

Students' types of interest in physics: A mixed Rasch model investigation

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Promoting students' interest in physics is a key goal of physics education. Describing students' types of interest provides a great opportunity to offer practical and gender-independent recommendations to teachers for designing interesting learning activities. We investigated students' types of interest in physics and their association with different student characteristics in a cross-cohort study involving German-speaking students aged 14–16 years ($N = 1219$). We assessed the students' interest in a classical and a modern physics content area, namely, mechanics and particle physics, as well as different student characteristics, such as physics-related self-concept. The collected data on students' interest was analyzed using mixed Rasch models to unveil qualitative differences in the assessed constructs between different groups of students. The study showed that the vast majority of students (71%) can be categorized into one single type of interest in both content areas. Students of this first interest type were only interested in physics content set in certain contexts, for example, the context “one's own body.” The second type of interest was specific to the different content areas. Students of the second interest type had relatively high physics-related self-concept and were interested in physics content, even when set in scientific or technical contexts. Whether students belong to one or the other type of interest was best described with a model comprising their degree of physics-related self-concept and their sex. Finally, we introduced the hierarchy of students' levels of interest in physics (HOLIP) to describe the relative interestingness of different contexts for the first type of interest (i.e., the vast majority of students). We recommend using the HOLIP as a guideline for designing learning activities that promote interest in physics.

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I. INTRODUCTION

Fostering interest in physics plays an important role in national and international physics education standards [1,2]. Empirical research has shown that interest is positively associated with persistence and achievement while engaging with an object of interest [3–5]. Moreover, an increasing number of jobs related to physics are facing a decreasing number of students aspiring to a career in physics [6–8]. Students' interest in physics has been argued and found to be crucial for their course and career choices [9–11]. Finally, today's society needs scientifically literate citizens to be able to make educated and critical decisions in life, considering, for example, ecological and

societal problems related to climate change [12]. Students' interest in science has been included in definitions and discussions about scientific literacy [13,14]. Although educators invest various efforts in making physics more interesting, students' interest in physics decreases over time [15–17]. Physics education researchers have also examined the characteristics of students that correlate with their interest in physics, such as age, gender, achievement, and physics-related self-concept (SC) [5,14,17–23]. However, past empirical studies mainly described students' interest in physics in terms of categories of interesting content and contexts and focused on differences between female and male students.

In the “IPN Interessensstudie Physik,” an important study on interest in physics, conducted by the Leibniz Institute for Science and Mathematics Education (IPN) at the University of Kiel, students' physics interest profiles were used to categorize them into different types of interest in physics [17,19,24–28]. Three types were distinguished, but across publications of the IPN study, these types are presented in different versions. The earlier publications [17,19,24,25] were based on initial data analyses and led to the distinction of three types: students generally and highly

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interested in physics (type A), students especially interested in applications of physics (type B), and students especially interested in physics set in contexts related to nature, humans, and society (type C). Their latest, not widely known, publications [26–28] were based on re-analyses of the data by Sievers [28], resulting in the types A, C, and NG. While type A is consistent with the earlier analyses, type C represents a combination of the initially claimed types B and C. The third type, NG, comprises students whose profiles resemble either type A or C depending on the content area. The defining characteristic of this type was not a unique interest profile but a specific response style: students predominantly used the extreme categories of the rating scale, which resulted in disordered (German: “nicht geordnet”, NG) thresholds between the rating-scale categories [26–28]. Describing students’ types of interest provides a great opportunity to offer practical and gender-independent recommendations to teachers for designing interesting learning activities. Yet, although more recent research projects (e.g., [29,30]) have also distinguished everyday-life contexts from others, such as scientific contexts, the findings of the IPN study have not been refined or verified in a follow-up study. Past empirical research on interest in physics has not covered modern physics content, such as particle physics. Moreover, the IPN study did not describe how interesting different contexts are relative to each other within the students’ different types of interest. In addition, when describing the interest types, the focus of the IPN study was on the students’ gender and only to a lesser extent on other student characteristics, such as physics-related self-concept. Nevertheless, the research approach (i.e., longitudinal and cross-cohort study), analysis method (i.e., mixed Rasch models), and results (i.e., students’ types of interest in physics) of the IPN study were unique for physics education research and yield great practical relevance as they provide gender-independent recommendations to teachers for designing interesting learning activities.

