

$$E_2 = E_{spann} = \frac{k}{2}x^2. \tag{D.17}$$

Die Gesamtenergie ergibt sich dann zu: $E_{ges} = E_1 = E_2$. Die Größe $x'$ berechnet sich folgendermaßen: $x' = \sin\alpha \cdot x$. Zunächst werden Gleichungen D.16 und D.17 gleichgesetzt. Man erhält eine quadratische Gleichung für $x$. Die positive Lösung dieser Gleichung ist die gesuchte Kompression $x$. *Ausführung* *des Lösungsplanes:*

$$\begin{aligned} E_1 &= E_2 \\ mg(h+\sin\alpha x) - \frac{k}{2}x^2 &= 0 \\ \Rightarrow x^2 - \frac{2mg}{k}\sin\alpha x - \frac{2mg}{k}h &= 0 \\ x &= \frac{mg}{k}\sin\alpha + \sqrt{\left(\frac{mg}{k}\sin\alpha\right)^2 + \frac{2mg}{k}h} \end{aligned}$$

Eingesetz folgt:

$$x = \frac{2,5\ \mathrm{kg} 9,81\ \mathrm{m\ s}^{-2}}{300\ \mathrm{N\ m}^{-1})\sin 40^\circ} + \sqrt{\left(\frac{2,5\ \mathrm{kg} 9,81\ \mathrm{m\ s}^{-2}}{300\ \mathrm{N\ m}^{-1}}\sin 40^\circ\right)^2 + 2\cdot 2,5\ \mathrm{kg}\cdot 9,81\ \mathrm{m\ s}^{-2}/300\ \mathrm{N\ m}^{-1}\cdot 4\ \mathrm{m}}$$
$$\Rightarrow x = 0,86\ \mathrm{m}.$$

*Kontrolle der Lösung:* Die Kompression ist berechnet. Vorzeichen und Einheit stimmen. In der Skizze wurde die Länge x so festgelegt, dass positive Werte "nach unten" gezählt werden. Wenn man eine Masse $m = 2,5$ kg auf die Feder legt, würde diese folgendermaßen zusammengedrückt:

$$\begin{aligned} m\cdot g &= k\cdot x \\ \Rightarrow x &= \frac{2,5\ \mathrm{kg}\cdot 9,81\ \mathrm{m\ s}^{-2}}{300\ \mathrm{N\ m}^{-1}} = 0,08\ \mathrm{m}. \end{aligned}$$

Durch die erreichte Endgeschwindigkeit sollte dieser Wert größer werden. Wenn man die Kompression für die Energie zum Beginn vernachlässigt, so ergibt sich eine Höhe von:

$$\begin{aligned} mgh &= \frac{k}{2}x^2 \\ \Rightarrow x &= \sqrt{\frac{2mgh}{k}} = \sqrt{\frac{2\cdot 2,5\ \mathrm{kg}\cdot 9,81\ \mathrm{m\ s}^{-2} 4\ \mathrm{m}}{300\ \mathrm{N\ m}^{-1}}} = 0,81\ \mathrm{m}. \end{aligned}$$

Durch die "zusätzliche" Höhe durch die Kompression sollte das in der Aufgabe berechnete x größer sein.

*Zusatz:* Gemäß dem EES würde die Masse wieder zum Ausgangsort zurückgelangen. Denn die gesamte potentielle Energie steckt nach der Umwandlung in kinetische Energie am Ende in der Feder. Die Feder wandelt diese Spannenergie erneut in kinetische Energie und schließlich in potentielle Energie. In einer idealen Welt wäre die Masse dann erneut am Ausgangsort.

Aufgrund der Umwandlung eines Teils der Energie in Wärme, würde die Kiste allerdings mit jedem Durchgang etwas weniger hoch gelangen und irgendwann schließlich würde die Schwingung zum Erliegen kommen.

# References

Abele, A. E., & Wojciszke, B. (2007). Agency and communion from the perspective of self versus others. *Journal of Personality and Social Psychology*, *93*(5), 751–763. doi: 10.1037/0022-3514.93.5.751

Abernathy, T., & Vineyard, R. (2001). Academic competitions in science. *The Clearing House*, *74*(5), 269–276.

Adams, J. D., & Gupta, P. (2015). Informal science institutions and learning to teach: An examination of identity, agency, and affordances. *Journal of Research in Science Teaching*, n/a. doi: 10.1002/tea.21270

Adamuti-Trache, M., & Andres, L. (2008). Embarking on and persisting in scientific fields of study: Cultural capital, gender, and curriculum along the science pipeline. *International Journal of Science Education*, *30*(12), 1557–1584.

Aguilar, L., Walton, G., & Wieman, C. (2014). Psychological insights for improved physics teaching. *Physics Today*, *67*(5), 43–49. doi: 10.1063/PT.3.2383

Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education*, *27*, 1–52.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*, 179–211.

Allport, G. W. (1954). *The nature of prejudice.* Cambridge, MA: Perseus Books.

Ancis, J. R., & Phillips, S. D. (1996). Academic gender bias and women's behavioral agency self-efficacy. *Journal of Counseling and Development*, *75*, 131–137.

Apple, M. W. (1992). Educational reform and educational crisis. *Journal of Research in Science Teaching*, *29*(8), 779–789.

APS. (2015). *15.2 statement on the status of women in physics.* Retrieved 29 April 2018, from `https://www.aps.org/policy/statements/15_2.cfm`

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012a). "balancing acts": Elementary school girls' negotiations of femininity, achievement, and science. *Science Education*, *96*(6), 967–989.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012b). Science aspirations, capital, and family habitus: How families shape children's engagement and identification with science. *American Educational Research Journal*, *49*, 881–908.

Archer, L., Moote, J., Francis, B., DeWitt, J., & Yeomans, L. (2017). The "exceptional" physics girl: A sociological analysis of multimethod data from young women aged 10–16 to explore gendered patterns of post-16 participation. *American Education Research Journal*, *54*(1), 88–126.

Arendt, H. (2018). *Die Freiheit, frei zu sein.* München: dtv.

Aronson, J., Fried, C. B., & Good, C. (2002). Reducing the effects of stereotype threat on african american college students by shaping theories of intelligence. *Journal of Experimental Social Psychology*, *38*(2), 113–125. doi: 10.1006/jesp.2001.1491

Aronson, J., & McGlone, M. S. (2009). Stereotype and social identity threat. In T. D. Nelson (Ed.), *Handbook of prejudice, stereotyping, and discrimination* (pp. 153–178). New York: Psychology Press.

Aschbacher, P., Li, E., & Roth, E. J. (2010). Is science me? high school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), 564–582.

Asendorpf, J. B. (2004). *Psychologie der Persönlichkeit.* Berlin and Heidelberg and New York: Springer.

Asimov, I., & White, F. (1992). *The march of the millennia: A key to looking at history.* Walker & Co.

Atkinson, J. W. (1957). Motivational determinants of risk-taking behavior. *Psychological Review*, *64*(6), 359–372.

Bakan, D. (1966). *The duality of human existence: An essay on psychology and religion.* Chicage, IL: Rand McNally.

Bakan, D. (1976). *Mensch im Zwiespalt: Psychoanalyt., soziolog. u. religiöse Aspekte d. Anthropologie* (Vol. Nr. 19). München and Mainz: Kaiser and Matthias-Grünewald-Verlag.

Bakeman, R. (2005). Recommended effect size statistics for repeated measures designs. *Behavior Research Methods*, *37*(3), 379–384.

Baker, D., & Leary, R. (1995). Letting girls speak out about science. *Journal of Research in Science Teaching*, *32*(1), 3–27.

Baker, D., & Leary, R. (2003). Letting girls speak out about science. *Journal of Research in Science Teaching*, *40*, 176–200.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* Englewood Cliffs, NJ: Prentice-Hall.

Bandura, A. (1997). *Self-efficacy: The exercise of control.* New York: W. H. Freeman.

Bandura, A. (2000). Exercise of human agency through collective efficacy. *Current Directions in Psychological Science*, *9*, 75–78.

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology*, *52*, 1–26.

Bandura, A. (2008). The reconstrual of "free will" from the agentic perspective of social cognitive theory. In J. Baer, J. C. Kaufman, & R. F. Baumeister (Eds.), *Are we free?* (pp. 86–127). Oxford, UK: Oxford University Press.

Bandura, A. (2018). Toward a psychology of human agency: Pathways and reflections. *Perspectives on psychological science : a journal of the Association for Psychological Science*, *13*(2), 130–136. doi: 10.1177/1745691617699280

Barbercheck, M. (2001). Mixed messages: Men and women in advertisements in science. In M. Wyer, M. Barbercheck, D. Geisman, H. O. Ozturk, & M. Wayne (Eds.), *Women, science, and technology* (pp. 117–131). New York: Routledge.

Baron-Cohen, S. (2005). The essential difference: the male and female brain. *Phi Kappa Phi Forum.*

Baron-Cohen, S. (2012). *The essential difference: Men, women and the extreme male brain.* Penguin.

Baumeister, R. F., & Leary, M. R. (1995). The need to belong: Desire for interpersonal attachments as a fundamental human motivation. *Psychological Bulletin*, *117*(3), 497–529.

Becerra-Labra, C., Gras-Martí, A., & Torregrosa, J. M. (2012). Effects of a problem-based structure of physics contents on conceptual learning and the ability to solve problems. *International Journal of Science Education*, *34*(8), 1235–1253. doi: 10.1080/09500693.2011.619210

Beck, U. (1986). *Risikogesellschaft: Auf dem Weg in eine andere Moderne.* Frankfurt am Main: Suhrkamp.

Behrman, J. (2018). Domesticating physics. *Physics Today*, *71*(5), 50–56. doi: 10.1063/PT.3.3922

Bell, J. F. (2001). Investigating gender differences in the science performance of 16-year-old pupils in the uk. *International Journal of Science Education*, *23*(5), 469–486.

Benbow, C. P., & Stanley, J. C. (1980). Sex differences in mathematical ability: fact or artifact? *Science*, 1262–1264.

Ben-Zeev, T., Fein, S., & Inzlicht, M. (2005). Arousal and stereotype threat. *Journal of Experimental Social Psychology*, *41*, 174–181.

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. de Corte, L. Verschaffel, N. Entwistle, & J. van Merriënboer (Eds.), *Unravelling basic components and dimensions of powerful learning environments.*

Berger, R. (2000). *Moderne bildgebende Verfahren der medizinischen Diagnostik: Ein Weg zu interessantem Physikunterricht.* Berlin: Logos.

Berger, R. (2002). Einfluss kontextorientierten physikunterrichts auf interesse und leistung in der sekundarstufe ii. *Zeitschrift für Didaktik der Naturwissenschaften*, *8*, 119–132.

Berlin, I. (1969). *Four essays on liberty.* Oxford University Press.

Bertenthal, B. I. (2007). Dynamical systems: It's about time. In S. M. Boker & M. J. Wenger (Eds.), *Data analytic techniques for dynamical systems* (pp. 1–24). Mahwah, NJ and New Jersey and London: Lawrence Erlbaum Associates Publishers.

Beyer, L. E., & Liston, D. P. (1996). *Curriculum in conflict: Social visions, educational agendas, and progressive school reform.* New York: Teachers College Press.

Bian, L., Leslie, S.-J., & Cimpian, A. (2017). Gender stereotypes about intellectual ability emerge early and influence children's interests. *Science (New York, N.Y.)*, *355*(6323), 389–391. doi: 10.1126/science.aah6524

Bigler, R. S., & Liben, L. S. (2006). A developmental intergroup theory of social stereotypes and prejudice. In R. V. Kail (Ed.), *Advances in child development and behavior* (pp. 39–89). San Diego, CA: Elsevier.

Bijleveld, Catrien C. J. H., van der Kamp, Leo J. Th., Mooijaart, A., van der Kloot, Willem A., van der Leeden, Rien, & van der Burg, Eeke. (1998). *Longitudinal data analysis: Design, models and methods.* London and Thousand Oaks, CA and New Delhi: SAGE Publications.

Bjorklund, D. F., & Brown, R. D. (1998). Physical play and cognitive development: Integrating activity, cognition, and education. *Child Development*, *69*(3), 604–606.

Blackwell, L., Trzesniewski, K., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, *78*, 246–263.

Bleeker, M. M., & Jacobs, J. E. (2004). Achievement in math and science: Do mothers' believes matter 12 years later? *Journal of Educational Psychology*, *96*(1), 97–109.

Block, K., Gonzalez, A. M., Schmader, T., & Baron, A. S. (2018). Early gender differences in core values predict anticipated family versus career orientation. *Psychological Science*, 956797618776942. doi: 10.1177/0956797618776942

Bortz, J., & Döring, N. (2002). *Forschungsmethoden und evaluation.* Berlin, Heidelberg: Springer Berlin Heidelberg. doi: 10.1007/978-3-662-07299-8

Boucher, K. L., Fuesting, M. A., Diekman, A. B., & Murphy, M. C. (2017). Can i work with and help others in this field? how communal goals influence interest and participation in stem fields. *Frontiers in psychology*, *8*, 901. doi: 10.3389/fpsyg.2017.00901

Bourdieu, P. (2005). *Die männliche Herrschaft.* Frankfurt am Main: Suhrkamp.

Bowlby, J. (1969). *Bindung: Eine analyse der mutter-kind-beziehung.* Kindler.

