Review Article

# Fostering female students in physics classes: A systematic literature review

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Previous reviews show that the proportion of women in the professional field of physics remains low in Europe, the United States, and Australia. The reasons for the low number of female physics graduates are manifold and have been examined in previous studies. However, the question persists as to how this development can be systematically countered. Insights from physics education research are particularly valuable in this regard. Notably, no review focusing specifically on female students in school physics has been published in the past decade. To deepen the understanding of female students' experiences in physics education and to assess the effectiveness of targeted interventions, a systematic review was conducted. The findings indicate that physics identity plays a central role in shaping female students' future engagement with the subject. As this identity develops during the school years, it offers a crucial window for fostering positive attitudes toward physics. Such attitudes, in turn, support active participation and sustained interest. In addition, the authors wish to highlight a 2010 study by Zara Hazari and others and revisit their model of physics identity, emphasizing the areas of social environment, teachers, and interventions. Based on these insights, approaches to improving the situation of female students in school physics are suggested.

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## I. INTRODUCTION

Although progress toward gender equality has been reported [1], women remain underrepresented across the science, technology, engineering, and mathematics (STEM) fields [1], and "gender equality has still not been attained in STEM" [2]. While research consistently shows that only a small proportion of women complete bachelor's degrees in STEM disciplines, the numbers are particularly low in physics [3]. Existing studies indicate that the development of physics identity strongly influences the educational and career trajectories of women [3] and that this identity formation is especially critical during the school years [4]. This raises the question of how a positive development of physics identity can contribute to improving the situation of female students in physics education. This review aims to provide a deeper understanding of the situation of female students in physics education, especially in Europe, the United States, and Australia. In addition, it seeks to identify how teachers can support female students in developing positive physics identities and how targeted interventions can contribute to this process.

## II. THEORETICAL FRAMEWORK

The theoretical framework of this review is based on the concepts of gender and sex, physics identity, motivation, interest, performance, and self-efficacy.

### A. Gender and sex

In contemporary gender research, *sex* and *gender* are understood as analytically distinct yet deeply interconnected categories.

*Sex* typically refers to the medical assignment of individuals to the categories "female" or "male," based on visible anatomical characteristics at birth. This assignment often overlooks chromosomal, hormonal, or anatomical variations—such as intersex traits—that do not conform to the normative $XX/XY$ binary [5]. Thus, even the category of *sex* is more complex and varied than binary classifications suggest.

*Gender*, by contrast, is conceptualized as a socially constructed system of norms, expectations, and roles [5]. It encompasses culturally shaped ideas about which behaviors, interests, and expressions are deemed appropriate for individuals based on their assigned sex [5]. These norms

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are learned through socialization and continuously reproduced in everyday interactions [5]. The theory of gender performativity further challenges the stability of both biological and social categories of sex [6]. From this perspective, gender is constituted through repeated cultural practices rather than reflecting an inherent identity [7]. This theoretical lens opens space for understanding gender as fluid, nonbinary, and context-dependent [6–8]. These distinctions are highly relevant for physics education research. Categorizing all students as "girls" or "boys" risks reinforcing binary assumptions and obscuring the diversity of gender identities present in classrooms [6]. Recent contributions to physics education indicate that gender diversity is increasingly acknowledged within the field [9]. However, naming diversity alone is insufficient [9]. Meaningful change requires a commitment to *gender equity*, understood as the creation of fair and supportive gender-based conditions that promote students' well-being, participation, and recognition in school contexts [10,11]. Intersections of gender with other social categories—such as ethnicity, socioeconomic background, or language—further shape students' experiences [11]. Intersectionality theory (Crenshaw) highlights that these categories interact to produce unique forms of advantage or disadvantage [10,12]. Teachers play a crucial role in this process: through their expectations, interactions, and instructional practices, they can either reproduce or challenge existing inequalities [13]. Despite these theoretical advances, most empirical studies in school settings continue to rely on binary gender categories [8]. For the purposes of this review, the authors therefore adopt the binary framework commonly used in school-based research while acknowledging its limitations [8]. Accordingly, the terms *girl* and *female student*, as well as *boy* and *male student*, refer to individuals assigned to these respective groups within the prevailing school context.

### B. Physics identity

Physics identity has become a central construct in research on students' participation and persistence in physics [2,3]. Existing reviews consistently demonstrate that physics identity is a key factor influencing whether students are drawn toward—or away from—physics education and physics-related careers [2,3,14]. Physics identity is conceptualized as the way individuals make sense of their scientific experiences within the broader social structures that shape possible meanings [15]. Identity development is therefore not merely an internal process but is embedded in cultural expectations, recognition by others, and opportunities for meaningful engagement [15]. This development occurs predominantly during adolescence [1], a period in which students' affinities for or aversions to scientific domains become increasingly visible and consequential [1]. Focusing on physics identity provides a powerful lens for understanding students' long-term personal connection to the discipline [16]. There is a clear relationship between identity-related measures and engagement [16,17]. Taken together, these perspectives underscore that physics identity is not a static trait but a dynamic, socially mediated process [16,17]. Understanding how this identity develops—and how it can be positively supported—is therefore essential for addressing gender disparities in physics education.

### C. Motivation, interest, performance, and self-efficacy

Within the broader framework of physics identity, the constructs of *motivation*, *interest*, *performance*, and *self-efficacy* play central roles in shaping students' engagement with physics.

Self-determination theory (SDT) provides a foundational understanding of *motivation* [18]. SDT distinguishes between intrinsic motivation, in which individuals engage in an activity out of genuine interest or internal satisfaction, and extrinsic motivation, in which behavior is driven by external incentives or pressures [18]. According to SDT, three universal psychological needs—autonomy, competence, and relatedness—are essential for fostering high-quality motivation [18]. When these needs are supported, students are more likely to develop sustained engagement and positive identity trajectories in physics [18].

*Interest* is another key construct linked to the development of physics identity. Situational factors were examined [19]. These factors influence topic-specific interest and learning from texts [19]. The findings suggest that both individual predispositions and contextual features—such as the framing of a topic—shape students' situational and long-term interest [19]. Interest, in turn, is closely tied to identity formation, as students are more likely to see themselves as "physics people" when they experience meaningful and enjoyable engagement with the subject [16].

*Self-efficacy* refers to individuals' beliefs in their ability to successfully perform tasks or achieve goals [20]. It reflects how confident students feel in their own capabilities within specific contexts, including physics learning [20]. This is mainly influenced by mastery experiences, vicarious experiences, social persuasion, and physiological and emotional states [20]. These sources shape students' expectations of success, which influence their choices, effort, and persistence [20]. In physics education, self-efficacy has been shown to affect not only classroom performance but also students' willingness to pursue physics-related pathways [20,21]. Self-efficacy influences a person's choices, effort, and persistence in various aspects of life, e.g., pursuing jobs related to physics [20].

## III. STATE OF RESEARCH

At the time of writing, no systematic review specifically examines the situation of female students in physics education in schools. Consequently, existing reviews from

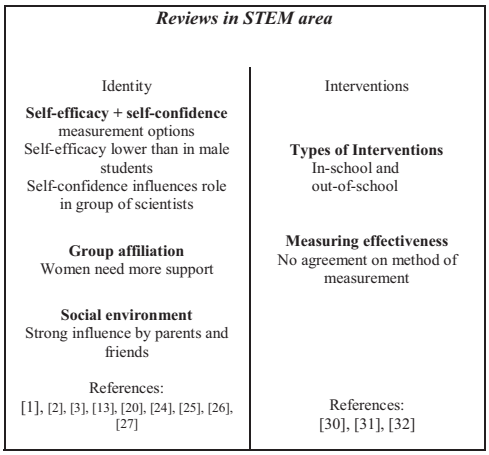



FIG. 1. Reviews in STEM area.

the broader STEM field are used to identify relevant themes and gaps that inform the research questions of this study. These reviews provide insights into how high school girls and college students experience STEM learning environments and which factors shape their participation. Two major research strands emerge from this body of work [1,3,22,23]: (1) identity development among female students and (2) interventions designed to support them (Fig. 1).

A substantial portion of STEM reviews focuses on gender differences in science identity, self-efficacy, and self-confidence [1,3,14]. The concept of self-efficacy is frequently used to explain these differences [20]. Four sources of self-efficacy beliefs are identified:

- Mastery experiences (successful performance in similar tasks)
- Vicarious experiences (observing others succeed)
- Social persuasion (encouragement and feedback)
- Physiological and emotional states (interpretation of stress and arousal) [20,24]

Reviews consistently show that female college students report lower self-efficacy in STEM subjects than their male peers, and this gap is particularly pronounced in physics [2]. A study focusing on Australian schools finds that both STEM identity and self-efficacy are systematically lower among female college students [2]. A relevant study reports similar patterns in physics specifically: female college students' self-efficacy declines significantly during introductory physics courses, often more sharply than that of male students [3]. These findings highlight the importance of considering gender differences when examining physics identity development. Another line of research examines self-confidence and its influence on women's behavior in scientific communities. Studies show that as women progress in STEM, they often become less active or visible within these fields, suggesting structural barriers that limit their participation [25,26]. Group affiliation and the social environment also play a crucial role in shaping science identity [1]. The concept of the social environment can be described in terms of students' recognition [15]. Here, the term "social environment" refers to teachers, parents, and peers [15].