This research project investigates students’ types of interest by considering both a classical and a modern physics content area, along with other relevant student characteristics. The focus is on grade 9 students, as by this stage students typically have already had to make a conscious decision either in favor of or against a school pathway focusing on the natural sciences. Examining their interest in physics after such a decision may yield particularly valuable insights for designing interesting learning activities. This focus also aligns with other large-scale studies, such as the PISA, the “Relevance of Science Education” study (ROSE), and the cross-cohort section of the IPN study [17,22,31,32], enabling direct comparison with their results.

First, we defined students’ interest in physics and identified associated characteristics (see Sec. II).

Second, based on previous research, we selected one classical and one modern physics content area. Our aim was to compare a classical physics content area that students are well familiar with and a rarely encountered modern physics content area. Mechanics was chosen because by grade 9, students have typically already learned about mechanics in school. Additionally, as one of the first physics content areas covered in school, we consider mechanics to play a key role in shaping students’ interest and physics-related self-concept [33]. Particle physics was selected as a contrasting content area, which is rarely taught before grade 11, and thus likely unfamiliar to most students. However, previous studies indicate high student interest in closely related content areas. For example, the IPN study found no gender differences in interest for nuclear physics and decreasing gender differences for radioactivity with age, suggesting that particle physics as a closely related content area may also be equally interesting for all students [17].

Third, we chose appropriate instruments to measure students’ interest and associated characteristics. To measure students’ interest, we used the IPN approach, combining an introductory text for each content area with corresponding interest items [17]. This approach is also well suited to mitigate students’ potential lack of prior knowledge of content areas, such as particle physics, with which most students likely have little experience in school or only through extracurricular out-of-school activities. For mechanics, we used the original instrument from the IPN study. Since particle physics was not included in the original IPN study, we developed and validated a new instrument to measure particle physics interest (IPPI) based on the IPN item category descriptions in our first study [34]. Combining the new IPPI with the existing mechanics interest instrument from the IPN study allowed us to test whether the original IPN findings can be replicated with today’s students and whether they can be extended to the content area “particle physics.” In our first study, we additionally introduced a preliminary version of the hierarchy of students’ levels of interest in physics (HOLIP), a three-level framework describing the contexts in which physics content is perceived as more or less interesting (see Sec. II B; Ref. [34]).

In this paper, we describe the main study of our research project, a cross-cohort study with 1219 German-speaking students aged 14–16 years from Austria, Switzerland, and Germany. Using mixed Rasch model analyses, we developed a typology of students’ interest in physics and examined whether the HOLIP, originally developed for particle physics, can be confirmed with a large sample and additionally be applied to interest types in both mechanics and particle physics, thereby strengthening the framework’s external validity. This tool is intended to aid teachers in designing interesting learning activities.

We formulated three research questions (RQ) to guide our study:

RQ1: Into which different types of interest in physics can German-speaking students aged 14–16 years be categorized while comparing a classical and a modern physics content area (namely, mechanics and particle physics)?

RQ2: To what extent can students' types of interest be described in terms of the HOLIP?

RQ3: To what extent is physics-related self-concept a better independent variable than gender for distinguishing between the different types of interest in mechanics and in particle physics?

II. THEORETICAL AND EMPIRICAL BACKGROUND

A. Structure and development of interest

The person-object theory of interest [35,36] is a well-established theory of interest in physics education research, describing the relationship between a person (e.g., a learner) and an object of interest. The term “object of interest” refers to an aspect of the cognitively represented environment [37]. When examining students' interests, several objects of interest can be relevant for education researchers, e.g., interest in a discipline, a school subject, a content, a context, or a task. A Delphi study carried out in the framework of the IPN interest study can be regarded as an important contribution to theory formation. In this study, three different dimensions that characterize learning activities were defined: (1) the content (e.g., buoyancy), (2) the context (e.g., swimming), and (3) the task (e.g., carrying out an experiment) of a learning activity. These dimensions were also taken up in more recent studies (e.g., [38]), and some studies added a fourth dimension, namely, (4) learning environments (e.g., school or leisure time; [39,40]). In addition to investigating interest in learning activities, education research also looks at subject interest, which more generally describes interest in a school subject (e.g., physics).

While individual interest describes a long-lasting and relatively stable personality trait, situational interest refers to the interest generated by the interesting design of a learning activity. Krapp and Prenzel [37] introduce the term “operating interest” to describe the psychological state of being interested in a learning activity, which can be experienced due to an existing individual interest and/or due to a triggered situational interest. Interest that is experienced due to an existing individual interest is also referred to as “actualized individual interest” [41].