Bransford, J., Brown, A. L., & Cocking, R. R. (2000). *How people learn.* Washington, D.C.: National Academies Press. doi: 10.17226/9853

Braun, G., Tierney, D., & Schmitzer, H. (2011). How rosalind franklin discovered the helical structure of dna: Experiments in diffraction. *The Physics Teacher*, *49*(3), 140–143. doi: 10.1119/1.3555496

Breger, L. (1974). *From instinct to identity: The development of personality.* Englewood Cliffs, NJ: Prentice Hall.

Brickhouse, N. W., Lowery, P., & Schultz, K. (2000). What kind of a girl does science? the construction of school science identities. *Journal of Research in Science Teaching*, *37*(5), 441–458.

Brickhouse, N. W., & Potter, J. T. (2001). Young woman's scientific identity formation in an urban context. *Journal of Research in Science Teaching*, *38*, 965–980.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design.* Cambridge, MA: Harvard University Press.

Brown, D. E. (1991). *Human universals.* New York: McGraw-Hill Education.

Brown, E. R., Smith, J. L., Thoman, D. B., Allen, J. M., & Muragishi, G. (2015). From bench to bedside: A communal utility value intervention to enhance students' biomedical science motivation. *Journal of Educational Psychology*, *107*(4), 1116–1135. doi: 10.1037/edu0000033

Burkam, D. T., Lee, V. E., & Smerdon, B. A. (1997). Gender and science learning early in high school: Subject matter and laboratory experiences. *American Educational Research Journal*, *34*(2), 297–331.

Burke, P. J., Owens, T. J., Serpe, R. T., & Thoits, P. A. (Eds.). (2003). *Advances in identity theory and research.* New York: Kluwer Academic.

Burke, P. J., & Stets, J. E. (1998). *Identity theory and social identity theory: Social psychology section session on theoretical frameworks at the annual meetings of the american sociological association.* San Francisco, CA.

BusinessEurope. (2011). *Plugging the gap: the clock is ticking.* Retrieved from `http://www.businesseurope.eu/Content/default.asp?pageid=568&docid=28659`

Buss, D. M., & Schmitt, D. P. (1993). Sexual strategies theory: An evolutionary perspective on human mating. *Psychological Review*, *100*(2), 204–232.

Bussey, K., & Bandura, A. (1999). Social cognitive theory of gender development and differentiation. *Psychological Review*, *106*, 676–713.

Butler, J. P. (1990). *Gender trouble: Feminism and the subversion of identity.* London: Routledge.

Butterworth, J. (2015). *Der Kosmos im Crashtest: So haben wir das Higgs gejagt.* Kosmos.

Campbell, J. R. (2000). *Overview of academic olympiad studies: Paper presented at the annual meeting of the american educational research association.*

Campbell, J. R., Wagner, H., & Walberg, H. J. (2000). Academic competitions and programs designed to challenge the exceptionally talented. In K. Heller, F. Monks, R. Sternberg, & R. Subotnik (Eds.), *International handbook of giftedness and talent* (pp. 523–535). Oxford, UK: Pergamon.

Campbell, P. B., & Steinbrueck, K. (1996). *Striving for gender equity: National programs to increase student engagement with math and science.* Washington, DC: American Association for the Advancement of Science.

Carlone, H. B. (2003). (re)producing good science students: Girls' participation in high school physics. *Journal of Women and Minorities in Science and Engineering*, *9*, 17–34.

Carlone, H. B. (2004). The cultural production of science in reform-based physics: Girls' access, participation, and resistance. *Journal of Research in Science Teaching*, *41*(4), 392–414.

Carlone, H. B., Haun-Frank, J., & Webb, A. W. (2011). Assessing equity beyond knowledge- and skills-based outcomes: A comparative ethnography of two fourth-grade reform-based science classrooms. *Journal of Research in Science Teaching*, *48*(5), 459–485.

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful woman of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218.

Carlone, H. B., Webb, A. W., Archer, L., & Taylor, M. (2015). What kind of boy does science? a critical perspective on the science trajectories of four scientifically talented boys. *Science Education*, *99*, 438–464.

Cass, C., Hazari, Z., Cribbs, J. D., Sadler, P., & Sonnert, G. (2011). *Examining the impact of mathematics identity on the choice of engineering careers for male and female students.*

Ceci, S. J., & Williams, W. (2011). Understanding current causes of women's underrepresentation in science. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(8), 3157–3162.

Ceci, S. J., Williams, W. M., & Barnett, S. M. (2009). Women's underrepresentation in science: sociocultural and biological considerations. *Psychological Bulletin*, *135*(2), 218–261. doi: 10.1037/a0014412

Chambers, D. W. (1983). Stereotypic images of the scientists: The draw-a-scientist test. *Science Education*, *67*, 255–265.

Chandrasekhar, M. (1987). *Truth and beauty: Aesthetics and motivations in science.* Chicage, IL: University of Chicago Press.

Chapman, M. (1988). *Constructive evolution: Origins and development of piaget's thought.* Cambridge: Cambridge Univ. Pr.

Chemers, M. M., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. *Journal of Social Issues*, *67*(3), 469–491. doi: 10.1111/j.1540-4560.2011.01710.x

Chen, X. (n.d.). *Students who study science, technology, engineering and mathematics (stem) in post-secondary education: Stats in brief: Nces 2009-161.*

Chen, X. (2013). *Stem attrition: College students' paths into and out of stem fields (nces 2014-001).* Washington, DC.

Cheryan, S., Plaut, V. C., Davies, P. G., & Steele, C. M. (2009). Ambient belonging: how stereotypical cues impact gender participation in computer science. *Journal of Personality and Social Psychology*, *97*(6), 1045–1060. doi: 10.1037/a0016239

Cho, S., & Lee, H. (2002). Korean gifted girls and boys: What influenced them to be olympians and non-olympians. *Journal of Research in Education*, *12*(1), 106–111.

Clandinin, D. J. (2006). Narrative inquiry: A methodology for studying lived experience. *Research Studies in Music Education*, *27*.

Close, E. W., Conn, J., & Close, H. G. (2016). Becoming physics people: Development of integrated physics identity through the learning assistant experience. *Physical Review Physics Education Research*, *12*(1). doi: 10.1103/PhysRevPhysEducRes.12.010109

Clynes, T. (2016). How to raise a genius: A long-running study of exceptional children reveals what it takes to produce the scientists who will lead the twenty-first century. *Nature*, *537*.

Cobb, P., & Hodge, L. L. (2011). Culture, identity, and equity in the mathematics classroom. In A. J. Bishop, E. Yackel, K. Gravemeijer, & A. Sfard (Eds.), *Mathematics education library* (pp. 179–195). New York.

Cohen, G. L., Garcia, J., Purdie-Vaughns, V., Apfel, N., & Brzustoski, P. (2009). Recursive processes in self-affirmation: intervening to close the minority achievement gap. *Science (New York, N.Y.)*, *324*(5925), 400–403. doi: 10.1126/science.1170769

Cohen, G. L., & Sherman, D. K. (2014). The psychology of change: self-affirmation and social psychological intervention. *Annual Review of Psychology*, *65*, 333–371. doi: 10.1146/annurev-psych-010213-115137

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis jor the behavioral sciences: 2nd edition.* Hillsdale, NJ: Erlbaum.

Colicchia, G. (2002). *Physikunterricht im Kontext von Medizin und Biologie: Entwicklung und Erprobung von Unterrichtseinheiten zur Steigerung des Interesses für den fachübergreifenden Physikunterricht* (Dissertation). Universität München, München.

Committee on Prospering in the Global Economy of the 21st Century. (2005). *Rising above the gathering storm: Energizing and employing america for a brighter economic future.* Washington, DC: National Academies.

Cook, J. E., Purdie-Vaughns, V., Garcia, J., & Cohen, G. L. (2012). Chronic threat and contingent belonging: protective benefits of values affirmation on identity development. *Journal of Personality and Social Psychology*, *102*(3), 479–496. doi: 10.1037/a0026312

Cooper, M. M., Cox, C. T., Nammouz, M., Case, E., & Stevens, R. (2008). An assessment of the effect of collaborative groups on students' problem-solving strategies and abilities. *Journal of Chemical Education*, *85*(6), 866. doi: 10.1021/ed085p866

Corbin, J., & Strauss, A. (1990). *Basics of qualitative research: Grounded theory procedures and techniques.* SAGE Publications.

Côte, J. E., & Levine, C. G. (2002). *Identity formation, agency, and culture: A social psychological synthesis.* London: Lawrence Erlbaum Associates Publishers.

Creswell, J. W. (2003). *Research design: Qualitative, quantitative and mixed methods approaches.* Thousand Oaks, CA and London and New Delhi: SAGE Publications.

Cribbs, J. D., Hazari, Z., Sonnert, G., & Sadler, P. M. (2015). Establishing an explanatory model for mathematics identity. *Child Development.* doi: 10.1111/cdev.12363

Croizet, J.-C., Després, G., Gauzins, M.-E., Huguet, P., Leyens, J.-P., & Méot, A. (2004). Stereotype threat undermines intellectual performance by triggering a disruptive mental load. *Personality & social psychology bulletin*, *30*(6), 721–731. doi: 10.1177/0146167204263961

Crowley, K., Callanan, M. A., Tenenbaum, H. R., & Allen, E. (2001). Parents explain more often to boys than to girls during shared scientific thinking. *Psychological Science*, *12*(3), 258–261.

Csikszentmihalyi, M. (2005). *Dem Sinn des Lebens eine Zukunft geben: Eine Psychologie für das 3. Jahrtausend.* Klett-Cotta.

Cvencek, D., Greenwald, A. G., & Meltzoff, A. N. (2012). Balanced identity theory: Review of evidence for implicit consistency in social cognition. In B. Gawronski & F. Strack (Eds.), *Cognitive consistency.* Guilford Press.

Danaher, K., & Crandall, C. S. (2008). Stereotype threat in applied settings re-examined. *Journal of Applied Social Psychology*, *38*(6), 1639–1655.

Dar-Nimrod, I., & Heine, S. J. (2006). Exposure to scientific theories affects women's math performance. *Science (New York, N.Y.)*, *314*(5798), 435. doi: 10.1126/science.1131100

Dasgupta, N. (2011). Ingroup experts and peers as social vaccines who inoculate the self-concept: The stereotype inoculation model. *Psychological Inquiry*, *22*(4), 231–246. doi: 10.1080/1047840X.2011.607313

Dasgupta, N., Scircle, M. M., & Hunsinger, M. (2015). Female peers in small work groups enhance women's motivation, verbal participation, and career aspirations in engineering. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(16), 4988–4993. doi: 10.1073/pnas.1422822112

Davies, B. (1990). Agency as a form of discursive practice: A classroom scence observed. *British Journal of Sociology of Education*, *11*(3), 341–361.

Dawson, E. (2017). Social justice and out-of-school science learning: Exploring equity in science television, science clubs and maker spaces. *Science Education*, *49*(2), 881. doi: 10.1002/sce.21288

Deaton, A. (2013). *The great escape: Health, wealth, and the origins of inequality.* Princeton, NJ: Princeton University Press.

de Beauvoir, S. (1949). *Le deuxième sexe.* Gallimard.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior.* New York: Plenum Press.

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, *11*(4), 227–268.

Deemer, E. D., Thoman, D. B., Chase, J. P., & Smith, J. L. (2014). Feeling the threat: Stereotype threat as a contextual barrier to women's science career choice intentions. *Journal of Career Development*, *41*(2), 141–158. doi: 10.1177/0894845313483003

de Fina, A. (2009). Narratives in interview-the case of accounts: For an interactional approach to narrative genres. *Narrative Inquiry*, *19*, 233–258.

Dennehy, T. C., & Dasgupta, N. (2017). Female peer mentors early in college increase women's positive academic experiences and retention in engineering. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(23), 5964–5969. doi: 10.1073/pnas.1613117114

DeSilver, D. (2018). *Women scarce at top of u.s. business - and in the jobs that lead there.* Retrieved 7 May 2018, from `http://www.pewresearch.org/fact-tank/2018/04/30/women-scarce-at-top-of-u-s-business-and-in-the-jobs-that-lead-there/#`

Diamond, J. (1997). *Guns, germs, and steel: The fates of human societies.* Norton.

Diekman, A. B., Brown, E. R., Johnston, A. M., & Clark, E. K. (2010). Seeking congruity between goals and roles: a new look at why women opt out of science, technology, engineering, and mathematics careers. *Psychological Science*, *21*(8), 1051–1057. doi: 10.1177/0956797610377342

Diekman, A. B., Clark, E. K., Johnston, A. M., Brown, E. R., & Steinberg, M. (2011). Malleability in communal goals and beliefs influences attraction to stem careers: evidence for a goal congruity perspective. *Journal of Personality and Social Psychology*, *101*, 902–918. doi: 10.1037/a0025199

Diekman, A. B., & Eagly, A. H. (2008). Of men, women, and motivation: A role congruity account. In W. L. Gardner & J. Y. Shah (Eds.), *Handbook of motivation science* (pp. 434–447). New York: Guilford Press.

Dobson, I. (2014). *Stem: Country comparisons: Europe...a critical examination of existing solutions to the stem skills shortage in comparable countries.*

Docktor, J. L., & Heller, K. (2008). Gender differences in both force concept inventory and introductory physics performance. *AIP Conf. Ser.*, *1064*(15).

Dou, R., Brewe, E., Zwolak, J. P., Potvin, G., Williams, E. A., & Kramer, L. H. (2016). Beyond performance metrics: Examining a decrease in students? physics self-efficacy through a social networks lens. *Physical Review Physics Education Research*, *12*(2), 1. doi: 10.1103/PhysRevPhysEducRes.12.020124

DPG. (2002). Retrieved from `https://www.dpg-physik.de/dpg/statuten/iupap.html`

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*, 287–312.