Reviews emphasize that support for female students—both those entering STEM and those already part of STEM communities—is essential [1]. Family, friends, and peer groups influence how female students perceive their abilities and whether they see themselves as belonging in science [27–29]. Parental expectations, especially mothers' perceptions, and the gender composition of peer groups are particularly influential [27]. Additionally, some studies highlight the relevance of social identity complexity, which describes how individuals navigate multiple social identities simultaneously [1]. This complexity shapes how students position themselves within scientific fields and how they negotiate belonging [1]. Notably, most of these findings stem from quantitative studies, indicating a need for more qualitative research to capture the nuanced experiences of female students [27]. The second major research strand concerns the evaluation of interventions aimed at increasing female students' participation in STEM. Existing reviews examine both school-based and out-of-school programs and assess whether these interventions influence students' decisions to pursue STEM subjects [30]. Researchers conclude that reporting practices in intervention studies need improvement to allow meaningful comparisons and evidence-based refinement of programs [22]. Similarly, further studies have shown that many investigations do not clearly demonstrate whether interventions have measurable effects, and there is little consensus on appropriate evaluation methods [31]. Other studies also emphasize the lack of standardized approaches for assessing motivational interventions in STEM, calling for more robust and generalizable evaluation frameworks [32]. Overall, the current state of research shows that female students in STEM require more targeted support. However, specific insights into physics education at the secondary school level remain limited. This gap underscores the need for a systematic review focused explicitly on female students in physics. Based on the identified research gaps, the following research questions guide this review:

RQ1: What influences the development of physics identity in female students, and how do these factors shape identity formation?

RQ2: How can teachers use the factors influencing physics identity to improve the situation of female students?

RQ3: In what ways can specific physics programs for female students improve their situation in physics?

## IV. METHODS

The general review procedure was based on the PRISMA statement [33]. The exact procedure can be

TABLE I. Search String and databases.

| Search string: Physics AND (girl* OR female OR Gender OR wom*n) AND (school OR class) AND study | |
|---|---|
| Database | Results |
| ERIC | 324 |
| Academic Search Premier | 103 |
| Web of Science | 142 |

found in Table I in addition to this description. Conducting the literature research, first a search string (Table I) was developed based on the current scientific state of research. The authors of this literature review used the databases Education Resources Information Center (ERIC), Academic Search Premier (via EBSCOhost), and Web of Science/ Social Sciences Citation Index.

The databases were selected because they mainly contain pedagogical literature but also literature in the science field. Therefore, we were able to collect all relevant results. Due to the high scientific standard of English-language literature, we have focused only on those articles. With the help of ERIC, the first author initially made a rough overview of the categories that are addressed in the field of female students in physics. This made it possible to locate key terms and include them in the further search strategy (Table II). Several inclusion criteria could be developed and applied to all three databases (Fig. 2). Then the results were sorted by publication date, and duplicates were sorted out. All studies were examined using a process starting with the title and abstract, and if the content was appropriate, the full text was read. The content was examined to see whether it answered the

TABLE II. Inclusion criteria applied to the databases.

| Item | Description |
|---|---|
| Period | In order to ensure relevance, studies published since 2011 (Web of Science, Academic Search Premier) or since 2013 (ERIC) are considered |
| Theme female students | The focus of the work is on the topic of female students in the subject of physics at school |
| Locality | Since the research is based on a cultural similarity in the education system, only studies conducted in specific areas or countries are considered: Europe, the United States, and Australia |
| Research questions | The topics of physics identity development, motivation, and interventions are to be answered by means of the three research questions |

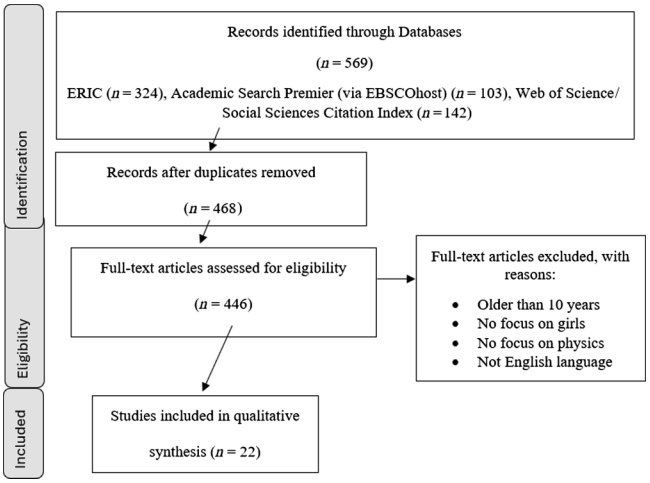



FIG. 2. Review procedure.

research questions. Some studies were eliminated based on topic, target group, or locality. At the end of the analysis, 22 studies remained from the three databases that were relevant to our research questions. The analytical categories used in this review were developed through a combination of deductive and inductive procedures. First, a deductive approach was applied by drawing on established theoretical frameworks in physics education research—particularly identity theory, motivation and self-efficacy models, and prior STEM-related reviews. These frameworks provided an initial set of guiding categories that structured the analysis. In the second step, an inductive approach was used to refine and expand these categories based on the empirical material. As the included studies were systematically reviewed, recurring themes, patterns, and concepts were identified and incorporated into the category system. This iterative process ensured that the analytical framework remained grounded in existing theory while also capturing the specific nuances and emergent insights present in the current body of research.

## V. RESULTS

In this part of the review, the authors present the results of the 22 contributed studies based on the three research questions. First, the relevant results are summarized in Table III, and more detailed information about the studies is provided. Then, the main results are considered in detail in relation to the research questions.

### A. Research question 1

What influences the development of physics identity in female students, and how do these factors shape identity formation?

Physics identity develops over many years and can be positively influenced by instructional approaches [35]. After reviewing all included studies, five main categories

TABLE III. Information about the studies and the main results.