Both individual and situational interests can be described as multidimensional constructs comprising three components [37,42]: (1) The emotional component refers to the positive feelings that a learner associates with an object. At the beginning of a student's interest development, these feelings can also be negative. (2) The value-related component refers to the personal relevance and

significance of an object for the learner. (3) The cognitive-epistemic component refers to the desire to understand an object better, to learn more about it, and to know more about it.

How situational interest can develop into individual interest is commonly described using the “four-phase model of interest development” by Hidi and Renninger [43]. First, interest can be triggered in a situation (“triggered situational interest,” cf. “catch” in Ref. [44]), whereby the emotional component of interest prevails. This means that students experience interest in the form of positive or negative feelings triggered by the interesting design of a learning activity. In the further course of interest development (“maintained situational interest,” cf. “hold” in Ref. [44]), students begin to recognize personal value on the basis of preexisting positive feelings (i.e., the value-related component of interest becomes more important). In the third and fourth phases of interest development (“emerging” and “well-developed individual interest”), the cognitive-epistemic component gains in importance. This means that students engage with an object of interest even without external stimuli (e.g., interesting design of a learning activity) to learn more about it.

In overview articles on learners' interest in science (e.g., [45]), motivation theories also play a role alongside the interest construct. For example, the self-determination theory of motivation by Deci and Ryan [46,47] describes the three basic psychological needs (experiencing autonomy, competence, and relatedness) as a prerequisite for the development of intrinsic motivation, while one of the regulatory processes relevant for intrinsic motivation is interest [48,49]. Indeed, prior research empirically demonstrates the importance of the basic psychological needs for intrinsic motivation to emerge and for situational and individual interests to develop and maintain [50].

The aim of our research project is to give recommendations for triggering situational interest through the design of learning activities, with a focus on embedding content into interesting contexts. In doing so, students' individual interests may also be actualized.

B. Promoting interest by contextualizing learning activities

The importance of contexts for promoting students' interest in learning activities has been demonstrated in various studies, for example, in the IPN study [17], the ROSE [23], and the PISA 2006 study [29].

The term “context” is not consensually defined in science education research. According to Parchmann *et al.* [51], the term context is often used to refer to the thematic embedding of a learning activity (e.g., linking a learning activity to topics with personal or social relevance) but also to the learning environment (e.g., the classroom or museum as a context). In this article, the term context is used exclusively in the former sense. Contexts can be

real-life situations or applications for which the respective content is relevant [17,52]. However, the term context can also refer to the “storyline” of a learning activity [53], that is, the story or plot on which a learning activity is based. This is in line with the PISA 2006 study, in which contexts are defined as “life situations that involve science and technology” (p. 25) [14]. For example, the content “effect of x-rays” in physics instruction can be embedded in a variety of contexts, such as medicine (e.g., x-rays for diagnostics), health (e.g., irradiation of food for preservation), or technology (e.g., airport security). In some cases, it is difficult to distinguish between content and context. Häußler *et al.* [54] argue that, when comparing the natural science domains, it is more difficult to make such a distinction in biology than in chemistry or physics. For example, when talking about human biology, the context “human body” is inherent. In chemistry education research, a research group compared the situational interest for the same content embedded in different contexts and for different contents embedded in the same context [55–57]. They showed that the effects of a context on interest are more distinct if it can be distinguished clearly from the content [55,56]. Moreover, they found that the positive effect of a context on interest is higher the less interesting the content itself is [55,56]. The focus on contexts is also supported by Blankenburg *et al.*, who showed that students with high interest in a given context tend to be interested in all activities embedded in this context [58].

When analyzing students’ interest in learning activities, previous studies recommend specific topics that are particularly interesting and can serve as contexts. In our first study [34], we developed the HOLIP, a three-level framework for students’ interest in particle physics, which describes how interesting different contexts for embedding physics content are relative to each other. This framework aligns closely with findings from other previous studies and was developed in two steps. First, the HOLIP was conceptually hypothesized based on prior empirical findings and theoretical considerations of students’ interest in physics [34]. Second, it was empirically evaluated using Rasch analysis by examining item measures and item wording. Based on the observed item difficulty hierarchy, the HOLIP was subsequently revised [34].