Drury, B. J., Siy, J. O., & Cheryan, S. (2011). When do female role models benefit women? the importance of differentiating recruitment from retention in stem. *Psychological Inquiry*, *22*(4), 265–269.

Duit, R., Niedderer, H., & Schecker, H. (2007). Teaching physics. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 599–629). Mawhah, New Jersey: Lawrence Erlbaum Associates Publishers.

Durik, A. M., & Harackiewicz, J. M. (2007). Different strokes for different folks: How individual interest moderates the effects of situational factors on task interest. *Journal of Educational Psychology*, *99*(3), 597–610. doi: 10.1037/0022-0663.99.3.597

Dweck, C. S. (2006). Is math a gift? believes that put females at risk. In S. J. Ceci & W. Williams (Eds.), *Why aren't more women in science?* Washington, DC.

Eagly, A. H., Beall, A. E., & Sternberg, R. J. (Eds.). (2004). *Psychology of gender.* New York: Guilford Press.

Eagly, A. H., & Diekman, A. B. (2004). The common-sense psychology of changing social groups. In J. T. Jost, M. R. Banaji, & D. A. Prentice (Eds.), *Perspectivism in social psychology.* Washington, DC: American Psychological Association Books.

Eagly, A. H., & Wood, W. (1999). The origins of sex differences in human behavior: evolved dispositions versus social roles. *American Psychologist*, *54*, 408–423.

Eccles, J. S. (1983). Expectancies, values, and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motives* (pp. 75–138). San Francisco, CA: Freeman and Company.

Eccles, J. S. (1994). Understanding women's educational and occupational choices: Applying the eccles ef al. model of achievement related choices. *Psychology of Women Quarterly*, *18*, 585–609.

Eccles, J. S. (1997). User-friendly science and mathematics: Can it interest girls and minorities in breaking through the middle school wall? In D. Johnson (Ed.), *Minorities and girls in school* (pp. 65–104). Thousand Oaks, CA: Sage.

Eccles, J. S. (2007). Gender differences in participation in physical science and engineering. In Why aren't more women in science (Ed.), *Top researcher debate the evidence* (pp. 199–210). Washington, DC: American Psychological Association.

Eccles, J. S. (2009). Who am i and what am i going to do with my life? personal and collective identities as motivators of action. *Educational Psychologist*, *44*(2), 78–89. doi: 10.1080/00461520902832368

Eccles, J. S. (2011). Gendered educational and occupational choices: Special section applying the eccles et al. model of achievement-related choices. *International Journal of Behavioural Development*, *35*(3), 195–201.

Eccles, J. S., & Wang, M. (2012). Part i commentary: So what is student engagement anyway. In S. L. Christenson, A. L. Reschly, & C. D. Wylie (Eds.), *Handbook of research on student engagement* (pp. 133–145). New York: Springer Sciences.

Eccles, J. S., & Wigfield, A. (1995). In the mind of the actor: The structure of adolescents achievement task values and expectancy-related beliefs. *Personality and Social Psychology Bulletin*, *21*(3), 215–225.

Eckert, P. (1990). Adolescent social categories—information and science learning. In M. Gardner, J. G. Greeno, F. Reif, A. Schoenfeld, A. diSessa, & E. Stage (Eds.), *Toward a scientific practice of science education* (pp. 203–217). Hillsdale, NJ: Lawrence Erlbaum Associates Publishers.

Eckes, T. (1994). Features of men, features of women: Assessing stereotypic beliefs about gender subtypes. *British Journal of Social Psychology*, *33*(1), 107–123. doi: 10.1111/j.2044-8309.1994.tb01013.x

Eisenhart, M., & Finkel, E. (1998). *Woman's science: Learning and succeeding from the margins.* Chicago, IL: University of Chicago Press.

Elkin, L. O. (2003). Rosalind franklin and the double helix. *Physics Today*, 42–48.

Else-Quest, N. M., Hyde, J. S., & Linn, M. C. (2010). Cross-national patterns of gender differences in mathematics: a meta-analysis. *Psychological Bulletin*, *136*(1), 103–127. doi: 10.1037/a0018053

EPS. (2018). *49th international physics olympiad, ipho2018: e-eps: Facts and info from the european physical society.* Retrieved from `http://www.epsnews.eu/2018/09/49th-international-physics-olympiad-ipho2018/`

Erikson, E. H. (1963). *Childhood and society.* New York: Norton.

Erikson, E. H. (1968). *Identity: Youth and crisis.* New York: Norton.

European Commission. (2012). *Eu skills panorama analytical highlight—science, technology, engineering, mathematics (stem) skills.* Retrieved from `http://euskillspanorama.ma.cedefop.europa.eu/docs/AnalyticalHighlights/STEMskills_en.pdf`

European Commission. (2014). *Eu skills panorama: Stem skills.*

Farenga, J. S., & Joyce, B. A. (1999). Intentions of young students to enroll in science courses in the future: An examination of gender differences. *Science Education*, *83*(1), 55–75.

Farland-Smith, D. (2009). How does culture shape students' perceptions of scientists? cross-national comparative study of american and chinese elementary students. *Journal of Elementary Science Education*, *21*, 23–42.

Farmelo, G. (2009). *The strangest man: The hidden life of paul dirac, quantum genius: The life of paul dirac.* Faber and Faber Ltd.

Faulstich-Wieland, H., Weber, M., & Willems, K. (2004). *Doing Gender im heutigen Schulalltag: Empirische Studien zur sozialen Konstruktion von Geschlecht in schulischen Interaktionen.* Weinheim and München.

Feng, A. X., Campbell, J. R., & Verna, M. A. (2001). The talent development of american physics olympians. *Gifted and Talented International*, *16*(2), 108–114.

Feng, A. X., Campbell, J. R., & Verna, M. A. (2005). *Understanding gender inequity in america: Interviews with academic olympians.* Retrieved from `http://www.olympiadprojects.com/v2/pubs_web%5Cch5_SS.pdf`

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science*, *18*, 850–855. doi: 10.1111/j.1467-9280.2007.01990.x

Ferreira, M. (2002). Ameliorating equity in science, mathematics, and engineering: A case study of an after-school science program. *Equity & Excellence in Education*, *35*(1), 43–49. doi: 10.1080/713845242

Fiebig, J. N. (2008). Gifted american and german adolescent women: A longitudinal examination of attachment, separation, gender roles, and career aspirations. *High Ability Studies*, *19*(1), 67–81. doi: 10.1080/13598130801980349

Field, A., & Miles, J. (2012). *Discovering statistics using r.* SAGE Publications.

Fiske, S. T., Cuddy, Amy J. C., & Glick, P. (2007). Universal dimensions of social cognition: warmth and competence. *Trends in Cognitive Science*, *11*, 77–83. doi: 10.1016/j.tics.2006.11.005

Fiske, S. T., Cuddy, Amy J. C., Glick, P., & Xu, J. (2002). A model of (often mixed) stereotype content: Competence and warmth respectively follow from perceived status and competition. *Journal of Personality and Social Psychology*, *82*(6), 878–902. doi: 10.1037//0022-3514.82.6.878

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, *34*(10), 906–911. doi: 10.1037/0003-066X.34.10.906

Flicker, E. (2003). Between brains and breasts - women scientists in fiction film: On the marginalization and sexualization of scientific competence. *Public Understanding of Science*, *12*, 307–318.

Fradd, S. H., & Lee, O. (1999). Teachers' roles in promoting science inquiry with students from diverse language backgrounds. *Educational Researcher*, *18*, 14–20.

Francis, B., Archer, L., Moote, J., de Witt, J., & Yeomans, L. (2016). Femininity, science, and the denigration of the girly girl. *British Journal of Sociology of Education*, *20*(3), 1–13. doi: 10.1080/01425692.2016.1253455

Francis, B., Read, B., & Skelton, C. (2010). The simultaneous production of educational achievement and popularity: How do some pupils accomplish it? *British Educational Research Journal*, *36*(2), 317–340.

Fredricks, J. A., & Eccles, J. S. (2002). Children's competence and value beliefs from childhood through adolescence: Growth trajectories in two male-sex-typed domains. *Developmental Psychology*, *38*, 519–533.

Fredricks, J. A., Hofkens, T., Wang, M.-T., Mortenson, E., & Scott, P. (2017). Supporting girls' and boys' engagement in math and science learning: A mixed methods study. *Journal of Research in Science Teaching*, *36*(4), 719. doi: 10.1002/tea.21419

Freedman, M. P. (2001). The influence of laboratory instruction on science achievement and attitude toward science among ninth grade students across gender differences. *Journal of Women and Minorities in Science and Engineering*, *8*, 191–200.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23), 8410–8415. doi: 10.1073/pnas.1319030111

Freeman, T. M., Anderman, L. H., & Jensen, J. M. (2007). Sense of belonging in college freshmen at the classroom and campus levels. *The Journal of Experimental Education*, *75*(3), 203–220. doi: 10.3200/JEXE.75.3.203-220

Freudiger, J. (1995). Platon und die Sache der Frau. *Kriterion*, *10*, 14–27.

Friedman, T. L. (2005). *The world is flat.* New York: Farrar, Straus, & Giroux.

Fritzsch, H. (2008). *Sie irren, Einstein! Newton, Einstein, Heisenberg und Feynman diskutieren die Quantenphysik.* Piper.

Galambos, N. L., Almeida, D. M., & Petersen, A. C. (1990). Masculinity, femininity, and sex role attitudes in early adolescence: exploring gender intensification. *Child Development*, *61*(6), 1905–1914.

Garcia, J., & Cohen, G. L. (2012). A social psychological approach to educational intervention. In E. Shafir (Ed.), *Behavioral foundations of policy* (pp. 329–350). Princeton, NJ: Princeton University Press.

Garvin, M. K. (1996). The development of math talent: Influences on students at a woman's college. *Journal of Secondary Gifted Education*, *11*, 476–485.

Gates, E. (2006). A scientific point of view. *Physics Today*, 64–65.

Gee, J. P. (1999). *An introduction to discourse analysis: Theory and method.* New York: Routledge.

Gee, J. P. (2000). Identity as an analytic lens for research in education. *Review of Research in Education*, *25*, 99–125.

Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models: Analytical methods for social research.* New York: Cambridge University Press.

Gelman, A., & Loken, E. (2013). The garden of forking paths: Why multiple comparisons can be a problem, even when there is no "fishing expedition" or "p-hacking" and the research hypothesis was posited ahead of time.

Giddens, A. (1979). *Central problems in social theory: Action, structure and contradiction in social analysis.* London: Macmillan.

Giddens, A. (1981). *A contemporary critique of historical materialism.* London: Macmillan.

Giddens, A. (1984). *The constitution of society: Outline of the theory of structuration.* Berkeley and Los Angeles: University of California Press.

Gigerenzer, G. (2008). *Bauchentscheidungen: Die Intelligenz des Unbewussten und die Macht der Intuition.* Goldmann.

Goffman, E. (1963). *Stigma: Notes on the management of spoiled identity.* New York: Simon and Schuster.

Gonsalves, A. (2014). 'physics and the girly girl – there is a contradiction somewhere': Doctoral students' positioning around discourses of gender and competence in physics. *Cultural Studies of Science Education*, *9*(2), 503–521.

Gonsalves, A. J., & Seiler, G. (2012). Recognizing "smart super-physicists": Gendering competence in doctoral physics. In M. Varelas (Ed.), *Identity construction and science education research* (pp. 156–172). Rotterdam and Boston, MA and Taipeh: Sense Publishers.

Good, C., Aronson, J., & Harder, J. A. (2008). Problems in the pipeline: Stereotype threat and women's achievement in high-level math courses. *Journal of Applied Developmental Psychology*, *29*(1), 17–28. doi: 10.1016/j.appdev.2007.10.004

Good, C., Aronson, J., & Inzlicht, M. (2003). Improving adolescents' standardized test performance: An intervention to reduce the effects of stereotype threat. *Journal of Applied Developmental Psychology*, *24*(6), 645–662. doi: 10.1016/j.appdev.2003.09.002

Good, C., Rattan, A., & Dweck, C. S. (2012). Why do women opt out? sense of belonging and women's representation in mathematics. *Journal of Personality and Social Psychology*, *102*(4), 700–717. doi: 10.1037/a0026659

Good, J. J., Woodzicka, J. A., & Wingfield, L. C. (2010). The effects of gender stereotypic and counter-stereotypic textbook images on science performance. *The Journal of Social Psychology*, *150*(2), 132–147.

Gottfredson, L. S. (1981). Circumscription and compromise: A developmental theory of occupational aspirations. *Journal of Counseling and Development*, *28*(6), 545–579.

Goyer, J. P., Garcia, J., Purdie-Vaughns, V., Binning, K. R., Cook, J. E., Reeves, S. L., … Cohen, G. L. (2017). Self-affirmation facilitates minority middle schoolers' progress along college trajectories. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(29), 7594–7599. doi: 10.1073/pnas.1617923114

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*(1), 5–26.

Greenwald, A. G., Banaji, M. R., Rudman, L. A., Farnham, S. D., Nosek, B. A., & Mellott, D. S. (2002). A unified theory of implicit attitudes, stereotypes, self-esteem, and self-concept. *Psychological Review*, *109*(1), 3–25. doi: 10.1037//0033-295X.109.1.3

Greenwald, A. G., McGhee, D. E., & Schwartz, J. K. (1998). Measuring individual differences in implicit cognition: The implicit association test. *Journal of Personality and Social Psychology*, *74*(6), 1464–1480.