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Abraham & Barker (2015), Australia | Exploring gender difference in motivation, engagement, and enrollment behavior of senior secondary physics students in New South Wales | Data were always collected after the completion of a physics module, for a total of 4 times, as required by the Year 11 curriculum. Females are less frequently represented in Australian physics education, which varied the samples across nine schools (males 178, 180, 147, and 140; females 92, 100, 92, and 82).<br>Year 11 secondary physics students from nine NSW schools (government and Catholic). | Motivation in physics studies was assessed. Three areas were surveyed: expectancy-value motivation constructs, sustained engagement, and intention to enroll. Gender differences were examined. This covered the module-specific, fine-grained level.<br>Cronbach's alpha estimation of the internal consistency of each *a priori* scale. Then, examination of the structure of the factors of a 6-factor model in a confirmatory factor analysis. In addition, tests for gender invariance for each physics module. | The results show that there is no need to plan interventions differently for girls and boys when planning lessons.<br>If girls are already enrolled in physics, they show just as much interest as their male counterparts. Electricity interests both genders equally, and the same is true for astrophysics. In the area of natural phenomena (e.g., waves), girls are more interested than boys. Participants reported higher or near average scores (mean of constructs = 3.5) for most physics modules for all variables except sexstereo. |
| Abraham & Barker (2020), Australia | An intervention to support young women's physics identity development | Data were collected 4 times. Gender differences in motivation, engagement, and continued participation in physics classes were to be recorded.<br>Year 11 female physics students in mixed-gender and coeducational high schools (8); total sample sizes in the eight schools varied by module (92, 100, 92, and 82, respectively). | With different scales, interest, recognition, competence, and engagement in the Physics Olympiad were evaluated | Results show that it did not matter whether girls participated in physics classes in a coed course or a same-sex course, motivation did not change. Participants reported higher or near average scores (mean of constructs = 3.5) across most physics modules for all variables except sexstereo. Girls chose to take physics or did not, regardless of whether they were more interested or saw greater benefit or were more engaged or better at the subject |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Archer *et al.* (2016), UK | A sociological analysis in Physics of multimethod data from young women aged 10–16 to explore gendered patterns of post-16 participation | For the analysis, interviews (132) were conducted with 62 parents and 70 students. Here, the results were recorded in writing after the interviews. Seven girls turned out to study physics after the age of 16.<br>Year 11 students (aged 15 and 16). This included a nationally representative school survey involving 13 421 students from 340 secondary schools in England. | The analysis sought to determine why some girls developed and pursued goals in the physical realm and other girls did not have this aspiration. This was based on two different concepts: the work of French sociologist Pierre Bourdieu and the work of U.S. critical feminist theorist Judith ButlerA discurs-analytic approach was used to examine the data collected. Seven girls who aspired to study physics after high school were identified. | In order to describe the subject of physics as popular among girls, the physics identity must be shaped positively. If the girls have a good relationship with the subject, they are more likely to choose it later. If structural and social differences prevail in the classes, this imbalance can have a bad influence on the girls. Physics is categorized by girls as difficult and masculine. If girls remain loyal to the subject of physics, they pride themselves on being seen as unusual.<br>Among Year 11 students who choose physics as their best subject, 61.1% are boys and 38.9% are girls. Those who identify physics as their "most difficult subject" are 36.0% boys and 64.0% girls. Only 47.3% of students agreed that physics is the most difficult subject. 32.6% of students agreed that physics is the most interesting subject. My teacher thinks "I am good at physics," 61.8% are boys and only 38.2% are girls. Those who want to be an engineer in the future were 75.7% male and 24.3% female. |
| Archer *et al.* (2020), UK | Impact of gender identification and sense of belonging on girls persisting in Physics or not | Interviews, private location 16 students, 17 and 18 years old | Four questionnaires were distributed to the subjects. The first three questionnaires asked about four areas: identification with one's own gender, the feeling of belonging, whether one perceives a threat to one's own identity, and the perception of stereotypes. The fourth questionnaire investigated the extent to which there is pressure to perform and whether physics could be considered as a future career | The results showed that there is a clear idea of correct behavior in physics and attitudes toward the subject. Physics is associated with masculinity, and participants show intelligence and smartness. Many women could not identify with these ideas. Girls repeatedly justified their success by saying they had worked hard and learned a lot. Whereas their male counterparts were able to report success without this effort |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Dare & Roehring (2016), USA | Understanding similarities and differences between girls' and boys' perceptions surrounding physics and physics-related careers. Understand how instructional strategies may influence and relate to students' perceptions. | Used a survey and focus group interviews to understand similarities and differences between girls' and boys' perceptions.<br>165 sixth grade students and their teachers participated a summer professional development in 2014. | In this study, quantitative and qualitative data are collected and examined. The results are then compared. First, surveys were taken on the influencing factors, focusing on instructional strategies. Then, qualitative, semistructured focus group interviews were conducted.<br>A 15-item Likert scale was used, with a scale of 0–4 ranging from "strongly disagree" to "strongly agree"; Cronbach's alpha of the survey showed good internal consistency. | The results show that girls are less interested in professions that have a strong physical background. Boys show great interest in the functionality of things and inform themselves about topics in the physical field. Girls show interest in the physical field with regard to social aspects, for example, group work. Here it is clear that girls want to advance the results through the distribution of roles in group work. Girls made a strong distinction between "doing science" and being a "scientist." Efforts to reform K–12 science could help more women pursue careers in physics.<br>Major responses, "I like learning how things work." M(girls) = 2.72; M(boys) = 2.98 "Science is one of my favorite subjects in school this year." M(girls) = 2.27; M(boys) = 2.55. |
| Durk *et al.* (2020), UK | Racial and gendered patterns of equity and inequity in high school physics Classrooms incorporating computational modeling, with an emphasis on group work | During a physics workshop weekend, students were initially surveyed before the start of a unit and at the end of a unit. The units, with an emphasis on active learning, were designed to promote girls' ability and self-efficacy. Demographic and underrepresented groups were included in the surveys Approximately 200 high school physics students | The EQUIP web application [34] was used to analyze the data. This identified quantitative patterns in student participation in the classroom. Three videos were then selected and themes of race, gender, and classroom interactions were examined | Students feel more self-efficient and capable after the workshop. In addition, the girls show a comparatively greater improvement than the boys |
| Hazari & Cass (2018), USA | Special 2-week program for girls in which the young women were specifically prepared for the introductory physics course after the holidays | Video recordings by teachers, notes from observers, interviews with teachers and students, teacher and student surveys, and student grades.<br>Four physics teachers (in 2011), 146 students. | Through the end-of-semester exam at the end of each semester, the performance of all chemistry and physics students is examined. This assessment went into the students' course grade at 15% | The teacher and classmates influence the physics development of the students. Often, the students consider themselves more talented than the teacher |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Jones & Hamer (2022), England | The link between parents and their child's physics uptake | Parent and Carer Survey<br>Parents and carers of Year 9 students in coeducational and single-sex schools | It was analyzed whether the present results are applicable to other population groups. Clarification was also provided on how the sample of respondents was obtained and the nature of the schools. The schools in the sample were compared with nonspecialist state schools in England | The parents of the students have a certain idea about the career of their children. Here, the students develop an affinity for physics and can imagine a professional career in the field of physics if their parents convey to them the possibility of this development.<br>When looking at the individual items and scales, a mean of 3.0 means that parents neither agree nor disagree with the scale or item, i.e., they are neutral. Parents generally have a positive attitude toward physics in terms of its utility and value. With a mean between 2.9 and 3.0, parents are generally neutral about their enjoyment of physics. Overall parents do not agree with stereotypes. However, with means of 2.3 and 2.5, there are still many parents who adhere to these stereotypes. The total sample with the full variables explains just under 40% of the variance in parents imagining their child in physics. |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Jurik *et al.* (2013), Germany | How student characteristics affect girls' and boys' verbal engagement in physics instruction | First, the students were interviewed and a pretest was administered. Four months after the pretest, a lesson was videotaped and analyzed. The Videograph software was used for this purpose 1378 students from 81 randomly selected physics classes of high schools in Germany and German-speaking Switzerland. | First, profiles were created for the participating students. These profiles were determined with the help of four focal points: cognitive abilities, prior knowledge of content, leisure interests, and self-assessment in physics. Cognitive abilities were analyzed using a test consisting of 25 reasoning tasks. Prior knowledge was assessed with 33 standardized test items. Leisure interests were determined using a five-point Likert scale, and self-assessment in physics was determined using a four-point Likert scale. Video analysis methods for student engagement: video analysis was based on three categories: "frequency and duration of student engagement," "type," and "function" of student engagement | Of all girls, 101 (16.0%) were allocated to the "strong" profile group, whereas 238 of all boys (31.9%) were labeled strong; "uninterested" girls ($n = 92$; 14.6%) and boys ($n = 61$; 8.2%); girls ($n = 200$; 31.6%) and boys ($n = 199$ boys; 26.7%) nearly even distributed in the "underestimating" profile; more girls ($n = 154$; 24.4%) than boys ($n = 107$; 14.3%) were classified as "struggling." The smallest group of girls ($n = 85$; 13.4%) and 141 boys (18.9%) were assigned to the "overestimating" profile. Multilevel analysis revealed that verbal engagement was highest for girls and boys with high cognitive and motivational-affective characteristics. The variance accounted for by the class on Level 2 varied between 18% and 38%. There are significant interactions between student profile and gender for girls with high-level characteristics. It is argued that the interaction between gender and other characteristics is a valuable predictor of verbal engagement in physics classes. More boys than girls would fit into profiles with positive cognitive and motivational-affective traits. More girls for girls were categorized as uninterested and "underappreciative." Cognitively and motivationally strong students participated statistically significantly more often, longer, and more intensely in classroom conversation than "difficult" students. |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Ladewig *et al.* (2020), Germany | Three factors that influence the development of physics identity: background, high school physics learning and college experience with Physics; investigated the influence of negative experiences in the classroom | Identify distinct student profiles<br>282 first-round participants of the German Physics Olympiad, 84 female 174 male gender, and 24 not indicate their gender | In this study, individual students are observed over 3 years. The different results are compared again and again: two main cases emerged: 1. students whose physics identity does not change; 2. students whose physics identity changes due to affective states | The results show that girls feel less attached to physics than their male counterparts. As a result, girls may be poorly influenced and later career intentions shift to a nonphysics field.<br>Mean scores of sense of belonging, domain-specific self-concept, and interest were greater than the scale mean. Agreement with stereotypes was rather low, although not significantly different for male and female participants [$t(182, 73) = 0.46$, $p = 0.650$, Cohen's $d = 0.07$]. Female participants reported significantly lower sense of belonging: sense of belonging [$t(258) = 3.14$, $p = 0.002$, Cohen's $d = 0.41$], expectations of success [$t(170, 54) = 4.58$, $p < 0.001$, Cohen's $d = 0.57$], and self-concept [$t(258) = 2.30$, $p = 0.022$, Cohen's $d = 0.31$] than male participants. Male and female participants did not differ on value [$t(141, 36) = 1.18$, $p = 0.242$, Cohen's $d = 0.16$] or interest [$t(156, 42) = 1.82$, $p = 0.071$, Cohen's $d = 0.24$]. In the total sample, sense of belonging and stereotype endorsement were negatively correlated with low correlation ($r = -0.13$, $p = 0.031$). A breakdown of the group by gender showed that women's sense of belonging was significantly correlated with endorsement of stereotypes ($r = -0.39$, $< 0.001$), whereas men's was not ($r = -0.01$, $p = 0.907$). |