The contexts that are very interesting for most students, regardless of their gender, fall into three broad categories, characterizing the level of focused interest:

- (1) Personal relevance: link to the human body (IPN [17]), “health and youth” and “young body” (ROSE [59,60]), and “bodily functions” and “damage to the body” (ROSE [61])
- (2) Societal relevance (“socio-scientific issues”): humans and the environment (“sustainability,” “greenhouse effect,” “ozone layer,” and “saving energy and using it efficiently,” ROSE [61]); “traffic safety

and accidents” [62], “smuggled arms” [34], “diseases and epidemics” (ROSE [61]; PISA 2015 [22]); and “medical diagnostics” [34]

- (3) Natural phenomena, Earth, and space (“existential questions of humankind”): natural phenomena: “rainbow” and “blue sky” (ROSE [61]), “colors of the sky” and “formation of clouds and precipitation” [63]; space: “Big Bang” [34], “possibility of life outside Earth” (ROSE [23]), “stars” (ROSE [61]), and “the universe and its history” (PISA 2015 [22])

The level of open interest includes students who are additionally interested in physics set in the broader context of everyday life, for example, “devices that detect particles (e.g., digital camera)” in our first study [34] or items falling into the category “practical use, everyday relevance” in the ROSE study [59].

Finally, the level of broad interest refers to being interested in physics even when it is set in a technical context, for example, “particle accelerators in electronics industry” [34], or in a scientific context. In this study, “scientific context” means that the item presents particle physics solely as a scientific content area or as a scientific endeavor.

C. Selected characteristics of a person associated with interest

Both the theoretical and empirical literature show that students’ interest in physics is intertwined with a broad range of desired educational outcomes, such as physics-related self-concept, achievement, and course and career choices. Many studies have linked learners’ other characteristics to the development of interest. For example, sex or gender and physics-related self-concept or identity are discussed below in more detail as relevant characteristics. These findings offer insights for designing learning activities tailored to specific learner groups with similar characteristics or for implementing differentiated instruction in heterogeneous classrooms.

1. Sex and gender

Many studies have analyzed the relationship between sex or gender and interest. Commonly, the term “sex” refers to the physiological/bodily aspects, whereas the term “gender” refers to the social and behavioral aspects of a person’s identity [64,65]. The terms may be confused and used interchangeably in English. Similarly, they may be translated to the same word in other languages (e.g., in German, “Geschlecht”). Consequently, the English term gender may be used in other languages (e.g., in German) to explicitly refer to the social and behavioral identity. In many studies, it is not clear whether sex or gender is assessed with a certain item. For example, in the PISA studies, students are asked, “Are you female or male?” [66,67].

When analyzing students' interest and its association with sex or gender, three different foci of analysis are commonly applied. First, male and female students are compared regarding their degrees of interest (e.g., [25,68,69]). Second, sex or gender differences in interest in physics as a school subject and as a scientific domain are analyzed. Most studies agree that the sex or gender difference in favor of boys is less pronounced when assessing domain interest in comparison to subject interest (e.g., [17,70]). Third, different contents and contexts and their interestingness for female students in comparison to male students are analyzed. Most studies distinguish between contents and contexts interesting for female and those interesting for male students (e.g., [22,23]). For example, the PISA study in 2015 [22] comes to the conclusion that boys are more interested in physics and chemistry ("Motion and forces" and "Energy and its transformation"), while girls are more interested in health topics ("How science can help us prevent disease"), suggesting a distinction between boys' and girls' topics. However, the alleged girls' topics were actually more interesting for boys than the alleged boys' topics (see p. 126 in Ref. [22]). Similarly, in the ROSE study, Jenkins and Nelson point out that "it is important to acknowledge that a high level of interest in a given topic by one gender does not necessarily mean that the same topic is of no interest to the other" (p. 50) [71]. Several studies also show that there are a few contents and contexts that are extremely and equally interesting for all students, for example, the Universe and its history [22,61], "the possibility of life outside earth" [23], and "the human body" [17,61] (see Sec. II B).

2. Self-concept and identity

Many studies address the correlation between physics-related self-concept or identity and interest. Broadly speaking, self-concept is one's perception of oneself [72]. It is a multifaceted and hierarchical construct that includes feelings about one's own competencies (self-evaluation) and is strongly influenced by social evaluation [72–74]. It is made up of one's different identities (e.g., physics identity; [75,76]) and influenced by one's perceptions of how others view oneself (a concept referred to as "looking-glass self"; [77]). Hence, in this paper, physics-related self-concept is defined as one's perception of one's own competence in physics [20,31,74,78,79], self-perception as a physics person, and perceived recognition as a physics person [20,78,79].