Gurian, M., & Stevens, K. (2004). With boys and girls in mind. *Educational Leadership*, *62*(21).

Guzzetti, B. J., & Williams, W. O. (1996). Gender, text, and discussion: Examining intellectual safety in the science classroom. *Journal of Research in Science Teaching*(33), 5–20.

Habermas, T., & Bluck, S. (2000). Getting a life: the emergence of the life story in adolescence. *Psychological Bulletin*, *126*(5), 748–769.

Halpern, D. F., Benbow, C. P., Geary, D. C., Gur, R., Hyde, J. S., & Gernsbacher, M. A. (2007). The science of sex differences in science and mathematics. *Psychological Science in the Public Interest*, *8*, 1–51.

Halpern, D. F., Eliot, L., Bigler, R. S., Fabes, R. A., Hanish, L. D., Hyde, J. S., … Martin, C. L. (2011). The pseudoscience of single-sex schooling. *Science*, *333*, 1706. doi: 10.1007/s11199-010-9903-2

Halpin, H. (Feb 18 2018). 'a gender equality paradox': Countries with more gender equality have fewer female stem grads. *The journal.* Retrieved from `http://www.thejournal.ie/gender-equality-countries-stem-girls-3848156-Feb2018/`

Handelsman, J., Cantor, N., Carnes, M., Denton, D., Fine, E., Grosz, B., … Sheridan, J. (2005). More women in science. *Science (New York, N.Y.)*, *309*, 1190–1191.

Hannover, B. (1991). Zur Unterrepräsentanz von Mädchen in Naturwissenschaften und Technik: Psychologische Prädiktoren der Fach-und Berufswahl, pages = 169–186, volume = 5, journal = Zeitschrift für Pädagogische Psychologie.

Hannover, B. (1997). *Das dynamische Selbst: Zur Kontextabhängigkeit selbstbezogenen Wissens.* Bern: Huber.

Hannover, B. (1998). The development of self-concept and interests. In L. Hoffmann, A. Krapp, K. A. Renninger, & J. Baumert (Eds.), *Interest and learning* (pp. 105–125). Kiel: IPN.

Hannover, B. (2000). Development of the self in gendered contexts. In T. Eckes & H. M. Trautner (Eds.), *The developmental social psychology of gender* (pp. 177–206). Hillsdale, NJ: Erlbaum.

Hannover, B. (2008). Vom biologischen zum psychologischen Geschlecht. In A. Renkl (Ed.), *Lehrbuch pädagogische Psychologie* (pp. 339–388). Bern: Huber.

Hannover, B., & Kessels, U. (2002). Challenge the science-stereotype: Der Einfluss von Technik-Freizeitkursen auf das Naturwissenschaften-Stereotyp von Schülerinnen und Schülern. In M. Prenzl & J. Doll (Eds.), *Bildungsqualität von Schule: Schulische und außerschulische Bedingungen mathematischer, naturwissenschaftlicher und überfachlicher Kompetenzen* (pp. 341–358). Weinheim: Beltz.

Hannover, B., & Kessels, U. (2004). Self-to-prototype matching as a strategy for making academic choices: Why german high school students do not like math and science. *Learning and Instruction*, *14*(1), 51–67.

Harackiewicz, J. M., & Priniski, S. J. (2018). Improving student outcomes in higher education: The science of targeted intervention. *Annual Review of Psychology*, *69*, 409–435.

Harackiewicz, J. M., Rozek, C. S., Hulleman, C. S., & Hyde, J. S. (2012). Helping parents to motivate adolescents in mathematics and science: an experimental test of a utility-value intervention. *Psychological Science*, *23*(8), 899–906. doi: 10.1177/0956797611435530

Harris, J. R., & Pinker, S. (2014). *The nurture assumption: Why children turn out the way they do.* [Place of publication not identified]: Free Press.

Harris, S. (2017). *Why we should fear AI.* Retrieved from `https://aiantichrist.blogspot.de/2017/09/ted-talk-sam-harris-on-why-we-should.html`

Haste, H. (2004). *Science in my future: A study of values and beliefs in relation to science and technology amongst 11–21 year olds.* London: Nestlé Social Research Programme.

Hausmann, L. R. M., Schofield, J. W., & Woods, R. L. (2007). Sense of belonging as a predictor of intentions to persist among african american and white first-year college students. *Research in Higher Education*, *48*(7), 803–839. doi: 10.1007/s11162-007-9052-9

Häußler, P., & Hoffmann, L. (1995). Physikunterricht: an den Interessen von Mädchen und Jungen orientiert. *Unterrichtswissenschaft*, *23*(2), 107–126.

Häußler, P., & Hoffmann, L. (2002). An intervention study to enhance girls' interest, self-concept, and achievement in physics classes. *Journal of Research in Science Teaching*, *39*(9), 870–888.

Hazari, Z., Brewe, E., Goertzen, R. M., & Hodapp, T. (2017). The importance of high school physics teachers for female students' physics identity and persistence. *The Physics Teacher*, *55*(96).

Hazari, Z., Cass, C., & Beattie, C. (2015). Obscuring power structures in the physics classroom: Linking teacher positioning, student engagement, and physics identity development. *Journal of Research in Science Teaching*, *52*(6), 735–762.

Hazari, Z., Sonnert, G., Sadler, P., & Shanahan, M.-C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978–1003.

Hazari, Z., Tai, R. H., & Sadler, P. (2007). Gender differences in introductory university physics performance: The influence of high school physics preparation and affective factors. *Science Education*, *91*, 847–876.

Heilbronner, N. N. (2012). The stem pathway for women: What has changed? *Gifted Child Quarterly*, *57*(1), 39–55. doi: 10.1177/0016986212460085

Heinicke, S., Paffhausen, C., Zeisberg, I., & Diehl, C. (2017). Genderspezifische Unterschiede? Mädchen und Jungen beim Experimentieren im Physikunterricht. In C. Maurer (Ed.), *Implementation fachdidaktischer Innovation im Spiegel von Forschung und Praxis.* Regensburg: Universität Regensburg.

Helgeson, V. S., & Fritz, H. L. (1999). Unmitigated agency and unmitigated communion: Distinctions from agency and communion. *Journal of Research in Personality*, *33*, 131–158.

Heller, K. A. (2004). Identification of gifted and talented students. *Psychology Science*, *46*(3), 302–323.

Heller, K. A., & Ziegler, A. (2010). Gender differences in mathematics and natural sciences. In *Munich studies of giftedness* (pp. 219–238). Berlin: Lit.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping: Part 2: Designing problems and structuring groups. *American Journal of Physics*, *60*(7), 637–644.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics*, *55*(5), 440–454.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, *30*, 141–158.

Hidi, S. (2000). An interest researcher's perspective: The effects of extrinsic and intrinsic factors on motivation. In C. Sansone & J. M. Harackiewicz (Eds.), *Intrinsic and extrinsic motivation.* New York: Academic Press.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127. doi: 10.1207/s15326985ep4102{\textunderscore}4

Hines, M. (2011). Gender development and the human brain. *Annual review of neuroscience*, *34*, 69–88. doi: 10.1146/annurev-neuro-061010-113654

Hirschauer, S. (2014). Wozu gender studies? ein forschungsfeld zwischen feminismus und kulturwissenschaft. *Forschung und Lehre*, *21*, 880–882.

Hodapp, T., & Hazari, Z. (2015). Women in physics: Why so few? *APS News*, *24*(10), 8.

Hoffmann, L., Häußler, P., & Peters-Haft, S. (1997). *An den interessen von mädchen und jungen orientierter physikunterricht.* Kiel: IPN.

Hoffmann, L., Krapp, A., Renninger, K. A., & Baumert, J. (Eds.). (1998). *Interest and learning: Proceedings of the seeon conference on interest and gender.* Kiel: IPN.

Holland, D., & Lave, J. (2001). *History in person: Enduring struggles, contentious practice, intimate identities.* Albuquerque: School of American Research Press.

Holstermann, N., & Bögeholz, S. (2007). Interesse von Jungen und Mädchen an naturwissenschaftlichen Themen am Ende der Sekundarstufe I. *Zeitschrift für Didaktik der Naturwissenschaften*, *13*, 71–86.

Hong, H.-Y., & Lin-Siegler, X. (2012). How learning about scientists' struggles influences students' interest and learning in physics. *Journal of Educational Psychology*, *104*(2), 469–484. doi: 10.1037/a0026224

Huffman, D. (1997). Effect of explicit problem solving instruction on high school students' problem-solving performance and conceptual understanding of physics. *Journal of Research in Science Teaching*, *34*, 551.

Huguet, P., & Régner, I. (2007). Stereotype threat among schoolgirls in quasi-ordinary classroom circumstances. *Journal of Educational Psychology*, *99*, 545–560.

Hume, D. (2012). *A treatise of human nature.* Newburyport: Dover Publications. Retrieved from `http://gbv.eblib.com/patron/FullRecord.aspx?p=1890034`

Hyde, J. S. (2005). The gender similarities hypothesis. *American Psychologist*, *60*, 581–592.

Hyde, J. S. (2014). Gender similarities and differences. *Annual Review of Psychology*, *65*, 373–398. doi: 10.1146/annurev-psych-010213-115057

Hyde, J. S., Fennema, E., Ryan, M., & Frost, L. A. (1990). Gender comparisons of mathematics attitudes and affect. *Psychology of Women Quarterly*, *14*, 299–324.

Hyde, J. S., Lindberg, S. M., Linn, M. C., Ellis, A. B., & Williams, C. C. (2006). Gender similarities in mathematics and science. *Science*, *314*, 599–600.

Inzlicht, M., & Ben-Zeev, T. (2000). A threatening intellectual environment: Why females are susceptible to experiencing problem-solving deficits in the presence of males. *Psychological Science*, *11*, 365–371.

IOP. (2012). *The importance of physics to the uk economy.* Retrieved from `http://www.iop.org/publications/iop/2012/file_58713.pdf`

Ivie, R., Cuzjko, R., & Stowe, K. (2001). *Women physicists speak: The 2001 international study of women in physics.* Retrieved from `http://www.aip.org/statistics/trends/gendertrends.html`

Ivie, R., & Guo, S. (2006). *Woman physicists speak again: American institute of physics report.* Retrieved 18.01.2009, from `http://www.aip.org/statistics/trends/reports/iupap05.pdf`

IW Köln. (n.d.). *Mint-Herbstreport 2016: Bedeutung und Chancen der Zuwanderung.*

IW Köln. (2016). *Physikerinnen und Physiker im Beruf: Anschlussstudie für die Jahre 2005 bis 2013.* Köln.

IW Köln. (2018). *Mint-Frühjahrsreport 2018: MINT – Offenheit, Chancen, Innovationen.*

Johnson, A. (2012). Consequential validity and science education research. In M. Varelas (Ed.), *Identity construction and science education research* (pp. 172–188). Rotterdam and Boston, MA and Taipeh: Sense Publishers.

Johnson, A., Ong, M., Ko, L. T., Smith, J., & Hodari, A. (2017). Common challenges faced by women of color in physics, and actions faculty can take to minimize those challenges. *The Physics Teacher*, *55*(6), 356–360. doi: 10.1119/1.4999731

Jonassen, D. H., & Strobel, J. (2005). *Everyday problem solving in engineering: Lessons for educators: American society for engineering education annual conference & exposition.*

Jones, G., Howe, A., & Rua, M. (2000). Gender differences in students' experiences, interests, and attitudes toward science and scientists. *Science Education*, *84*(2), 180–192.

Jones, M. G., & Wheatley, J. (1990). Gender differences in teacher–student interactions in science classrooms. *Journal of Research in Science Teaching*, *27*, 861–874.

Josselson, R. (1996). *Revising herself: The story of women's identity from college to midlife.* New York: Oxford University Press.

Jost, J. T., Banaji, M. R., & Nosek, B. A. (2004). A decade of system justification theory: Accumulated evidence of conscious and unconscious bolstering of the status quo. *Political Psychology*, *25*(6), 881–919. doi: 10.1111/j.1467-9221.2004.00402.x

Jovanovic, J., & Steinbach King, S. (1998). Boys and girls in the performance-based science classroom: Who's doing the performing? *American Educational Research Journal*, *35*(3), 477–496.

Kahan, D. M., Jenkins-Smith, H., & Braman, D. (2010). Cultural cognition of scientific consensus. *SSRN Electronic Journal*. doi: 10.2139/ssrn.1549444

Kahneman, D. (2012). *Schnelles Denken, langsames Denken*. Siedler Verlag.

Kaku, M. (2012). *Physics of the future: How science will shape human destiny and our daily lives by the year 2100*. Anchor.

Kane, J. M. (2012). Young african american children constructing academic and disciplinary identities in an urban science classroom. *Science Education*, *96*, 457–487.

Kane, J. M. (2016). Young african american boys narrating identities in science. *Journal of Research in Science Teaching*, *53*(1), 95–118. doi: 10.1002/tea.21247

Kelly, A. (1985). The construction of masculine science. *British Journal of Sociology of Education*, *6*, 133–153.

Kelly, A. (1988). Option choice for girls and boys. *Research in Science & Technological Education*, *6*(1), 5–23. doi: 10.1080/0263514880060102

Kenway, J., & Gough, A. (1998). Gender and science education in schools: A review "with attitude.". *Studies in Science Education*, *31*(1), 1–30.

Kerr, B. (2000). Guiding gifted girls and young woman. In K. Heller, F. Monks, R. Sternberg, & R. Subotnik (Eds.), *International handbook of giftedness and talent* (pp. 649–657). Oxford, UK: Pergamon.