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TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Ladewig *et al.* (2022), Germany | Self-confidence and self-efficacy of young women | Experimenting and solving tasks at home, weekend seminars 298 students, 28% female | Through the study, it was investigated how much self-confidence the students had in their performance. At a later stage, actual abilities were tested. Results were analyzed using CCL Confidence Achievement Window proposed by Covington Clarkson *et al.* | After the girls finished the project, their career plans did not change, although they had had negative preconceptions about their abilities. On the first assessment of test scores, the girls felt more threatened in their position than their male counterparts [$t(281) = -4.77,\ p < 0.001$]. These results continued to be evident on the second [$t(122, 40) = -3.04,\ p = 0.003$] and third [$t(128, 75) = -2.77,\ p = 0.006$] runs. No differences were found in the measurement of the sense of belonging at the first three runs. At the fourth assessment, boys rated belongingness higher than girls [$t(114, 42) = 2.13,\ p = 0.036$]. When examining agreement with prejudice, it was found that at the first [$t(167, 03) = 2.39,\ p = 0.006$] and fourth [$t(139, 21) = 2.23,\ p = 0.027$] runs, boys showed higher agreement than girls |
| Lawton *et al.* (2021), USA | Whether girls show a lower daily engagement in science lessons than their male classmates | Data on 925 (PPG = 174, control = 751) unique students, the 2-week camp included 10 modules. Students typically worked in groups of four with each group rotating members. physics program for girls (PPG) students and female peers of PPG students who did not participate in PPG | With different scales, the results were evaluated | The results show that girls were able to develop better in a safe environment, as they had more confidence in themselves after participation. A separate model was developed to measure the changes. Here, a physics data vector was created (0 = missing, 1 = present) and its relationship with a chemistry score was examined. The results showed that missing data in de physics showed higher chemistry scores [estimate = 5.0, $t(617) = 2.87,\ p = 0.004$]. However, both the effect of PPG status and the interaction between missing data and PPG status were found to be nonsignificant [PPG status: $F(1; 617) = 0.34,\ p = 0.560$; interaction: $F(1; 617) = 2.71,\ p = 0.100$] |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Lock & Hazari (2016), USA | Discussing underrepresentation to facilitate female students' physics identity development | All data used in the present study were generated during research on educational measures. The goal of this overarching project is to identify such measures that have a positive impact on the development of physics identity. The study here focused on the underrepresentation of women in the physics sciences. Two classroom examples of such a discussion were first filmed and the students and teachers involved were interviewed. In addition, student work relevant to the topic was pulled in for analysis. These data were collected for two consecutive yearsTwo out of five teachers mentioned such discussions as part of their teaching, and one of them explained such a lesson in more detail. This paper is about that teacher. He taught physics and chemistry in a medium-sized public school with about 1500 students. Twenty students, 11 male and 9 female, were videotaped in the first year. Fifteen students, 8 male and 7 female, were enrolled in the second year. | Two observers visited for a week during each year. Data included video recordings, field notes, student and teacher surveys, student and teacher interviews, and student work. Video was recorded by two cameras during the site visits. At the end of the site visit, the teacher was given one camera to collect video of key lessons for the remainder of the school year | Students' essays were used to measure current perceptions. Results following the class sessions show that students change their attitudes toward women in science when their scientific underrepresentation is discussed in class. Classes reflect on their biases and entrenched norms can be loosened. Through this, students are willing to have their physics identity development positively encouraged. Male students reported a significantly higher self-image in physics than their female peers ($p < 0.001$). |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Marchand & Taasoobshirazi (2013), USA | The goal of this study was to extend the research on gender differences in physics and the research on stereotype threat (ST) by examining the impact of ST on high school females' physics performance | To identify clues about the influence of ST on student performance, three different cases were constructed:<br>1. Explicit ST condition (students are told that males perform better than females on the physics exam).<br>2. An implicit ST condition (students are not told about the effect of gender on performance but are in a traditional physics exam situation).<br>3. A nullified condition (students are told that no gender differences in performance were found on the exam).<br>Of the 16 classrooms, 5 were in the implicit ST condition, 6 were in the explicit ST condition, and 5 were in the annulled condition, with each condition assigned at least once at each of the four schools.<br>Of the 312 students, 167 participants identified themselves as male (53.5%). Students were 16 years old on average, and the majority of them attended grade 11 (59.6%) | After the students were divided into the different groups (explicit ST condition, implicit ST, and nullified condition), the tasks were provided in a packet. A formula sheet and a calculator were available for assistance.<br>In the explicit ST condition group, participants were given four tasks to solve based on physics content already covered. In the "implicit ST condition" group, participants were given four physics tasks to solve. These tasks are based on previously covered physics material. Gender differences have been shown on this test, with males performing better on the tasks than females. For "nullified condition," participants are given four physics tasks to solve. These tasks are based on the physics material you have already covered. No gender differences in performance were found on this test. Students were given 20 min to complete the four tasks | Analysis of variance, with performance on the physics problems as the dependent variable, indicated that the three conditions did not differ significantly by grade, age, or ethnicity. The results of the $2 \times 3$ Analysis of covariance indicated a statistically significant main effect for gender ($F1(290) = 14.25,\ p < 0.001$) but not for condition. The interaction between gender and condition code was statistically significant ($F2(290) = 3.30,\ p < 0.05$. The conditions included an explicit ST condition, an implicit ST condition, and a nullified condition. Results indicated that males in all three conditions performed similarly on a set of physics problems. Females in the nullified condition outperformed females in the explicit ST condition and females in the implicit and explicit conditions performed similarly ($p = 0.07$). Males performed better than females in the implicit and explicit ST conditions, but male and female performance on the physics problems was not significantly different in the nullified condition |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Mackenzie *et al.* (2021), Australia | Is growth orientation in science, achievement orientation, self-efficacy, and perceived teacher support influence intention to study biology, chemistry, and physics in high school? | Demographic and attitudinal data were collected with online surveys. Participants were then asked to volunteer. 125 adolescent girls between the ages of 14 and 17 living in Australia | Regressions were used to examine the psychological and social factors that predicted subject-selection intentions | In this study, it was found that most girls' self-efficacy and their own abilities do not seem great enough to make further schooling in these subjects worthwhile. The girls rate their performance in biology better. If the girls surveyed have great confidence in their abilities, they are also more willing to pursue school careers in physics or chemistry |
| Mujtaba & Reiss (2014) | Factors that influence 15-year-old students' intentions to study physics post-16, when it is no longer compulsory | Extrinsic material gain motivation, intrinsic value of physics, home support for achievement in physics, emotional response to physics lessons, perceptions of physics lessons, physics self-concept, and advice-pressure to study physics 5034 students from 137 England schools as learners of physics during the academic year 2008–2009 | A questionnaire was used to determine whether students intended to continue taking physics after the age of 16. A six-point Likert scale was used, where a high score indicates a high intention. The chi-square likelihood ratio test was used to determine whether more complex models fit better than simpler models, and the variance statistic was examined to determine whether individual predictors were statistically significant | It appears that it is primarily the differences between the students themselves that determine whether they continue studying physics after the age of 16. Only 7% of the different decisions can be attributed to secondary schools. Extrinsic motivation turned out to be the biggest influence. If classmates and teachers encouraged the student to continue studying physics, these students actually took physics. This analysis also showed that boys viewed their mathematics and physics classes more positively than girls |
| Patall *et al.* (2018), USA | The prejudices and attitudes toward and of physics students | Six-week instructional unit, questionnaire after every science class 208 students, 13–18 years old | A Bourdieusian analysis of longitudinal interview data from 75 interviews | The results show that prejudice against women is very present in the subjects of chemistry, physics, and engineering. Further, girls perceive their teachers as less supportive of autonomous behavior (1/8 of a standard deviation). Psychological need satisfaction in the classroom turned out to be less strong (1/6 of a standard deviation) than for boys |
| Shah *et al.* (2020), USA | If the growth mindset in science was related to the girls' intention to study science in high school | Video data were collected and analyzed as basis for developing action plans8 teachers in 8 different schools, 60 students (26 boys, 34 girls), grades 9–12 | With the help of adapted scales, the points growth mindset, achievement goal orientation, perceived support from teachers and peers, self-efficacy, and intentions to study science were examined | Girls feel disadvantaged in group work. Developing new positions in groups allows girls to be more involved in developing outcomes. If there are more girls in a group, the girls feel stronger and assert their participation briskly. The topics of group work also have an impact on girls' sense of belonging |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Stoeckel *et al.* (2021), USA | Difference in self-efficacy between boys and girls | Study examined confidence and self-efficacy as an aspect of physics identity in an AP Physics 1 class using a mixed-methods, sequential explanatory design<br>92 students enrolled in AP Physics 1 at the target high school, with small sample sizes in some subgroups | To measure the differences in self-efficacy between girls and boys, principal component analysis (PCA) was used. This measures the state of self-efficacy using specific questions about ability, control, and success. PCA identifies coherent subsets of variables that are relatively independent and is often used in Experience Sampling Method studies. They included Cronbach's $\alpha$ as an additional measure of internal consistency.<br>A model was developed using HLM 7 software that both analyzed the data obtained and included gender differences in instruction. | The results show that the more the classes cooperate in the lab, the more self-confidence they can develop in their abilities. If you develop a result with your own effort, you end up having more confidence in the scientific field. This result is independent of the gender of the students. 53% of the students fell into the public profile and 26% of the students fell into the unknown profile, indicating that most of the students were good at assessing their confidence. 13% of students met the underestimation profile and 8% met the overestimation profile, indicating that lower confidence was slightly more common than overconfidence among students in this study |
| Wang *et al.* (2018), USA | Stereotype threat and its effects on sense of belonging in the German Physics Olympiad science competition | Attitudes and motivations toward learning physics after a single physics course in high school; data are drawn from 3 years of student interviews and one initial student survey<br>Six female students | Three areas were examined using questionnaires adapted from the 15-item version of the Math Sense of Belonging Scale of Good:<br>1. sense of belonging<br>2. interest and self-concept in physics<br>3. value and success expectations of the studies | The results show that the more competent the students consider themselves to be in mathematics and science, the more interested they are in these subjects. It can be seen that the grades are then also better.<br>The teachers' interaction with the students has a predominant influence on the positive development of physics identity. |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Ward *et al.* (2015) | Using engineering activities to engage middle school students in physics and biology | Questionnaires (Draw-A-Scientist Test [DAST]) were used to collect data from students who completed a 4-week learning program. The surveys were conducted both before and after the learning session. Later analysis sought to examine the impact of the learning program on student identification with careers in physics and biology and student engagement. Students were given 30–45 min to complete the questionnaires. During the learning programs, learning activities about STEM fields were conducted by students.<br>Fifty-seven grade 6 students (11–12 years old), 28 males and 29 females from two schools | The survey also included a modified version of the DAST | The results show that the learning program was able to positively impact students when they were actively engaged. When ideas and concepts are taught through hands-on experiences, students have challenging and motivating experiences in science. Students showed more understanding of problem-solving in engineering tasks when they were actively engaged.<br>To the statement "I think biology and physics have a lot in common," 16% of students responded "true," 39% responded "not true," and 44% responded "unsure." These data contrast with the responses in the postworkshop survey, where 63% answered true and 18% answered "we are not sure."<br>On average, 55% of students confirmed that professions such as doctors, engineers, and medical researchers were related to physics, while the profession of speech therapist was mentioned by only 25% of respondents.<br>In the follow-up survey, the number of mentions increased for all professions<br>Preference for studying physics remained relatively stable in the pre- and postsurveys at 31% and 28%, respectively. DAST responses from female students indicate that predominantly females work in biology-related situations (69% of pre- and postsurveys), while those who work in physics-related situations are predominantly male (69% of pre- and 62% of postsurveys). |