When analyzing students' interest and its association with physics-related self-concept, two different foci of analysis are commonly applied in empirical studies. First, the nature of the association of physics-related self-concept and interest is investigated. Most studies agree that there is a positive correlation between students' competency beliefs and interest in science and in physics

specifically [17,20,40,70,78,80,81]. Moreover, it has been shown that interest in physics is positively associated with self-perception as a physics person ("physics identity") and perceived recognition as a physics person [20,78], which had earlier been shown for engineering [82]. Second, the structure of self-concept, that is, the relationship among the different aspects of self-concept, is investigated. Some studies point out that the students' ability, self-concept, and self-perception as a science person are impacted by the perceived recognition by others (e.g., [83–85]). Given that some constructs, although typically examined separately, do not factor out (e.g., sense of belonging and self-efficacy), Kalender *et al.* [20] called for examining multiple motivational factors jointly.

D. Categorizing students based on their interest

Beyond the IPN interest study, other researchers have sought to categorize students based on their interest and other characteristics, notably based on analyses of data collected in the PISA studies. Drechsel *et al.* [29] analyzed data from PISA 2006, focusing on students' expressed interest in the content and contexts of the cognitive test units. They identified a four-dimensional content model ("Earth and space," "living," "physical," and "technology") and a four-dimensional context model ("health and environment," "frontiers," "hazards," and "resources"). For subsequent analyses, they employed a simplified two-dimensional content model distinguishing between "living systems" and "physical and technology systems." While both boys and girls were equally interested in living systems, physical and technology systems were even more interesting for boys, but less interesting for girls. High-performing boys were equally interested in both systems. Overall, high performers expressed higher interest in both systems than lower-performing peers [29].

More recently, Radišić *et al.* [86] analyzed PISA 2015 data from Italy. Using a latent profile analysis, they distinguished five groups of students based on their interest, enjoyment, instrumental motivation, self-efficacy, epistemological beliefs, and engagement in science activities. The largest group (59%) were the "informal inquirers," who pursued their interest in science primarily through leisure activities. The second largest group (24%) were the "uninterested," who, on average, reported less enjoyment of science and lower engagement in school and leisure science activities. In contrast, the "scientists" (12%) were those most interested in both school and leisure science activities, while also reporting the highest levels of self-efficacy and instrumental motivation. The "uncommitted" (3%) showed the lowest levels across all considered variables. Finally, the "practical inquirers" (2%) reported high self-efficacy and instrumental motivation and engaged in leisure science activities but showed the lowest interest in science topics. Performance outcomes reflected these groupings: the scientists achieved

the highest mean performance, followed by the informal inquirers and the uninterested students [86].

III. METHOD

We conducted a cross-cohort study with German-speaking students aged 14–16 years ($N = 1219$) from May to September 2021 (during the COVID-19 pandemic). The main aims of our study were to investigate (RQ1) students' types of interest in a classical and a modern physics content area (namely, mechanics and particle physics), (RQ2) to what extent these types can be described in terms of a hierarchy of students' levels of interest, and (RQ3) to what extent physics-related self-concept is a better independent variable for these types than gender. Below we describe the measurement instrument and the participants and the preparation of the collected data.

A. Measurement instrument

We used an online measurement instrument in the German language to assess the students' interest in mechanics and particle physics, physics-related self-concept, sex, and other background variables. We implemented all the items in the “SoSci Survey” platform [87].

1. Students' interest

As outlined in Sec. II A, person-object theory allows for varying levels of granularity in defining the object of interest. In research on physics interest, this granularity ranges from broad conceptualizations of physics as a scientific discipline (e.g., [20]) to more fine-grained approaches that distinguish between content areas (e.g., mechanics and electronics; [19,88]). In the present study, we adopt a content-area level of granularity and focus on students' interest in mechanics and in particle physics. These are conceptualized as distinct yet related constructs. They are distinct because they refer to different curricular content areas that are typically taught separately (e.g., in