Kersey, A. J., Braham, E. J., Csumitta, K. D., Libertus, M. E., & Cantlon, J. F. (2018). No intrinsic gender differences in children's earliest numerical abilities. *npj Science of Learning*, *3*(1), 221. doi: 10.1038/s41539-018-0028-7

Kessels, U., & Hannover, B. (2002). Die Auswirkungen von Stereotypen über Schulfächer auf die Berufswahlabsichten Jugendlicher. In B. Spinath & E. Heise (Eds.), *Pädagogische Psychologie unter gewandelten gesellschaftlichen Bedingungen* (pp. 53–67). Hamburg: Kovac.

Kessels, U., & Hannover, B. (2006). Zum Einfluss des Image von mathematisch-naturwissenschaftlichen Fächern auf die schulische Interessenentwicklung. In M. Prenzel & L. Allolio-Näcke (Eds.), *Untersuchungen zur Bildungsqualität von Schule*. Münster: Waxmann.

Kessels, U., Rau, M., & Hannover, B. (2006). What goes well with physics? measuring and altering the image of science. *British Journal of Educational Psychology*, *76*(4), 761–780.

Khazan, O. (June 22, 2012). E.u.'s 'science, it's a girl thing' campaign sparks a backlash. *Washington Post*. Retrieved 8 May 2018, from `https://www.washingtonpost.com/blogs/blogpost/post/eus-science-for-girls-campaigns-spark-a-backlash/2012/06/22/gJQAOi1HvV_blog.html?utm_term=.34263fe10e25`

Kiefer, A. K., & Sekaquaptewa, D. (2007). Implicit stereotypes, gender identification, and math-related outcomes: A prospective study of female college students. *Psychological Science*, *18*, 13–18.

Kimura, D. (1999). Sex differences in the brain. *Scientific American.*

Kimura, D. (2004). Human sex differences in cognition, fact, not predicament. *Sexualities, Evolution & Gender*, *6*(1), 45–53. Retrieved from `http://dx.doi.org/10.1080/14616660410001733597` doi: 10.1080/14616660410001733597

King, N., & Horroks, C. (2010). *Interviews in qualitative research.* SAGE Publications.

Kirkpatrick, J. D., & Kirkpatrick, W. K. (2016). *Kirkpatrick's four levels of training evaluation.* Alexandria, VA: ATD Press. Retrieved from `http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&AN=1364594`

Kitchen, J. A., Sonnert, G., & Sadler, P. M. (2018). The impact of college- and university-run high school summer programs on students' end of high school stem career aspirations. *Science Education*, *40*(5), 499. doi: 10.1002/sce.21332

Kite, M. E., Deaux, K., & Haines, E. L. (2008). Gender stereotypes. In F. L. Denmark & M. A. Paludi (Eds.), *Psychology of women* (pp. 205–236). New York: Praeger.

Klauer, K. C., & Wegener, I. (1998). Unraveling social categorization in the "who said what?" paradigm. *Journal of Personality and Social Psychology*, *75*(5), 1155–1178.

Kleinert, A. (1978). Vom Trieb zur theoretischen Physik: Eine Stellungnahme Plancks zur Frage des Frauenstudiums. *Physikalische Blätter*, *34*, 31–33.

Klimstra, T. A., Luyckx, K., Hale, W. A., Frijns, T., van Lier, Pol A. C., & Meeus, Wim H. J. (2010). Short-term fluctuations in identity: Introducing a micro-level approach to identity formation. *Journal of Personality and Social Psychology*, *99*(1), 191–202. doi: 10.1037/a0019584

Kohlberg, L. (1984). *Essays on moral development: The psychology of moral development.* San Francisco, CA: Harper & Row.

Köhler, C. (2017). *Naturwissenschaftliche Wettbewerbe für Schülerinnen und Schüler: Charakterisierung der Anforderungen und Teilnehmenden hinsichtlich spezifischer Leistungsmerkmale: Dissertation zur Erlangung des Doktorgrades der Mathematisch-Naturwissenschaftlichen Fakultät der Christian-Albrechts-Universität zu Kiel.* Retrieved from `http://macau.uni-kiel.de/servlets/MCRFileNodeServlet/dissertation_derivate_00007106/Koehler-C-2017.pdf;jsessionid=0F2FD4AA04D6F82E155D89A54CEA96C3`

Köller, O., Baumert, J., & Schnabel, K. (2001). Does interest matter? the relationship between academic interest and achievement in mathematics. *Journal of Research in Mathematics Education*, *32*, 448–470.

Köller, O., Daniels, Z., Schnabel, K., & Baumert, J. (2000). Kurswahlen von Mädchen und Jungen im Fach Mathematik: Zur Rolle von fachspezifischem Selbstkonzept und Interesse. *Zeitschrift für Pädagogische Psychologie*, *14*(1), 26–37.

Kulik, J. A., & Kulik, C. L. C. (1992). Meta-analytic findings on grouping programs. *Gifted Child Quarterly*, *36*, 73–77.

Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind.* University of Chicago Press.

Langdon, D., McKittrick, G., Beede, D., Khan, B., & Doms, M. (2011). *Stem: Good jobs now and for the future: Esa issue brief #03-11.*

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.

Leaper, C. (1987). Agency, communion, and gender as predictors of communication style and being liked in adult male-female dyads. *Sex Roles*, *16*(3-4), 137–149. doi: 10.1007/BF00289645

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science (a review of the research). *Journal of Research in Science Teaching*, *29*, 331–359.

Lee, J. J., Wedow, R., Okbay, A., Kong, E., Maghzian, O., Zacher, M., ... Cesarini, D. (2018). Gene discovery and polygenic prediction from a genome-wide association study of educational attainment in 1.1 million individuals. *Nature Genetics*, *92*, 109. doi: 10.1038/s41588-018-0147-3

Lee, O., Fradd, S. H., & Sutman, F. X. (1995). Science knowledge and cognitive strategy use among culturally and linguistically diverse students. *Journal of Research in Science Teaching*, *32*, 797–816.

Lengfelder, A., & Heller, K. A. (2002). German olympiad studies: Findings from a retrospective evaluation and from in-depth interviews. where have all the gifted females gone? *Journal of Research in Education*, *12*(1), 86–92.

Lent, R. W., Brown, S. D., Cover, M. R., & Nijjer, S. K. (1996). Cognitive assessment of the sources of mathematics self-efficacy: A thought-listing analysis. *Journal of Career Assessment*, *4*(1), 33–46.

Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unified social cognitive theory of career/academic interest, choice, and performance. *Journal of Vocational Behavior*, *45*, 79–122.

Lent, R. W., Brown, S. D., & Larkin, K. C. (1987). Comparison of three theoretically derived variables in predicting career and academic behavior: Self-efficacy, interest congruence, and consequence thinking. *Journal of Counseling Psychology*, *34*.

Lent, R. W., Lopez, F. G., Brown, S. D., & Gore, P. A. (1996). Latent structure of the sources of mathematics self-efficacy. *Journal of Vocational Behavior*, *49*, 292–308.

Lepper, M. R., Ross, L., & Lau, R. R. (1986). Persistence of inaccurate beliefs about the self: perseverance effects in the classroom. *Journal of Personality and Social Psychology*, *50*(3), 482–491.

Leslie, S.-J., Cimpian, A., Meyer, M., & Freeland, E. (2015). Expectations of brilliance underlie gender distributions across academic disciplines. *Science (New York, N.Y.)*, *347*(6219), 262–265.

Lichtwarck-Aschoff, A., van Geert, P., Bosma, H., & Kunnen, S. (2008). Time and identity: A framework for research and theory formation. *Developmental Review*, *28*(3), 370–400. doi: 10.1016/j.dr.2008.04.001

Lightman, A. (1989). *Interview with vera rubin.* College Park, MD USA. Retrieved 26 January 2018, from `https://www.aip.org/history-programs/niels-bohr-library/oral-histories/33963#top`

Lind, G. (2001). *Herausforderung, Selbstbestätigung durch Erfolg, Erfahrung der eigenen grenzen: Eine Befragung ehemaliger Teilnehmer der Physikolympiade.* Kiel.

Lindahl, B. (2007). *A longitudinal study of student's' attitudes towards science and choice of career: Paper presented at the 80th narst international conference new orleans, louisiana.* New Orleans, Louisiana.

Lin-Siegler, X., Ahn, J. N., Chen, J., Fang, F.-F. A., & Luna-Lucero, M. (2016). Even einstein struggled: Effects of learning about great scientists' struggles on high school students' motivation to learn science. *Journal of Educational Psychology*, *108*(3), 314–328. doi: 10.1037/edu0000092

Lock, R. M., Hazari, Z., & Potvin, G. (2012). *Physics career intentions: The effect of physics identity, math identity, and gender.* Philadelphia, PA.

Loevinger, J. (1976). *Ego development.* San Francisco, CA: Jossey-Bass.

Logel, C., Walton, G. M., Spencer, S. J., Iserman, E. C., von Hippel, W., & Bell, A. E. (2009). Interacting with sexist men triggers social identity threat among female engineers. *Journal of Personality and Social Psychology*, *96*(6), 1089–1103. doi: 10.1037/a0015703

Long, J. D. (2012). *Longitudinal data analysis for the behavioral sciences using r.* SAGE Publications. Retrieved from `https://studysites.sagepub.com/long/main.htm`

Lubinski, D. (2010). Spatial ability and stem: A sleeping giant for talent identification and development. *Personality and Individual Differences*, *49*(4), 344–351. doi: 10.1016/j.paid.2010.03.022

Lubinski, D., & Benbow, C. P. (1992). Gender differences in abilities and preferences among the gifted. *Current Directions in Psychological Science*, *1*(1), 61–66.

Lubinski, D., & Benbow, C. P. (2006). Study of mathematically precocious youth after 35 years: Uncovering antecedents for the development of math-science expertise. *Perspectives on Psychological Science*(4), 316–345.

Lubinski, D., Benbow, C. P., & Kell, H. (2014). Life paths and accomplishments of mathematically precocious males and females four decades later. , *25*.

Lubinski, D., Benbow, C. P., & Morelock, M. J. (2000). Gender differences in engineering and the physical sciences among the gifted: An inorganic-organic distinction. In K. Heller, F. Monks, R. Sternberg, & R. Subotnik (Eds.), *International handbook of giftedness and talent* (pp. 633–648). Oxford, UK: Pergamon.

Luhmann, N. (2017). *Systemtheorie der Gesellschaft* (1. Auflage ed.). Berlin: Suhrkamp Verlag.

Lykkegaard, E., & Ulriksen, L. (2016). Choices and changes: Eccles' expectancy-value model and upper-secondary school students' longitudinal reflections about their choice of a stem education. *International Journal of Science Education*, 1–24. doi: 10.1080/09500693.2016.1156782

Maalouf, A. (2001). *In the name of identity: Violence and the need to belong.* New York: Arcade.

Maccoby, E. E. (1999). *The two sexes: Growing up apart, coming together.* Belknap Press.

Madsen, A., McKagan, S. B., & Sayre, E. C. (2013). Gender gap on concept inventories in physics: What is consistent, what is inconsistent, and what factors influence the gap? *Physical Review Special Topics - Physics Education Research*, *9*(2). doi: 10.1103/PhysRevSTPER.9.020121

Maltese, A., & Tai, R. H. (2010). Eyeballs in the fridge: Sources of early interest in science. *International Journal of Science Education*, *32*(5), 669–685.

Maltese, A., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in stem among us students. *Science Education*, *95*, 877–907.

Marchand, G. C., & Taasoobshirazi, G. (2013). Stereotype threat and women's performance in physics. *International Journal of Science Education*, *35*(18), 3050–3061. doi: 10.1080/09500693.2012.683461

Marcia, J. E. (1966). Development and validation of ego identity status. *Journal of Personality and Social Psychology*, *3*, 551–558.

Marcia, J. E. (1980). Identity in adolescence. In J. Adelson (Ed.), *Handbook of adolescent psychology* (pp. 159–187). New York: Wiley.

Marsh, H. W. (1984). Relations among dimensions of self-attributions, dimensions of self-concept and academic achievement. *Journal of Educational Psychology*, *76*, 1291–1308.

Marsh, H. W., Chessor, D., Craven, R., & Roche, L. (1995). The effects of gifted and talented programs on academic self-concept: The big fish strikes again. *American Educational Research Journal*, *32*(2), 285–319.

Martens, A., Johns, M., Greenberg, J., & Schimel, J. (2006). Combating stereotype threat: The effect of self-affirmation on women's intellectual performance. *Journal of Experimental Social Psychology*, *42*(2), 236–243. doi: 10.1016/j.jesp.2005.04.010

Martin, J. (n.d.). *Feminist theory and critical theory: Unexplored synergies.*

Marx, D. M., & Roman, J. S. (2002). Female role models: Protecting women's math test performance. *Personality and Social Psychology Bulletin*, *28*, 1183–1193.

Maslow, A. (1968). *Toward a psychology of being.* New York: Van Nostrand.

Maturana, H. R., & Varela, F. J. (1987). *Der baum der erkenntnis: Die biologischen wurzeln des erkennens.* München: Goldmann.

Matzdorf, R., & Düchs, G. (2013). Immer mehr Parkstudierende: Statistiken zum Physikstudium an den Universitäten in Deutschland 2013. *Physik Journal*, *12*(8/9), 29–33.

Mayer, R. (2013). Problem solving. In D. Reisberg (Ed.), *The oxford handbook of cognitive psychology* (pp. 769–778). Oxford and New York: Oxford University Press.