*(Table continued)*

TABLE III. *(Continued)*

| Authors, Country | Research topic | Study design, Sample & setting and participants | Analysis | Main results |
|---|---|---|---|---|
| Wulff *et al.* (2018) | Students' skills as well as their self-efficacy in physics | Investigated physics identity development of young women, 1-day interventions, the students received the intervention in three separate groups, 6 h on a single day, introductory game to get to know each other, and same-sex groups were formed, group tables and a discussion session was available<br>30 German students, who participated in the German Physics Olympiad | Evaluation before and after the workshop, success was analyzed with the help of performance tests and scaled questionnaires | The positive effect of extracurricular activities on girls' interest in physics was confirmed |

emerged with regard to the first research question. The resulting categories are: interest in physics at school, a self-confident attitude, social environment, identification as a scientist, and specific interventions. After reviewing all included studies, five analytical categories emerged that address the first research question. The authors represented in the table contributed to identifying these categories.

### *1. Interest*

The development of physics identity is closely connected to students' interest in the subject of physics [4]. In a 3-year longitudinal study with six female students, researchers found that interest increased when students felt more competent in physics [4]. Already in middle school, it becomes apparent whether students develop an interest in physics, and this early interest strongly shapes whether physics identity evolves positively or negatively [4]. In addition, the study shows that parental encouragement further enhances students' interest in physics, highlighting the importance of family support in the identity-building process [4].

### *2. Self-confident attitude*

In the longitudinal study mentioned above, researchers also found that students' grades in mathematics and science were closely linked to their competence beliefs [4]. Although the participating female students expressed a desire to continue studying physics, two of the six did not enroll in physics courses at the beginning of college despite strong prior performance [4]. This discrepancy was attributed to environmental cues that made the students feel insufficiently intelligent or capable, even when their grades suggested otherwise [4]. In 2016, 165 students were surveyed using quantitative questionnaires. It was found that many girls perceived their performance in physics as inadequate for future success [35]. Some of the students used language indicating that they did not see themselves as fitting the image of a scientist, suggesting a lack of recognition and belonging—key components of identity development [35]. A study in 2017 confirmed these findings through an analysis of interviews and surveys with 16 female students, showing that doubts about competence and belonging were widespread [36]. In contrast, boys tended to interpret discontinuing physics as a matter of personal choice rather than a reflection of ability. This pattern indicates a more robust physics identity among male students, as they frame setbacks as situational rather than as evidence of personal inadequacy [36]. Importantly, the classroom experiences that shaped female students' self-confidence had a substantial impact on their identity development. Positive or negative interactions in physics lessons played a decisive role in whether students came to see themselves as capable of succeeding in the subject [4].

### 3. Social environment

As noted earlier, the social environment is defined in connection with a previously mentioned study [16]. Its authors describe the social environment using the concept of recognition and, in this context, mention teachers, parents, and peers [16]. We endorse this approach.

A longitudinal study involving six female students over 3 years examined sense of belonging, interest and self-concept in physics, and value and success expectations [4]. The findings show that the way the social environment treats female students significantly influences the development of their physics identity [4]. Even when teachers actively attempt to foster positive identity development, structural inequalities and social disparities can still hinder female students from pursuing physics pathways [37].

During a 2-week preparatory program for 146 female students taking an introductory course in physics, the students were interviewed regularly [15]. Their results highlight the central role of teachers and classmates. In one case, a teacher who did not personally expect a student to continue in physics nevertheless conveyed encouragement and support. This positive recognition strengthened the student's sense of competence and contributed to her continued engagement in physics [15,38]. Such findings underscore the importance of teachers responding to individual needs and ensuring that no student is left behind [4]. Conversely, two of the six girls in the study mentioned above reported negative classroom experiences, which hindered their science identity development and reduced their perceived competence [4].

Researchers in a study in 2020 found that many of the 16 female students in their study described physicists using terms such as "masculine" and "effortlessly smart" [36]. These stereotypical images contributed to feelings of not fitting in and reduced confidence. The authors argue that such perceptions may lead girls to disengage or fail courses, even when they are academically capable [36]. Despite achieving strong A-level results comparable to male students, many girls had developed a weaker physics identity over time [36]. Their responses suggested that they did not see themselves reflected in the typical image of a physicist and therefore ruled out physics careers [36]. Notably, a female student succeeded in physics despite her teacher's initial doubts, as she received positive recognition from those around her. This particularity was documented in a study in 2018 [15]. The broader social environment also plays a decisive role. A study in the German Physics Olympiad 2015 found that girls developed a more positive physics identity when they received recognition from their surroundings [39]. A large-scale study in England involving 2049 parents further demonstrated the strong influence of parental expectations: when parents could imagine their children in a physics-related career, the children were significantly more likely to express similar aspirations [38]. These findings suggest that targeted parental guidance could positively influence subject choices [38]. Negative attitudes toward physics among female students can be traced not only to teachers but also to the broader social community in which children grow up [36]. A study involving 298 girls who participated in weekend seminars confirmed this pattern [40]. The girls reported feeling that they did not belong in physics, even when they were already part of physics-related programs [39]. The authors conclude that these students were not given sufficient opportunities to demonstrate their abilities, which limited their sense of belonging and hindered identity development [39]. Finally, the pedagogical experiences shaping students' views are influenced by multiple institutions—primary schools, secondary schools, and the various teachers they encounter. These institutional contexts collectively shape identity development and students' sense of belonging in physics [36,39].

### 4. Identification as a scientist

In a study with 298 participants (28% female), no gender differences were observed in the first three surveys regarding sense of belonging [40]. However, by the fourth survey, female participants reported a significantly lower sense of belonging than their male peers [39]. Sense of belonging is a crucial predictor of later career intentions, academic effort, and ultimately study choices [39]. The decline among female students appears to be linked to male-dominated environments, which activate negative gender stereotypes and undermine identification with science [39]. Researchers found that female students—regardless of whether they had taken physics courses—tended to describe scientists with adjectives such as masculine, "strange," and "intelligent" [36]. Physics itself was perceived as a male-dominated field, and while male students could partially identify with these descriptors, female students did not see themselves reflected in them [35,36]. Even when female students expressed positive attitudes toward science, they struggled to imagine themselves pursuing scientific careers [35].

The 16 female participants in a study in 2020 reported feeling that success in physics required exceptional effort and constant hard work, whereas male students were perceived as achieving success with comparatively less effort simply because they were male [36]. This perception contributed to many girls underestimating their own intelligence and capabilities [36]. Overall, the image of a physicist emerged as predominantly male and inherently intelligent—an image that many female students felt excluded from Ref. [36]. These perceptions were formed partly during adolescence and partly reinforced over several years into adulthood [36].

### 5. Specific interventions

As already mentioned in the section on the theoretical framework, research on the development of physics

identity shows that this development is a process that is constantly changing. Since this change arises from interest, self-confidence, the social environment, and identification as a scientist, a connection to specific interventions is obvious. Certain programs can motivate female students and thus influence the development of their physics identity [29,39]. The third research question focuses more strongly on the topic of interventions.

### B. Research question 2

How can teachers use the factors influencing physics identity to improve the situation of female students?

The following categories, "teachers' recognition" and "equality in group work," emerged as influencing the female students' physics identity and situation:

#### *1. Teachers' recognition*

Interviews with 208 students aged 13–18 years revealed that female students were disadvantaged in physics, chemistry, and engineering, which resulted in very low motivation for these subjects [41]. One central reason for this disadvantage is that female students receive less autonomy support from teachers in their daily classroom experiences compared to male students [41]. When teachers provided stronger autonomy support, students—especially girls—showed higher levels of verbal participation in class [41]. A study conducted in 2013 confirms that cognitively and motivationally strong students participate more frequently and for longer periods during lessons [42]. This pattern held for both male and female students, contradicting earlier assumptions that boys participate more simply because of gender [42]. When students were identified as cognitively and motivationally strong, they were more likely to engage verbally in class discussions. Thus, teacher support for autonomy and recognition of students' strengths can significantly increase engagement and motivation in physics [41,42]. Another study also showed that teachers' recognition and confidence in students' abilities strengthened students' own confidence in dealing with physics content [4]. The authors emphasize that educators must be aware that some students are particularly vulnerable to societal messages about group-based differences in ability and performance [31]. To counteract these effects, teachers should actively reassure female students of their competence [42]. Even brief affirmations during exam situations can improve female students' emotional state and lead to better performance outcomes [42].