Mazur, E. (1997). *Peer instruction: A user's manual.* Upper Saddle River, NJ: Prentice-Hall.

McAdams, D. P. (2001). The psychology of life stories. *Review of General Psychology*, *5*, 100–122.

McAdams, D. P., & McLean, K. C. (2013). Narrative identity. *Current Directions in Psychological Science*, *22*(3), 233–238. doi: 10.1177/0963721413475622

Mcbride, B. (2009). *Teaching to gender differences.* [Place of publication not identified]: Incentive Pubns.

McClelland, D. C. (1978). Managing motivation to expand human freedom. *American Psychologist*, *33*(3), 201–210.

McGregor, L., Gee, D., & Posey, K. (2008). I feel like a fraud and it depresses me: The relation between the imposter phenomenon and depression. *Social Behavior and Personality*, *36*, 43–48.

McIntyre, R. B., Paulson, R. M., & Lord, C. G. (2003). Alleviating women's mathematics stereotype threat through salience of group achievements. *Journal of Experimental Social Psychology*, *39*, 83–90.

McNamara, D., Kintsch, E., Butler Songer, N., & Kintsch, W. (1996). Are good texts always better? interactions of text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and Instruction*, *14*(1), 1–43.

McNay, L. (2000). *Gender and agency: Reconfiguring the subject in feminist and social theory.* Cambridge: Polity Press.

Mead, G. H. (1934). *Mind, self, and society.* Chicago: University of Chicago Press.

Meeus, W. (1996). Studies on identity development in adolescence: An overview of research and some new data. *Journal of Youth and Adolescence*, *25*, 569–598.

Meeus, W. (2016). Adolescent psychosocial development: A review of longitudinal models and research. *Developmental Psychology*, *52*(12), 1969–1993. doi: 10.1037/dev0000243

Meeus, W., Iedema, J., Helsen, M., & Vollebergh, W. (1999). Patterns of adolescent identity development: Review of literature and longitudinal analysis. *Developmental Review*, *19*(4), 419–461.

Meltzer, D. E., & Thornton, R. K. (2012). Resource letter alip–1: Active-learning instruction in physics. *American Journal of Physics*, *80*(6), 478–496.

Mercier, H., & Sperber, D. (2017). *The enigma of reason.* Cambridge, Massachusetts: Harvard University Press.

Merton, R. K. (Ed.). (1973). *The sociology of science: Theoretical and empirical investigations.* Chicage, IL: Chicago University Press.

Miller, D. I., Eagly, A. H., & Linn, M. C. (2015). Women's representation in science predicts national gender-science stereotypes: Evidence from 66 nations. *Journal of Educational Psychology*, *107*(3), 631–644. doi: 10.1037/edu0000005

Miller, G. A., & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology*, *110*(1), 40–48.

Miller, P. H., Rosser, S. V., Benigno, J., & Zieseniss, M. L. (2000). A desire to help others: Goals of high achieving female science undergraduates. *Women's Studies Quarterly*, *28*, 128–142.

Miller, P. H., Slawinski Blessing, J., & Schwartz, S. (2006). Gender differences in high-school students' views about science. *International Journal of Science Education*, *28*(4), 363–381.

Mischel, W. (1996). *Personality and assessment.* Routledge.

Miyake, A., Kost-Smith, L. E., Finkelstein, N., Pollock, S. J., Cohen, G. L., & Ito, T. A. (2010). Reducing the gender achievement gap in college science: A classroom study of values affirmation. *Science*, *330*, 1234–1237.

Mokhonko, S., Nickolaus, R., & Windaus, A. (2014). Förderung von Mädchen in Naturwissenschaften: Schülerlabore und ihre Effekte. *Zeitschrift für Didaktik der Naturwissenschaften*, *20*(1), 143–159. doi: 10.1007/s40573-014-0016-2

Möller, J., & Trautwein, U. (2015). Selbstkonzept. In E. Wild & J. Möller (Eds.), *Pädagogische Psychologie* (pp. 177–199). Berlin and Heidelberg: Springer.

Morgan, C., Isaac, J. D., & Sansone, C. (2001). The role of interest in understanding the career choices of female and male college students. *Sex Roles*, *44*(5/6), 295–320.

Mujtaba, T., & Reiss, M. J. (2013). What sort of girl wants to study physics after the age of 16? findings from a large-scale uk survey. *International*

*Journal of Science Education*, *35*(17), 2979–2998. doi: 10.1080/09500693.2012.681076

Mujtaba, T., & Reiss, M. J. (2014). A survey of psychological, motivational, family and perceptions of physics education factors that explain 15-year-old students' aspirations to study physics in post-compulsory english schools. *International Journal of Science and Mathematics Education*, *12*(2), 371–393. doi: 10.1007/s10763-013-9404-1

Murphy, M., Steele, C. M., & Gross, J. (2007). Signaling threat: How situational cues affect women in math, science, and engineering. *Psychological Science*, *18*, 879–885.

National Academies. (n.d.). *Rising above the gathering storm: Revisited: Rapidly approaching category 5.* Washington, DC.

National Science Foundation. (2015). *Revisiting the stem workforce: A companion to science and engineering indicators 2014.* Arlington, VA.

Navarro, D. (2015). *Learning statistics with r: A tutorial for psychology students and other beginners: version 0.5.* Retrieved from `https://health.adelaide.edu.au/psychology/ccs/teaching/lsr/`

Nelson, D. J., & Brammer, C. N. (2010). *A national analysis of minorities in science and engineering faculties at research universities. 2010.* Retrieved from `http://chem.ou.edu/~djn/diversity/faculty_Tables_FY07/FinalReport07.html`

Nelson, T. D. (Ed.). (2009). *Handbook of prejudice, stereotyping, and discrimination.* New York: Psychology Press. Retrieved from `http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10285315`

Nespor, J. (1994). *Knowledge in motion: Space, time and curriculum in undergraduate physics and management.* Washington, DC: Falmer.

Nguyen, H., & Ryan, A. M. (2008). Does stereotype threat affect test performance of minorities and women? a meta-analysis of experimental evidence. *Journal of Applied Psychology*, *93*, 1314–1334.

Nickerson, R. S. (1994). The teaching of thinking and problem solving. In R. J. Sternberg (Ed.), *Thinking and problem solving* (pp. 409–449). San Diego, CA and New York and Boston, MA: Academic Press.

Niedenthal, P. M., Cantor, N., & Kihlstrom, J. F. (1985). Prototype matching: A strategy for social decision making. *Journal of Personality and Social Psychology*, *48*, 575–584.

Nisbett, R. E., Aronson, J., Blair, C., Dickens, W., Flynn, J., Halpern, D. F., & Turkheimer, E. (2012). Intelligence: new findings and theoretical developments. *The American psychologist*, *67*(2), 130–159. doi: 10.1037/a0026699

Nokelainen, P., Tirri, K., & Campbell, J. R. (2004). Cross-cultural predictors of mathematical talent and academic productivity. *High Ability Studies*, *15*, 229–242.

Nosek, B. A., Banaji, M. R., & Greenwald, A. G. (2002). Math=male, me=female, therefore math is not me. *Journal of Personality and Social Psychology*, *83*(1), 44–59.

Nosek, B. A., Hawkins, C. B., & Frazier, R. S. (2012). Implicit social cognition. In S. T. Fiske & C. N. Macrae (Eds.), *The sage handbook of social cognition* (pp. 31–53). London: SAGE Publications.

NOVA. (2004). *A conversation with Neil DeGrasse Tyson.* Retrieved 18 January 2009, from `http://www.pbs.org/wgbh/nova/origins/tyson.html`

Nussbaum, M. (2000). *Women and human development: The capabilities approach.* Cambridge, UK: Cambridge University Press.

Nussbaum, M. (2007). *Frontiers of justice: Disability, nationality, species membership.* Cambridge, MA: Belknap Press.

O'Connor, S. (2002). How do the theoretical paradigms fit the findings of the international olympiad studies? *Journal of Research in Education*, *12*(1), 112–116.

OECD. (2015). *How is the global talent pool changing (2013, 2030)? education indicators in focus, no 31.* Paris: Author. doi: 10.1787/9789264204256-en

Olitsky, S. (2006). Structure, agency, and the development of students' identities as learners. *Cultural Studies of Science Education*, *1*, 745–766.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*, 1049–1079.

Oswald, F., Hanisch, G., & Hager, G. (2004). *Wettbewerbe und "Olympiaden": Impulse zur (Selbst)-Identifikation von Begabungen* (1. Aufl. ed.). Lit.

Oyserman, D. (2015). *Pathways to success through identity-based motivation.* New York: Oxford University Press.

Pajares, F., & Graham, L. (1999). Self-efficacy, motivation constructs, and mathematics performance of entering middle school. *Contemporary educational psychology*, *24*, 124–139.

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching*, *46*(2), 147–165. doi: 10.1002/tea.20263

Parker, L. H., & Rennie, L. J. (2002). Teachers' implementation of gender-inclusive instructional strategies in single-sex and mixed-sex science classrooms. *International Journal of Science Education*, *24*(9), 881–897.

Parsons, E. (1997). Black high school females' images of the scientist: Expression of culture. *Journal of Research in Science Teaching*, *14*, 745–768.

Patall, E. A., Vasquez, A. C., Steingut, R. R., Trimble, S. S., & Pituch, K. A. (2017). Supporting and thwarting autonomy in the high school science classroom. *Cognition and Instruction*, *35*(4), 337–362. doi: 10.1080/07370008.2017.1358722

PCAST. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics: President's council of advisors on science and technology.*

Pentland, A. (2007). *The human nervous system has come alive: Edge.* Retrieved from `https://www.edge.org/responsedetail/11497`

Perels, F., Gürtler, T., & Schmitz, B. (2005). Training of self-regulatory and problem-solving competence. *Learning and Instruction*, *15*(2), 123–139. doi: 10.1016/j.learninstruc.2005.04.010

Petersen, S., & Wulff, P. (2017). The german physics olympiad—identifying and inspiring talents. *European Journal of Physics*, *38*(3), 034005. doi: 10.1088/1361-6404/aa538f

Phillips, K. A., Barrow, L. H., & Chandrasekhar, M. (2002). Science career interests among high school girls one year after participation in a summer science program. *Journal of Women and Minorities in Science and Engineering*, *8*, 235–247.

Piaget, J. (1976). *Die äquilibration der kognitiven Strukturen.* Stuttgart.

Pickett, C. L., Gardner, W. L., & Knowles, M. (2004). Getting a cue: the need to belong and enhanced sensitivity to social cues. *Personality & social psychology bulletin*, *30*(9), 1095–1107. doi: 10.1177/0146167203262085

Pinel, E. C. (1999). Stigma consciousness: The psychological legacy of social stereotypes. *Journal of Personality and Social Psychology*, *76*(1), 114–128.

Pinker, S. (2003). *The blank slate: The modern denial of human nature.* London: Penguin.

Pinker, S. (2018). Counter-enlightenment convictions are 'surprisingly resilient'. *Quillette.*

Platon. (2012). *Der Staat: (politeia).* Reclam.

Podgorsak, E. B. (2010). *Radiation physics for medical physicists.* Heidelberg and Dordrecht and London and New York: Springer.

Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at k-12 levels: a systematic review of 12 years of educational research. *Studies in Science Education*, *50*(1), 85–129. doi: 10.1080/03057267.2014.881626

Preacher, K. J. (2015). Extreme groups designs. In R. L. Cautin & S. O. Lilienfeld (Eds.), *The encyclopedia of clinical psychology* (pp. 1189–1192). Hoboken, NJ: John Wiley & Sons.

Prenzel, M., Reiss, K., & Hasselhorn, M. (2009). *Förderung der kompetenzen von kindern und jugendlichen.* Berlin: Springer.

Purdie-Vaughns, V., Steele, C. M., Davies, P. G., Ditlmann, R., & Crosby, J. R. (2008). Social identity contingencies: how diversity cues signal threat or safety for african americans in mainstream institutions. *Journal of Personality and Social Psychology*, *94*(4), 615–630. doi: 10.1037/0022-3514.94.4.615

Pyryt, M. C. (2000). Talent development in science and technology. In K. Heller, F. Monks, R. Sternberg, & R. Subotnik (Eds.), *International handbook of giftedness and talent* (pp. 427–437). Oxford, UK: Pergamon.

Quaiser-Pohl, C. (2012). Mädchen und Frauen in MINT: Ein überblick. In H. Stöger, A. Ziegler, & M. Heilemann (Eds.), *Mädchen und Frauen in MINT* (pp. 9–40). Berlin: Lit.

Radelet, S. (2015). *The great surge: The ascent of the developing world.* New York: Simon and Schuster.

Raffaelli, M., & Duckett, E. (1989). "we were just talking.": Conversations in early adolescence. *Jounral of Youth and Adolescence*, *18*(6), 567–582.

Rahm, J., & Moore, J. C. (2016). A case study of long-term engagement and identity-in-practice: Insights into the stem pathways of four underrepresented youths. *Journal of Research in Science Teaching*, *53*(5), 768–801. doi: 10.1002/tea.21268

Raine, D., & Symons, S. (2012). Problem-based learning: undergraduate physics by research. *Contemporary Physics*, *53*(1), 39–51. doi: 10.1080/00107514.2011.615162

Rampino, T., & Taylor, M. (2013). *Gender differences in educational aspirations and attitudes.*

Randall, L. (2011). *Knocking on heaven's door: How physics and scientific thinking illuminate the universe and the modern world.* Ecco.