#### *2. Equality in group work*

Researchers surveyed 26 boys and 34 girls across eight schools in a study in 2020 and found that female students expressed a clear desire for greater equality during group work [43]. Analysis of student conversations revealed that girls often felt marginalized in mixed-gender groups and wished for more balanced participation [43]. When groups were thoughtfully composed, students showed higher motivation to contribute to discussions and to engage in the development of results [43]. Teacher-assigned group placement also played a decisive role in shaping female students' motivation, particularly when they were placed in groups that were actively engaged in physics lessons [42]. Participation in same-sex versus mixed-gender courses had only a minor effect on female students' motivation [43]. Nevertheless, the findings suggest that teachers must create structures that allow disadvantaged female students to participate more fully in collaborative work. This includes designing group tasks and roles that ensure equitable involvement and prevent dominant group members from overshadowing others [43]. Female students also reported that they value group work as an opportunity for communication and shared problem-solving [35]. Through collaborative exchanges, they were able to recognize connections between their own interests and physics content, which in turn increased their motivation to engage with the subject [35].

### C. Research question 3

In what ways can specific physics programs for female students improve their situation in physics?

The following analysis categories could be established for the included studies: specific interventions, overcoming prejudices, self-efficacy, and further results.

#### *1. Specific interventions*

Several studies demonstrate that programs tailored specifically to female students can enhance motivation and support the development of a positive physics identity [29,39]. A study in 2014 and another study in 2018 show that targeted interventions increase girls' engagement and interest in physics [29,39]. In a qualitative evaluation of questionnaires from 30 female participants in a physics competition, all students reported higher motivation when they were provided with a safe learning environment and when their participation was actively supported [39]. These findings highlight the importance of creating protected spaces in which girls can explore physics without fear of judgment.

#### *2. Overcome prejudices*

Research indicates that many female students have limited familiarity with physics as a scientific discipline [35]. Using a 15-item Likert scale (0–4), the authors found statistically significant gender differences based on a Mann–Whitney–Wilcoxon test [35]. For example, the statements "I like to learn how things work" and "Science is one of my favorite subjects this school year" yielded mean scores of $M(\text{girls}) = 2.72$ vs $M(\text{boys}) = 2.98$ and $M(\text{girls}) = 2.27$ vs $M(\text{boys}) = 2.55$,

respectively [35]. These differences appear to be shaped by gender stereotypes that discourage girls from identifying with physics. However, targeted interventions can counteract these stereotypes. In a study of 30 female participants in a physics competition, students rated their liking of physics at an average of 3.66 (SD = 0.35) on a five-point scale, indicating substantial interest and openness toward physics careers [39]. Similarly, in a study with 925 students, 174 girls participated in a 2-week camp involving 10 physics modules [44]. Working in a protected environment where questions were encouraged and mistakes accepted, the girls developed greater confidence and showed improved engagement [44]. These findings suggest that safe, supportive learning environments help female students overcome personal prejudices and prejudices in their environment and develop a more positive view of physics.

#### 3. Self-efficacy

A recent study surveyed 200 male and female students before, during, and after a weekend workshop designed to examine girls' skills and self-efficacy [45]. Results showed significant increases in self-efficacy for all participants, with female students demonstrating comparatively larger gains than the boys [45]. Interestingly, students also reported improved confidence in mathematics, even though the workshop did not include math instruction [45]. Another study found that after a 4-week program allowing students to work independently, their perceptions of careers in physics and biology changed markedly [46]. Students recognized overlaps between the two fields, which sparked greater interest and broadened their career aspirations [46].

#### 4. Further results

In contrast to the studies above, an investigation related to the Physics Olympiad and conducted in 2021 found no gender-specific differences in expectations of success or appreciation of physics [47]. This study, involving 298 participants (28% female), showed that female participants were not negatively affected by stereotype threat or threats to social identity regarding their sense of belonging or gender identification [47]. These findings suggest that in highly selective or self-selected groups—such as Olympiad participants—gender disparities may be less pronounced (Fig. 3).

## VI. DISCUSSION

### A. Merging of the main results

The results of 22 studies were used to answer the research questions. If these are summarized, a clear picture emerges: The situation of female students in physics and especially in the school learning environment is complex. A popular model was developed during a study in 2010 [16]. It provides an excellent systematization of this

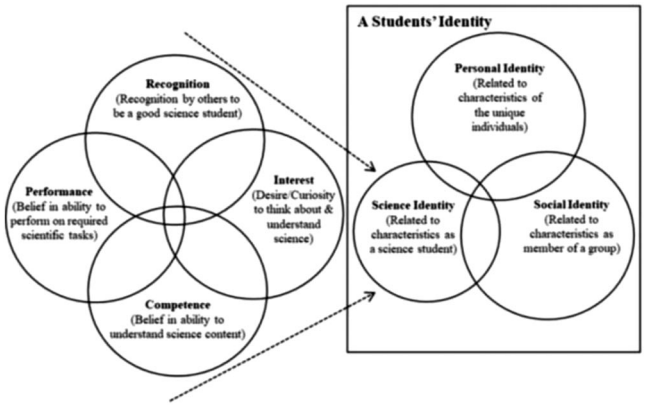



FIG. 3. Framework for students' identification with physics [16].

complex structure and is well suited to structure this discussion section, and it consists of the following elements: performance, competence, interest, and recognition. In addition, this section will discuss a refinement of the physics identity model to include the areas of social environment, teachers, and interventions.

#### 1. Performance

One of the most influential components of physics identity is performance. When female students experience success in physics, this strengthens their motivation and encourages further engagement with the subject. Such positive performance experiences can be supported through targeted interventions, which provide structured opportunities for success and reinforce students' sense of competence. Importantly, performance is never an isolated construct; it is shaped by the social environment, teachers, and interventions. Parents, for example, differ in the extent to which they believe their children can succeed in specific subjects. When parents express confidence in their daughters' abilities in physics, these students are more likely to perform well and to view themselves as capable in the subject [38]. However, parental expectations are often influenced by gendered assumptions, which can limit girls' opportunities to develop a strong physics identity. Early and informed parental counseling may help counteract these biases. Teachers and school institutions also play a decisive role in shaping how female students interpret their performance. When teachers communicate high expectations and provide recognition for students' achievements, they reinforce positive self-perceptions and support identity development. Conversely, environments that implicitly or explicitly question girls' abilities undermine their confidence, even when their performance is strong. Ultimately, the more positively the image of a physicist is presented within a student's social environment, the more easily female students can envision themselves in this role and develop a robust physics identity.

### 2. Competence

Motivation—understood as related to competence—is another central factor influencing the development of physics identity. According to SDT, competence as one of three universal psychological needs is essential for fostering high-quality motivation [18]. Students' motivation is shaped by their everyday classroom experiences; it fluctuates in response to the learning environment. As the findings of this review show, female students' motivation to engage with physics is strongly influenced by three contextual domains: their social environment, teachers, and interventions. When female students experience high motivation, they participate more actively in physics lessons. Positive classroom experiences reinforce their belief that they can understand physics content, thereby strengthening their competence beliefs [38]. These shifts in competence not only affect classroom engagement but also shape students' long-term career intentions in physics-related fields [41]. Teachers play a crucial role in this process. By supporting students' autonomy—responding to their needs, designing equitable group work, and integrating targeted interventions—teachers can create conditions that foster motivation. The design of group work is particularly important, as interpersonal relationships are central to identity development for many female students [39]. Higher motivation was associated with a greater readiness to pursue physics careers, illustrating the close connection between motivation and physics identity development [39]. Teachers' appreciation of students' performance and explicit confidence in their abilities further enhance motivation [4]. At the same time, female students are highly sensitive to biases and social expectations communicated by their environment [39]. It was demonstrated that subjective experiences—how students feel in learning situations—are among the strongest predictors of motivation and engagement [41]. Social context therefore plays a decisive role in shaping girls' motivation in physics [4]. It was shown that emotionally arousing information can heighten attention and create lasting memories [4]. Pedagogically, this suggests that teachers can challenge students' reasoning through high-arousal, counterintuitive examples that stimulate curiosity and engagement [4].

### 3. Interest

Interest constitutes a third major factor influencing the development of physics identity. A strong interest in physics supports a more positive identity trajectory and, similar to competence and motivation, is shaped by the social environment, teachers, and interventions.

Parents and friends play a significant role in shaping girls' interest in physics. Their encouragement can help female students develop a positive attitude toward the subject and motivate them to explore physics more deeply [4,38]. Interventions also offer effective ways to increase interest. Through hands-on activities, supportive learning environments, and opportunities to overcome personal prejudices, interventions enable female students to reshape their self-perceptions and develop curiosity about physics [45]. Teacher autonomy support within these programs further strengthens interest by validating students' engagement and fostering a sense of agency [39]. Although some studies found that interventions benefit male and female students equally, the positive effects on girls remain clear [47]. This suggests that interventions do not need to be exclusively gender-targeted to support female students' interests; rather, well-designed programs can benefit all learners while still addressing the specific needs of girls.