Rawls, J. (1971). *A theory of justice: Reprint 2005.* Harvard University Press.

Reeves, R., & Haidt, J. (2018). *All minus one: John Stuart Mill's ideas on free speech illustrated* (No. 17 April 2018). Retrieved from `https://indd.adobe.com/view/c9d4e11b-6e6b-4551-bf67-4c13f05a6ed0`

Reif, F. (1995). Millikan lecture 1994: Understanding and teaching important thought processes. *American Journal of Physics*, *63*(1), 17–31.

Reilly, D., Neumann, D. L., & Andrews, G. (2015). Sex differences in mathematics and science achievement: A meta-analysis of national assessment of educational progress assessments. *Journal of Educational Psychology*, *107*(3), 645–662.

Reis, S. M., & Park, S. (2001). Gender differences in high-achieving students in math and science. *Journal for the Education of the Gifted*, *25*, 52–73.

Reiss, M. J. (7. - 10. September 2000). *Gender issues in science lessons as revealed by a longitudinal study: Paper presented at the british educational research association annual conference.*

Renold, E., & Allen, A. (2006). Bright and beautiful: High achieving girls, ambivalent femininities and the feminization of success in the primary school. *Discourse: Studies in the Cultural Politics of Education*, *27*(4), 457–473.

Riessman, C. K. (2002). Analysis of personal narratives. In H. Gubrium (Ed.), *Handbook of interview research* (pp. 695–710).

Rizzi, T. S., & Posthuma, D. (2013). Genes and intelligence. In D. Reisberg (Ed.), *The oxford handbook of cognitive psychology* (pp. 823–841). Oxford and New York: Oxford University Press.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context.* New York , NY: Oxford Univ. Press.

Rosch, E. (1975). Cognitive reference points. *Cognitive Psychology*, *7*, 532–547.

Roseberry, A., Warren, B., & Conant, F. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences*, *2*, 61–94.

Rosenthal, L. (2016). Incorporating intersectionality into psychology: An opportunity to promote social justice and equity. *The American psychologist*, *71*(6), 474–485. doi: 10.1037/a0040323

Rosling, H., & Rosling Rönnlund, A. (2018). *Factfulness: Ten reasons we're wrong about the world and why things are better than you think.* London: Sceptre.

Rost, D. H. (2010). *Klare worte zur hochbegabungs-diskussion: Viel seichtes in pädagogik und pädagogischer psychologie.* Retrieved 05.01.2015, from `http://dms-schule.bildung.hessen.de/allgemeines/begabung/Marburger_Hochbegabtenprojekt/HOCHBEGABUNG_F-334R_DIEHL.pdf`

Roth, G. (2015). *Aus Sicht des Gehirns* (4. Aufl. - Vollst. überarb. Neuaufl. ed., Vol. 1915). Frankfurt am Main: Suhrkamp.

Ruble, D. N. (1994). A phase model of transitions: Cognitive and motivational consequences. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (pp. 163–214). San Diego, CA: Academic Press.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1), 68–78. doi: 10.1037//0003-066X.55.1.68

Saltzmann Chafetz, J. (1990). *Gender equity: An integrated theory of stability and change.* London: Sage.

Sapolsky, R. M. (2018). *Behave: The biology of humans at our best and worst.* London: Vintage Books.

Scantlebury, K. (2014). Gender matters: Building on the past, recognizing the present, and looking toward the future. In N. G. Lederman & S. Abell (Eds.), *Handbook of research on science education* (pp. 187–204). New York: Routledge.

Scantlebury, K., & Baker, D. (2007). Gender issues in science education research: Remembering where the difference lies. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 257–286). Mawhah, New Jersey: Lawrence Erlbaum Associates Publishers.

Schiebinger, L. (1993). *Schöne Geister: Frauen in den Anfängen der Wissenschaft.* Stuttgart.

Schmader, T. (2002). Gender identification moderates stereotype threat effects on women's math performance. *Journal of Experimental Social Psychology*, *38*(2), 194–201. doi: 10.1006/jesp.2001.1500

Schmader, T., & Johns, M. (2003). Converging evidence that stereotype threat reduces working memory capacity. *Journal of Personality and Social Psychology*, *85*(3), 440–452. doi: 10.1037/0022-3514.85.3.440

Schmader, T., Johns, M., & Barquissau, M. (2004). The costs of accepting gender differences: The role of stereotype endorsement in women's experience in the math domain. *Sex Roles*, *50*(11/12), 835–850.

Schmader, T., Johns, M., & Forbes, C. (2008). An integrated process model of stereotype threat effects on performance. *Psychological Review*, *115*(2), 336–356. doi: 10.1037/0033-295X.115.2.336

Schoon, I. (2001). Teenage job aspirations and career attainment in adulthood: A 17-year follow-up study of teenagers who aspired to become scientists, health professionals, or engineers. *International Journal of Behavioral Development*, *25*(2), 124–132. doi: 10.1080/01650250042000186

Schulkes, P. G. S., Hong, J., & Versendaal, R. M. (2018). *Miniature innovations with monumental implications: An interview with professor ben l. feringa.* Retrieved 16 January 2018, from `http://www.honoursreview.nl/interview-ben.html`

Schuster, C., & Martiny, S. E. (2016). Not feeling good in stem: Effects of stereotype activation and anticipated affect on women's career aspirations. *Sex Roles.* doi: 10.1007/s11199-016-0665-3

Schwartz, D. (1997). *Culture & power: The sociology of pierre bourdieu.* Chicago, IL: The University of Chicago Press.

Schwartz, D. L., Cheng, K. M., Salehi, S., & Wieman, C. (2016). The half empty question for socio-cognitive interventions. *Journal of Educational Psychology*, *108*(3), 397–404. doi: 10.1037/edu0000122

Schwartz, S. J., Klimstra, T. A., Luyckx, K., Hale, W. W., Frijns, T., Oosterwegel, A., … Meeus, Wim H. J. (2011). Daily dynamics of personal identity and self-concept clarity. *European Journal of Personality*, *25*(5), 373–385. doi: 10.1002/per.798

Schwartz, S. J., Pantin, H., Prado, G., Sullivan, S., & Szapocznik, J. (2005). Family functioning, identity, and problem behavior in hispanic immigrant early adolescents. *The Journal of early adolescence*, *25*(4), 392–420. doi: 10.1177/0272431605279843

Sekaquaptewa, D., & Thompson, M. (2003). Solo status, stereotype threat, and performance expectancies: Their effects on women's performance. *Journal* *of Experimental Social Psychology*, *39*(1), 68–74.

Sen, A. (1984). Well-being, agency and freedom: The dewey lectures. *The Journal of Philosophy*, *82*(4), 169–221.

Sen, A. (2000). *Development as freedom* (1. ed., [Nachdr.] ed.). New York: Knopf. Retrieved from `http://www.loc.gov/catdir/description/random044/99031061.html`

Sewell, W. H. (1992). A theory of structure: Duality, agency, and transformation. *American Journal of Sociology*, *98*, 1–29.

Seymour, E., & Hewitt, N. (1994). *Talking about leaving: Factors contributing to high attrition rates among science, mathematics, and engineering undergraduate majors.* Boulder, CO.

Sfard, A., & Prusak, A. (2005). Telling identities: In search of an analytic tool for investigating learning as a culturally shaped activity. *Educational Researcher*, *34*(4), 14–22.

Sharp, L., Carey, N., Frechtling, J. A., & Burgdorf, K. (n.d.). *Short-term impact study of the national science foundation's young scholars program.* Washington, DC.

Siegle, D., & Reis, S. M. (1998). Gender differences in teacher and student perceptions of gifted students' ability and effort. *Gifted Child Quarterly*, *42*(1), 39–47.

Silverman, I., & Eals, M. (1992). Sex differences in spatial ability: Evolutionary theory and data. In J. Barkow, L. Cosmides, & J. Tooby (Eds.), *The adapted mind* (pp. 533–549). Oxford University Press.

Silvermann, L. V., & Miller, N. B. (2009). A feminine perspective of giftedness. In L. V. Shavininia (Ed.), *International handbook of giftedness* (pp. 99–128). Springer Science + Business B. V.

Simon, H. A. (1965). *The shape of automatation for men and management.* New York: Harper & Row.

Simpkins, S. D., Price, C. D., & Garcia, K. (2015). Parental support and high school students' motivation in biology, chemistry, and physics: Understanding differences among latino and caucasian boys and girls. *Journal of Research in Science Teaching*, *52*(10), 1386–1407. doi: 10.1002/tea.21246

Sjøberg, S., & Schreiner, C. (2005). How do learners in different cultures relate to science and technology? results and perspectives from the project rose (the relevance of science education). *Asia-Pacific Forum on Science Learning and Teaching*, *6*(2), 1–17.

Sjøberg, S., & Schreiner, C. (2010). *The rose project: Overview and key findings.*

Skelton, C., Francis, B., & Read, B. (2010). "brains before 'beauty'?" high achieving girls, school and gender identities. *Educational Studies*, *36*(2), 185–194. doi: 10.1080/03055690903162366

Skinner, E., Furrer, C., Marchand, G., & Kindermann, T. (2008). Engagement and disaffection in the classroom: Part of a larger motivational dynamic? *Journal of Educational Psychology*, *100*(4), 765–781. doi: 10.1037/a0012840

Smart Richman, L., & Leary, M. R. (2009). Reactions to discrimination, stigmatization, ostracism, and other forms of interpersonal rejection: A multimotive model. *Psychological Review*, *116*(2), 365–383. doi: 10.1037/a0015250

Smith, E. (2011). Women into science and engineering? gendered participation in higher education stem subjects. *British Educational Research Journal*, *37*(6), 993–1014.

Snow, C. P. (1958). *The two cultures.* New York: Cambridge University Press.

Sowell, T. (1997). *Migrations and cultures: A world view.* Basic Books.

Spelke, E. S. (2005). Sex differences in intrinsic aptitude for mathematics and science? a critical review. *The American psychologist*, *60*(9), 950–958. doi: 10.1037/0003-066X.60.9.950

Spencer, S. J., Logel, C., & Davies, P. G. (2016). Stereotype threat. *Annual Review of Psychology*, *67*, 415–437. doi: 10.1146/annurev-psych-073115-103235

Stadler, H., Duit, R., & Benke, G. (2000). Do boys and girls understand physics differently? *Physics Education*, *35*(6), 417–422.

Stake, J. E., & Mares, K. R. (2001). Science enrichment programs for gifted high school girls and boys: Predictors of program impact on science confidence and motivation. *Journal of Research in Science Teaching*, *38*(10), 1065–1088.

Stanat, P., & Kunter, M. (2002). Geschlechterspezifische Leistungsunterschiede bei Fünfzehnjährigen im internationalen Vergleich. *Zeitschrift für Erziehungswissenschaft*, *5*(1), 28–48.

Steegh, A., Höffler, T. N., Keller, M., & Parchmann, I. (2019). Gender differences in mathematics and science competitions: A systematic review: Manuscript accepted for publication. *Journal of Research in Science Teaching.*

Steele, C. M. (1988). The psychology of self-affirmation: sustaining the integrity of the self. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (pp. 261–302). New York: Academic Press.

Steele, C. M. (1997). A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist*, *52*, 613–629.

Steele, C. M. (1998). Stereotyping and its threat are real. *American Psychologist*, *53*, 680–681.

Steele, C. M., & Aronson, J. (1995). Stereotype threat and the intellectual test performance of african americans. *Journal of Personality and Social Psychology*, *69*, 797–811.

Steele, C. M., Spencer, S. J., & Aronson, J. (2002). Contending with group image: The psychology of stereotype and social identity threat. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (pp. 379–440). San Diego, CA: Academic Press.

Steffens, M. C., & Jelenec, P. (2011). Separating implicit gender stereotypes regarding math and language: Implicit ability stereotypes are self-serving for boys and men, but not for girls and women. *Sex Roles*, *64*(5-6), 324–335. doi: 10.1007/s11199-010-9924-x

Stoeger, H., Duan, X., Schirner, S., Greindl, T., & Ziegler, A. (2013). The effectiveness of a one-year online mentoring program for girls in stem. *Computer & Education*, *69*, 408–418.

Stoet, G., & Geary, D. C. (2018). The gender-equality paradox in science, technology, engineering, and mathematics education. *Psychological Science*, 956797617741719. doi: 10.1177/0956797617741719

Stout, J. G., Dasgupta, N., Hunsinger, M., & McManus, M. A. (2011). Steming the tide: Using ingroup experts to inoculate women's self-concept in science, technology, engineering, and mathematics (stem). *Journal of Personality and Social Psychology*, *100*, 255–270.

Strobel, J., & van Barneveld, A. (2009). When is pbl more effective? a meta-synthesis of meta-analyses comparing pbl to conventional classrooms. *Interdisciplinary Journal of Problem-based Learning*, *3*(1). doi: 10.7771/1541-5015.1046

Su, R., Rounds, J., & Armstrong, P. I. (2009). Men and things, women and people: a meta-analysis of sex differences in interests. *Psychological Bulletin*, *135*(6), 859–884. doi: 10.1037/a0017364

Subotnik, R. F., & Arnold, K. D. (Eds.). (1995). *Beyond terman: Contemporary longitudinal studies of giftedness and talent.* Norwood, NJ: Ablex.

Subotnik, R. F., Duschl, R., & Selmon, E. H. (1993). Retention and attrition of science talent: A longitudinal study of westinghouse science talent search winners. *International Journal of Science Education*, *15*(1). doi: 10.1080/0950069930150105

Tai, R. H., Qi Liu, C., Maltese, A., & Fan, X. (2006). Planning early for careers in science. *Science*, *312*, 1143–1145.