### 4. Recognition

Recognition plays a decisive role in the development of physics identity [38]. How students believe others perceive them strongly shapes how they perceive themselves, and these self-perceptions influence subsequent decisions and aspirations [38]. Recognition is conveyed by the people who interact with female students on a daily basis: their social environment, teachers, and individuals involved in interventions. Parents exert substantial influence on whether girls feel capable of succeeding in physics. When parents believe their daughters can perform well, the students are more likely to internalize this belief and act accordingly. The findings related to Research Question 2 highlight the specific importance of teacher recognition. Teachers' expectations, feedback, and expressions of confidence directly affect students' self-efficacy and their willingness to engage with physics content. The findings related to Research Question 3 emphasize the role of recognition within interventions. In these settings, mentors, instructors, and peers provide additional sources of validation that can strengthen girls' sense of belonging and competence. Together, these forms of recognition create a social environment in which female students can develop a more robust and positive physics identity.

### 5. Refinement of the physics identity model

The model of physics identity provides a foundational framework for understanding how students come to see themselves as physics people. In this model, physics identity is conceptualized as part of a person's broader identity system, shaped through the interaction of personal identity, social identity, and disciplinary identity. The present review affirms this perspective but argues for a more explicit differentiation of the contextual factors that influence the four core components of the model—recognition, performance, interest, and competence. Four constructs were identified as central to physics identity, but the model does not explicitly specify which groups of people or which environmental structures shape them [16]. Yet the empirical studies synthesized in this review consistently demonstrate that the social environment,

teachers, and targeted interventions exert substantial influence on each of these components. For this reason, the authors propose an expanded version of the model that integrates these contextual domains more explicitly. In the original formulation, "performance" refers to a student's belief in their ability to understand physics [16]. The review supports this interpretation but highlights that performance is not experienced in isolation. Rather, it is continuously mediated by feedback from teachers, peers, and family members. Positive performance is often accompanied by positive recognition from these groups, reinforcing competence beliefs and strengthening identity. Conversely, even strong performance may fail to translate into a positive physics identity when the social environment communicates doubt or low expectations. This dynamic underscores the need to situate performance within the broader ecology of students' lived experiences. Similarly, the construct of "recognition" is not defined in detail in the original model, yet the review findings show that recognition is deeply relational. It emerges through interactions between students and the people around them—teachers who express confidence in their abilities, parents who encourage scientific curiosity, peers who validate their interest, and mentors who provide opportunities for meaningful engagement. The text of Hazari *et al.* supports this interpretation: it is important how other people see a student, and this influences how a student sees him or herself [16]. These examples clearly position recognition within the domain of the social environment, suggesting that this dimension should be explicitly represented in the model. The review also shows that teachers play a central role in shaping all four identity components. It is confirmed that high school is a critical period in which teachers and classroom environments strongly influence students' impressions of physics [16]. The studies included in this review reinforce this point: teacher autonomy support increases participation, teacher recognition strengthens self-efficacy, and teacher expectations shape students' sense of belonging. These findings justify the inclusion of "teachers" as a distinct contextual factor in the refined model. Finally, the review highlights the importance of interventions, which were mentioned only briefly [16]. Interventions—whether camps, workshops, competitions, or preparatory courses—provide structured opportunities for students to experience competence, receive recognition, and develop interest in physics. Evidence from the reviewed studies shows that such programs can counteract negative stereotypes, enhance self-efficacy, and create safe environments for exploration. These insights support the argument that interventions should be explicitly integrated into the model as a mechanism for shaping identity development.

Taken together, the findings of this review suggest that the four core components of the model of Hazari *et al.*—recognition, performance, interest, and competence—are best understood as embedded within and shaped by the broader domains of the social environment, teachers, and interventions. By making these contextual influences explicit, the refined model provides a more comprehensive and actionable framework for understanding how physics identity develops and how it can be supported in educational practice.

### *6. Promising approaches for teachers and specific programs*

The findings of this review highlight several promising approaches that can support female students in developing a positive physics identity. These approaches emerge from two complementary areas: the everyday practices of teachers in physics classrooms and the design of targeted programs that create additional learning opportunities for girls. A central insight from the studies is that teachers play a decisive role in shaping girls' experiences and identity development in physics. Female students frequently receive less autonomy support than their male peers, which negatively affects their motivation and participation. When teachers actively foster autonomy—by encouraging independent thinking, valuing students' ideas, and providing space for exploration—girls demonstrate higher levels of verbal engagement and confidence. Teacher recognition also emerges as a powerful factor: when teachers express confidence in students' abilities, female students' self-efficacy increases, enabling them to approach physics tasks with greater assurance. Even brief affirmations during assessments can improve emotional states and performance, underscoring how sensitive identity development is to everyday interactions. Another promising approach lies in structuring group work more equitably. Female students repeatedly expressed a desire for fairer participation in collaborative settings. Thoughtfully composed groups, in which girls are not overshadowed by dominant peers, can enhance motivation and engagement. Group work also provides opportunities for communication and shared problem-solving—activities that help students connect their personal interests with physics content. When teachers design group structures that ensure balanced participation, they create learning environments in which girls can experience competence and recognition, both of which are essential for identity development. Beyond classroom practices, specific physics programs for female students offer additional avenues for strengthening physics identity. Interventions such as physics camps, competitions, weekend workshops, and preparatory courses create safe and supportive environments, where girls can explore physics without the pressure of stereotypes. These programs consistently show positive effects on motivation, interest, and self-efficacy. For example, girls participating in physics competitions or camps reported feeling more motivated when they were encouraged and supported in a protected environment.

Similarly, workshops designed to enhance scientific skills led to significant increases in self-efficacy, sometimes even extending to related domains such as mathematics. Importantly, these interventions also help girls overcome internalized prejudices about physics. Many female students initially report limited familiarity with physics or perceive it as a masculine domain. Targeted programs counteract these perceptions by offering hands-on experiences, exposure to female role models, and opportunities to ask questions freely. In such settings, girls begin to see themselves as capable of succeeding in physics and can imagine pursuing physics-related careers. Programs that emphasize the overlap between physics and other scientific fields, such as biology, further broaden students' understanding of potential career pathways. However, the review also shows that not all interventions produce gender-specific effects. In highly selective contexts, such as the Physics Olympiad, female participants did not differ from male participants in their expectations of success or sense of belonging. This suggests that interventions may be most effective for students who have not yet developed a strong physics identity or who face structural barriers in everyday classroom environments.

Taken together, the findings indicate that promising approaches combine everyday pedagogical practices with targeted programs. Teachers can foster autonomy, provide recognition, challenge stereotypes, and design equitable group work, while specific interventions can offer additional spaces for exploration and identity development.

## VII. LIMITATIONS

This review focuses exclusively on studies situated within school and classroom contexts. Research that could not be clearly classified within this educational setting was excluded. Nevertheless, the initial literature search made it evident that the situation of female students across the broader scientific landscape—beyond schools and teaching—is also highly challenging [1]. Additional inclusion and exclusion criteria were defined by the authors to determine the relevance of studies for this review. Article selection followed a rigorous and transparent protocol [33]. The thematic analysis was shaped by ongoing discussions among the authors, and the existing literature and the research questions guided the final selection of studies. A further limitation concerns the treatment of gender. This review adopts a binary classification of "female students" and "male students," reflecting the categorization used in all included studies. As discussed in the theoretical framework, this binary approach is itself problematic and raises important questions about how the findings might differ if gender diversity were considered more comprehensively. However, using a nonbinary framework would have made it impossible to synthesize the available research, as all included studies rely on binary gender categories. This highlights the need for future research to move beyond binary classifications and to incorporate a more inclusive understanding of gender diversity.

## VIII. RECOMMENDATIONS FOR SCHOOL PRACTICE AND FURTHER RESEARCH

Teachers exert a major influence on female students' experiences in physics lessons [4], which means that meaningful improvement can be achieved through targeted measures that support teachers in their daily practice. The findings of this review clearly show that the development of physics identity is central to transforming physics education for female students. To enable teachers to foster this development effectively, further knowledge is needed about how identity formation can be positively shaped in classroom contexts. Future research should therefore deepen the investigation of known influencing factors—such as the social environment, teacher behavior, and targeted interventions—and examine how these factors interact in shaping physics identity. At the same time, research should explore whether additional, yet unidentified, factors play a supportive role. Another important research direction concerns the design of systematic interventions. Since identity development unfolds over many years [4,35], it is crucial to understand which characteristics of interventions lead to long-term improvements in female students' engagement and confidence in physics. The more thoroughly these influencing factors are understood, the better future interventions and teaching units can be tailored to the needs of female students. For school practice, teachers need to be aware of these factors in order to adapt their teaching accordingly. The findings of this review suggest several concrete implications. First, students should be given more opportunities to solve problems independently, as this strengthens their confidence and supports the development of a positive physics identity [15]. Second, interventions should be integrated into everyday lessons rather than offered only as isolated activities, as continuous exposure increases their effectiveness. Third, teachers can actively shape students' perceptions of physicists by highlighting female role models and encouraging girls to see themselves as capable of succeeding in physics. This can contribute to a more positive and sustainable self-concept. Finally, well-structured group work can enhance motivation and interest among female students. Higher motivation, in turn, fosters greater participation and autonomy.

Ultimately, the broader societal and economic situation of women also requires improvement [1,2,22]. Schools alone cannot resolve these structural issues, but they can play a decisive role in counteracting stereotypes and opening pathways into physics for female students.