Tajfel, H. (1982). *Social identity and intergroup relations.* Cambridge University Press.

Tan, E., & Calabrese Barton, A. (2012). *Empowering science and mathematics education in urban schools.* Chicago, IL: Chicago Press.

Tate, W. (2001). Science education as a civil right: Urban schools and opportunity-to-learn considerations. *Journal of Research in Science Teaching*, *38*(9), 1015–1028.

Taylor, S. E., Fiske, S. T., Etcoff, N. L., & Ruderman, A. J. (1978). Categorical and contextual bases of person memory and stereotyping. *Journal of Personality and Social Psychology*, *36*(7), 778–793. doi: 10.1037/0022-3514.36.7.778

Taylor, V. S., Erwin, K. W., Ghose, M., & Perry-Thornton, E. (2001). Models to increase enrollment of minority females in science-based careers. *Journal of the National Medical Association*, *93*, 74–77.

Tirri, K. (2002). Developing females talent: Case studies of finnish olympians. *Journal of Research in Education*, *12*(1), 80–85.

Tooby, J. (2017). *Coalitional instincts.* Retrieved 22 April 2018, from `https://www.edge.org/response-detail/27168`

Trivers, R. L. (1972). Parental investment and sexual selection. In *Sexual selection and the descent of man : 1871-1971* (pp. 136–179). Chicago: Aldine.

Tschannen-Moran, M., Woolfolk-Hoy, A., & Hoy, W. K. (1998). Teacher efficacy: Its meaning and measure. *Review of Educational Research*, *68*, 202–248.

Turner, J. C. (1987). *Rediscovering the social group: A self-categorization theory.* Oxford: Blackwell.

Turner, S. L., Steward, J. C., & Lepan, R. T. (2004). Family factors associated with sixth-grade adolescents' math and science career interest. *The Career Development Quarterely*, *53*, 41–52.

United Nations Girls' Education Initiative. (2017). *Guidance for developing gender-responsive education sector plans.* The Global Partnership for Education.

Updegraff, K. A., Eccles, J. S., Barber, B. L., & O'Brien, K. M. (1996). Course enrollment as self-regulatory behavior: Who takes optional high school-math courses? *Learning and individual differences*, *8*, 239–259.

Urhahne, D., Ho, L. H., Parchmann, I., & Nick, S. (2012). Attempting to predict success in the qualifying round of the international chemistry olympiad. *High Ability Studies*, *23*(2), 167–182.

U.S. Department of Commerce. (2011). *Women in stem: A gender gap to innovation.* Retrieved from `http://www.esa.doc.gov/sites/default/files/reports/documents/womeninstemagaptoinnovation8311.pdf`

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: a meta-analysis of training studies. *Psychological Bulletin*, *139*(2), 352–402. doi: 10.1037/a0028446

van Heuvelen, A. (1991). Learning to think like a physicist: A review of research-based instructional strategies. *American Journal of Physics*, *59*, 891–897.

Varelas, M., Tucker-Raymond, E., & Richards, K. (2015). A structure-agency perspective on young children's engagement in school science: Carlos's performance and narrative. *Journal of Research in Science Teaching*, *52*(4), 516–529.

Vogl, S. (2013). Telephone versus face-to-face interviews: Mode effect on semistructured interviews with children. *Sociological Methodology*, *43*(1), 133–177.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for stem domains: Aligning over fifty years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*, 817–835.

Wai, J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2010). Accomplishment in science, technology, engineering, and mathematics (stem) and its relation to stem educational dose: A 25-year longitudinal study. *Journal of Educational Psychology*, *102*(4), 860–871.

Walton, G. M., & Carr, P. B. (2012). Social belonging and the motivational and intellectual achievement of negatively stereotyped students. In M. Inzlicht & T. Schmader (Eds.), *Stereotype threat* (pp. 89–106). Oxford and New York: Oxford University Press.

Walton, G. M., & Cohen, G. L. (2003). Stereotype lift. *Journal of Experimental Social Psychology*, *39*(5), 456–467. doi: 10.1016/S0022-1031(03)00019-2

Walton, G. M., & Cohen, G. L. (2011). A brief social-belonging intervention improves academic and health outcomes of minority students. *Science (New York, N.Y.)*, *331*(6023), 1447–1451. doi: 10.1126/science.1198364

Walton, G. M., Logel, C., Peach, J. M., Spencer, S. J., & Zanna, M. P. (2015). Two brief interventions to mitigate a "chilly climate" transform women's experience, relationships, and achievement in engineering. *Journal of Educational Psychology*, *107*(2), 468–485. doi: 10.1037/a0037461

Wang, J., & Hazari, Z. (2018). Promoting high school students' physics identity through explicit and implicit recognition. *Physical Review Physics Education Research*, *14*(2), 297. doi: 10.1103/PhysRevPhysEducRes.14.020111

Wang, M.-T., & Degol, J. L. (2017). Gender gap in science, technology, engineering, and mathematics (stem): Current knowledge, implications for practice, policy, and future directions. *Educational psychology review*, *29*(1), 119–140. doi: 10.1007/s10648-015-9355-x

Warrington, M., & Younger, M. (2000). The other side of the gender. *Gender and Education*, *12*(4), 493–508.

Watson, J., Dawson, A., & McEwen, S. (1994). Sixth form a level students' perceptions of the difficulty, intellectual freedom, social benefit and interest of science and arts subjects. *Research in Science and Technological Education*, *12*(1), 43–52.

Weiner, B. (1985). An attributional theory of achievement motivation and emotion. *Psychological Review*, *92*(4), 548–573. doi: 10.1037/0033-295X.92.4.548

Wieman, C., & Perkins, K. (2005). Transforming physics education. *Physics Today*, *58*, 36–41.

Wiesner, H., Schecker, H., & Hopf, M. (Eds.). (2011). *Physikdidaktik kompakt.* Hallbergmoos: Aulis Verlag.

Wigfield, A., & Eccles, J. S. (1992). The development of achievement task values: A theoretical analysis. *Developmental Review*, *12*, 265–310.

Will, H., Winteler, A., & Krapp, A. (1987). *Evaluation in der beruflichen aus- und weiterbildung.* Heidelberg: Sauer-Verlag.

Williams, W. M., & Ceci, S. J. (2015). National hiring experiments reveal 2:1 faculty preference for women on stem tenure track. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(17), 5360–5365. doi: 10.1073/pnas.1418878112

Wilson, K., Low, D., Verdon, M., & Verdon, A. (2016). Differences in gender performance on competitive physics selection tests. *Physical Review Physics Education Research*, *12*(2). doi: 10.1103/PhysRevPhysEducRes.12.020111

Wilson, T. D., & Linville, P. W. (1985). Improving the performance of college freshmen with attributional techniques. *Journal of Personality and Social Psychology*, *49*(1), 287–293.

Wirt, J. L. (2011). *An analysis of science olympiad participants' perceptions regarding their experience with the science and engineering academic competition* (Dissertation, Seton Hall University). Retrieved from `https://scholarship.shu.edu/dissertations/26/`

Wodzinski, R. (2007). Mädchen im Physikunterricht. In E. Kircher, R. Girwidz, & P. Häußler (Eds.), *Physikdidaktik* (pp. 559–580). Heidelberg and Berlin and New York: Springer.

Woodward, B., Shurkin, J., & Gordon, D. (2009). *Scientists greater than Einstein: The biggest lifesavers of the twentieth century.* New York: Quill Driver.

Yeager, D. S., & Walton, G. M. (2011). Social-psychological interventions in education: They're not magic. *Review of Educational Research*, *81*(2), 267–301. doi: 10.3102/0034654311405999

Young, D. M., Rudman, L. A., Buettner, H. M., & McLean, M. C. (2013). The influence of female role models on women's implicit science cognitions. *Psychology of Women Quarterly*, *37*(3), 283–292. doi: 10.1177/0361684313482109

Zeldin, A., & Pajares, F. (2000). Against the odds: Self-efficacy beliefs of women in mathematical, scientific, and technological careers. *American Educational Research Journal*, *37*(1), 215–246.

Zeyer, A. (2017). Gender, complexity, and science for all: Systemizing and its impact on motivation to learn science for different science subjects.

*Journal of Research in Science Teaching*, *52*(3), 263. doi: 10.1002/tea.21413

Ziegler, A. (2004). *The actiotope model of giftedness: Ulmer forschungsberichte aus der pädagogischen psychologie* (Nr. 6 ed.).

Ziegler, A. (2005). The actiotope model of giftedness. In R. J. Sternberg & J. E. Davidson (Eds.), *Conceptions of giftedness* (pp. 411–434). Cambridge: Cambridge Univ. Press.

Ziegler, A., & Heller, K. A. (2000). Effects of an attribution retraining with female students gifted in physics. *Journal for the Education of the Gifted*, *23*, 217–243.

Ziegler, A., & Stoeger, H. (2009). Identification of underachievement: an empirical study on the agreement among various diagnostic sources. In D. Eyre (Ed.), *Gifted and talented education* (pp. 389–405). London: Routledge.

Zwick, M. M., & Renn, O. (n.d.). *Die Attraktivität von technischen und ingenieurswissenschaftlichen Fächern bei der Studien- und Berufswahl junger Frauen und Männer.* Stuttgart.

# Erklärung

Folgende Erklärung mache ich für die vorliegende Dissertation:

- Die Abhandlung wurde nach Inhalt und Form eigenständig und nur mit angegebenen Hilfsmitteln verfasst.
- Die Arbeit wurde nicht an einer anderen Stelle im Rahmen eines Prüfungsverfahrens vorgelegt.
- Auf der Basis der Daten in dieser Dissertation ist ein Artikel veröffentlicht (durch Fußnote kenntlich gemacht), der sich allerdings in der Darstellung von Motivation, Design und Ergebnissen grundsätzlich von der in der Dissertation präsentierten Studie 3 unterscheidet.
- Die Arbeit ist unter Einhaltung der Regeln guter wissenschaftlicher Praxis der Deutschen Forschungsgemeinschaft entstanden.
- Mir wurde bisher kein akademischer Grad entzogen.

Peter Wulff
Kiel, 11. Juni 2019

# Danksagung

Die vorliegende Dissertation ist unter dem positiven Einfluss zahlreicher Personen entstanden. Für die Unterstützung möchte ich mich an dieser Stelle bedanken.

Mein besonderer Dank gilt meinem Doktorvater und Erstbetreuer Prof. Dr. Knut Neumann, der das Entstehen der Arbeit über Jahre durch konstruktive Anregungen und viel Verständnis und Geduld für die potentielle Entwicklung unterstützt hat. Ebenso bedanke ich mich ganz herzlich bei Prof.in Dr. Ilka Parchmann, die meine Doktorarbeit als zweite Gutachterin betreut und mich bei wissenschaftlichen Gutachten für meine Weiterbildung sehr unterstützt hat.

Für die stete Unterstützung zur Forcierung und wissenschaftlichen Qualitätssicherung meiner Arbeit bedanke ich mich bei Dr. Stefan Petersen, der meine Arbeit von Anfang an unterstützt hat und damit zur Verwirklichung sehr beigetragen hat. Ebenso bedanke ich mich bei Kolleginnen und Kollegen, die mir in den Physikdidaktiken am IPN sowie an der Universität Potsdam wichtige Impulse für die Durchführung, Auswertung und Verschriftlichung meiner Studien gegeben haben.

Großer Dank gilt schließlich den drei Seminarleiterinnen, die mit Akribie und Souveränität bei der Materialerstellung mitgeholfen und die Seminare durchgeführt haben. Genauso danke ich den Schülerinnen und Schülern für ihr Engagement bei der Teilnahme an den Seminaren und den insbesondere auch den Fragebögen. Weiterer Dank gilt den Schülerinnen, die sich bereiterklärt haben, in Interviews ihre Erfahrungen in der Physik und der PhysikOlympiade zu teilen. Ebenso bedanke ich mich bei den Teams kostenloser Softwarelösungen wie R, RStudio sowie von LaTeX. Ohne diese Programme wären die statistischen Analysen und die formale Aufbereitung dieser Arbeit in dieser Form undenkbar. Ebenso danke ich Marcus Kubsch und Anneke Steegh, die wertvolle Anregungen zu Teilen dieser Arbeit gegeben haben.

Im Rahmen meiner Forschung wurde mir weiterhin die Möglichkeit gegeben, einen Forschungsaufenthalt in der Arbeitsgruppe von Prof.in Dr. Zahra Hazari zu machen, wo ich viel über physikdidaktische Forschung auch im internationalen Kontext und über Identitäts- und Motivationsforschung in der Physik gelernt habe.

Schließlich gilt mein aller herzlichster Dank meinen Freundinnen und Freunden für die vielen schönen gemeinsamen Erlebnisse und Erfahrungen. Dies war die wertvollste Unterstützung, um in schwierigen Zeiten abschalten zu können und die Balance zu wahren, wo man sich vertieft in seine Studien manchmal zu verlieren droht.

Mein größter Dank gilt meiner Familie für die jahrelange Unterstützung, den ständigen Rückhalt und die große Anteilnahme an all meinen Entscheidungen: meinen Brüdern, die meine Vorbilder sind; meinen Eltern, die mich motivieren; meinen Omas und Opas, die mir in ihrer Ruhe Kraft geben; sowie meinen Tanten, Onkels, Cousinen und Cousins.

Meiner verschiedenen Oma ist diese Arbeit gewidmet.