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[1] A. Y. Kim, G. M. Sinatra, and V. Seyranian, Developing a STEM identity among Young women: A social identity perspective, Rev. Educ. Res. **88**, 589 (2018).
[2] C. R. Fisher, C. D. Thompson, and R. H. Brookes, 95% of the time things have been okay: The experience of undergraduate students in science disciplines with higher female representation, Int. J. Sci. Educ. **42**, 1430 (2020).
[3] R. Henderson, V. Sawtelle, and J. M. Nissen, Gender & self-efficacy: A call to physics educators, Phys. Teach. **58**, 345 (2020).
[4] J. Wang, Z. Hazari, C. Cass, and R. Lock, Episodic memories and the longitudinal impact of high school physics on female students' physics identity, Int. J. Sci. Educ. **40**, 1543 (2018).
[5] M. Kaufman, E. Eschliman, and T. Sanchez Karver, Differentiating sex and gender in health research to achieve gender equity, Bull. W. H. O. **101**, 666 (2023).
[6] M. M. Lantz, R. L. Fix, B. L. Davis, L. N. Harrison, A. Oliver, C. Crowell, A. M. Mitchell, and J. J. García, Grad students talk: Development and process of a student-led social justice initiative, J. Diversity Higher Educ. **9**, 290 (2016).
[7] J. Butler, *Gender Trouble: Feminism and the Subversion of Identity (First Issued in Hardback)* (Taylor & Francis Group, Routledge, 2015).
[8] A. M. García and G. Slesaransky-Poe, The heteronormative classroom: Questioning and liberating practices, Teach. Educ. **45**, 244 (2010).
[9] G. Cochran, R. Bellwied, F. Geurts, R. Rapp, C. Ratti, A. Timmins, and I. Vitev, Demystifying and defending diversity, equity, and inclusion, in *EPJ Web of Conferences* (EDP Science, Les Ulis, France, 2024), Vol. 296, p. 01011, 10.1051/epjconf/202429601011.
[10] M. Boveda and B. A. Aronson, Special education preservice teachers, intersectional diversity, and the privileging of emerging professional identities, Remedial Spec. Educ. **40**, 248 (2019).
[11] A. Keddie, Student activism, sexual consent and gender justice: Enduring difficulties and tensions for schools, Aust. Educ. Res. **50**, 503 (2023).
[12] K. Crenshaw, Demarginalizing the intersection of race and sex: A black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics, University of Chicago Legal Forum **1989**, 139 (1989).
[13] Jón Ingvar Kjaran and H.(Hrsg) Sauntson, *Schools as Queer Transformative Spaces: Global Narratives on Sexualities and Genders* (Routledge, Milton Park (Abingdon UK), New York (USA), 2020).
[14] J. S. Brotman and F. M. Moore, Girls and science: A review of four themes in the science education literature, J. Res. Sci. Teach. **45**, 971 (2008).
[15] Z. Hazari and C. Cass, Towards meaningful physics recognition: What does this recognition actually look like?, Phys. Teach. **56**, 442 (2018).
[16] Z. Hazari, G. Sonnert, P. M. Sadler, and M.-C. Shanahan, Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study, J. Res. Sci. Teach. **47**, 978 (2010).
[17] H. B. Carlone and A. Johnson, Understanding the science experiences of successful women of color: Science identity as an analytic lens, J. Res. Sci. Teach. **44**, 1187 (2007).
[18] R. M. Ryan and E. L. Deci, Intrinsic and extrinsic motivations: Classic definitions and new definitions, Contemp. Educ. Psychol. **25**, 54 (2000).
[19] M. Ainley, S. Hidi, and D. Berndorff, Interest, learning, and the psychological processes that mediate their relationship, J. Educ. Psychol. **94**, 545 (2002).
[20] A. Bandura, Self-efficacy, Harvard Ment. Health Lett. **13**, 4 (1997) Academic Search Premier.
[21] J. M. Nissen, Gender differences in self-efficacy states in high school physics, Phys. Rev. Phys. Educ. Res. **15**, 013102 (2019).
[22] A. Decker and M. M. McGill, A systematic review exploring the differences in reported data for pre-college educational activities for computer science, engineering, and other STEM disciplines, Educ. Sci. **9**, 69 (2019).
[23] R. D. Robnett and S. E. Thoman, STEM success expectancies and achievement among women in STEM majors, J. Appl. Dev. Psychol. **52**, 91 (2017).
[24] A. Bandura, C. Barbaranelli, G. V. Caprara, and C. Pastorelli, Self-efficacy beliefs as shapers of children's aspirations and career trajectories, Child Dev. **72**, 187 (2001).
[25] P. Murphy and E. Whitelegg, Girls in the physics classroom (2006).
[26] N. A. Fouad, G. Hackett, P. L. Smith, N. Kantamneni, M. Fitzpatrick, S. Haag, and D. Spencer, Barriers and supports for continuing in mathematics and science: Gender and educational level differences, J. Vocational Behav. **77**, 361 (2010).
[27] M. Gottfried, A. Owens, D. Williams, H. Y. Kim, and M. Musto, Friends and family: A literature review on how high school social groups influence advanced math and science coursetaking, Educ. Policy Anal. Arch. **25**, 62 (2017).
[28] R. M. Lock and Z. Hazari, Discussing underrepresentation as a means to facilitating female students' physics identity development, Phys. Rev. Phys. Educ. Res. **12**, 020101 (2016).
[29] T. Mujtaba and M. J. Reiss, A survey of psychological motivational family and perceptions of physics education factors that explain 15-year-old students' aspiration to study physics in post-compulsory english schools, Int. J Sci. Math. Educ. **12**, 371 (2014).
[30] E. Prieto-Rodriguez, K. Sincock, and K. Blackmore, STEM initiatives matter: Results from a systematic review of secondary school interventions for girls, Int. J. Sci. Educ. **42**, 1144 (2020).
[31] A. van den Hurk, M. Meelissen, and A. van Langen, Interventions in education to prevent STEM pipeline leakage, Int. J. Sci. Educ. **41**, 150 (2019).
[32] E. Q. Rosenzweig and A. Wigfield, STEM motivation interventions for adolescents: A promising start, but further to go, Educ. Psychol. **51**, 146 (2016).
[33] M. J. Page, J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M. M. Lalu, T. Li, E. W. Loder, E. Mayo-Wilson, S. McDonald, and D. Moher,

The PRISMA. 2020 statement: An updated guideline for reporting systematic reviews, BMJ **372**, n71 (2021).
[34] https://www.equip.ninja
[35] E. A. Dare and G. H. Roehrig, If I had to do it, then I would": Understanding early middle school students' perceptions of physics and physics-related careers by gender, Phys. Rev. Phys. Educ. Res. **12**, 020117 (2016).
[36] L. Archer, J. Moote, and E. MacLeod, Learning that physics is not for me: Pedagogic work and the cultivation of habitus among advanced level physics students, J. Learn. Sci. **29**, 347 (2020).
[37] L. Archer, J. Moote, B. Francis, J. DeWitt, and L. Yeomans, The "Exceptional" physics girl: A sociological analysis of multimethod data from young women aged 10-16 to explore gendered patterns of Post-16 participation, Am. Educ. Res. J. **54**, 88 (2016).
[38] K. L. Jones and J. M. M. Hamer, Examining the relationship between parent/carer's attitudes, beliefs and their child's future participation in physics, Int. J. Sci. Educ. **44**, 201 (2022).
[39] P. Wulff, Z. Hazari, S. Petersen, and K. Neumann, Engaging young women in physics: An intervention to support young women's physics identity development, Phys. Rev. Phys. Educ. Res. **14**, 020113 (2018).
[40] A. Ladewig, M. Keller, and U. Klusmann, Sense of belonging as an important factor in the pursuit of physics: Does it also matter for female participants of the German physics Olympiad?, Front. Psychol. **11**, 548781 (2020).
[41] E. A. Patall, R. R. Steingut, J. L. Freeman, K. A. Pituch, and A. C. Vasquez, Gender disparities in students' motivational experiences in high school science classrooms, Sci. Educ. **102**, 951 (2018).
[42] V. Jurik, A. Gröschner, and T. Seidel, How student characteristics affect girls' and boys' verbal engagement in physics instruction, Learn. Instr. **23**, 33 (2013).
[43] N. Shah, J. A. Christensen, N. A. Ortiz, A.-K. Nguyen, S. Byun, D. Stroupe, and D. L. Reinholz, Racial hierarchy and masculine space: Participatory in/equity in computational physics classrooms, Comput. Sci. Educ. **30**, 254 (2020).
[44] E. Lawton, C. Obenland, C. Barr, M. Cushing, and C. Nichol, Improving high school physics outcomes for young women, Phys. Rev. Phys. Educ. Res. **17**, 010111 (2021).
[45] J. Durk, A. Davies, R. Hughes, and L. Jardine-Wright, Impact of an active learning physics workshop on secondary school students' self-efficacy and ability, Phys. Rev. Phys. Educ. Res. **16**, 020126 (2020).
[46] L. Ward, S. Lyden, N. Fitzallen, and B. León de la Barra, Using engineering activities to engage middle school students in physics and biology, Australas. J. Eng. Educ. **20**, 145 (2015).
[47] A. Ladewig, O. Köller, and K. Neumann, Persisting in physics and the physics Olympiad—impact of gender identification and sense of belonging on expectancy-value outcomes, Eur. J. Psychol. Educ. **38**, 435 (2022).