different grades and instructional units). At the same time, they are related insofar as both are embedded within the broader school subject and scientific discipline of physics. In line with measurement theory, each construct (i.e., interest in particle physics and interest in mechanics) is defined as a unidimensional latent trait reflecting different degrees of interest in the respective content area [89]. Hence, we measured students' interest following the approach used in the IPN study. In that study, interest in 8 curricular content areas of physics (e.g., mechanics and electronics) was assessed using an introductory text and 11 rating-scale items for each content area. The introductory text on each content area preceded the corresponding part of the questionnaire to cover students' possible deficit in previous experience with the content area by giving them an idea of what it is about [90]. The 11 interest items for each content area were based on 11 item categories (e.g., the first category is “Learning more about the functional principle of technical devices”). Each item category represents a certain combination of seven different contexts and four different tasks (e.g., the first category is based on the context “technical devices in everyday life” and the task “Receiving information (observing, reading, and listening)”) [17]. Thus, the item categories reflect a range of behaviors corresponding to different levels of interest. Table I lists three example item categories and the corresponding items used in our study in (not-validated) English translations. All original items in the German language and English paraphrases are provided in Appendix A (see Tables VIII and IX). For all items, the question was: “How interested are you in doing the following related to this topic?” The students expressed their degree of interest in each item on a five-category rating scale [“My interest in this is ...” *very high* (= 5), *high* (= 4), *medium* (= 3), *low* (= 2), or *very low* (= 1)] [17]. We argue that students express operating interest while responding to each item in a measurement instrument composed of an introductory text and corresponding

TABLE I. Three exemplar IPN item categories and corresponding IPN items of interest in mechanics [54] and the items of interest in particle physics developed for the IPPI [34].

No.	IPN item category	IPN item on interest in mechanics (ID)	IPPI item (ID)
04	Learning more about qualitative physics	Learning more about how the kinetic energy of a car is transformed into other forms of energy (e.g., in the brakes or in the crumple zone) (M04)	Learning more about which elementary particles are in the nucleus space of an atom (PP04)
07	Getting insight into jobs related to humans	Learning more about the artificial organs (e.g., heart as blood pump) and joints used in medicine (M07)	Gaining insight into the workflow in a medical diagnostic center (PP07)
08	Constructing technical devices	Constructing different pulleys and trying them out (M08)	Transforming a mobile phone into a particle detector and trying it out (PP08)

Note: Categories and items are translated into English. Each item has a corresponding item ID. For example, the item M01 measures interest in mechanics (M) and the two digits indicate the item category (01).

items. Operating interest may be triggered by the interest-iness of an individual item, by the introductory text serving as a prior stimulus, or by the students' preexisting individual interest.

Students' interest in mechanics: To examine whether the IPN study's findings remain applicable to today's students, we assessed students' interest in mechanics with the corresponding introductory text and interest items used in the IPN questionnaire for half of the students. When deciding on which part of the original IPN instrument to use in our study, we considered the constructional flaws reported by Häußler, Hoffmann *et al.* [17,25]. We could not find any reported constructional flaws for the content-area "mechanics." We also analyzed the item wordings and compared them with the predefined item categories. Our analysis showed that the items are overall in line with the category descriptions. Only the second item "pumping oil from great depths" does not represent the category "Learning more about natural phenomena" well. Table I lists three example items used to measure students' interest in mechanics in (not-validated) English translations.

Students' interest in particle physics: To explore students' types of interest in a modern physics content area, we applied the IPPI, which consists of an introductory text and 11 items developed in our previous study [34]. The IPPI was modeled after the IPN instrument to allow for a comparison between students' interest in particle physics and their interest in mechanics. This parallel structure enables us to draw conclusions about the potential universality of students' types of interest. Table I also presents three example items of the IPPI in (not-validated) English translations.

2. Students' physics-related self-concept

Students' physics-related self-concept was assessed using a combination of two measurement instruments to align with the definition of physics-related self-concept given in Sec. II. In particular, the two aspects "ability self-concept" (self-perception of physics ability) and "perceived recognition" (beliefs about the perception as a physics person by relevant others) were assessed. The item set used to assess self-concept in the IPN study also addressed both aspects [17]. For all items, the question was: "How much do you agree with the following statements?" The students expressed their degree of agreement in each item on a four-category rating scale ranging from *fully agree* (= 4), *rather agree* (= 3), *rather disagree* (= 2), to *fully disagree* (= 1) [92]. Each item has a corresponding item ID. For example, the item SC01 measures physics-related SC and the two digits indicate the item number (01).

Physics ability self-concept: The physics ability self-concept (self-perception of ability) was assessed using the corresponding instrument in German to assess science ability self-concept from the PISA 2006 study [92]. It consists of six items. We adapted the item wording to measure the physics

ability self-concept instead of the science ability self-concept (e.g., "Physics topics are easy for me" instead of "Science topics ..."). This is based on Marsh, who argues that ability self-concept is domain specific [74].

Perceived recognition as a physics person: The perceived recognition as a physics person was assessed using the corresponding instrument consisting of three items from Kalender *et al.* (e.g., "My parents see me as a physics person") [20,78,79]. We translated the original items from English into German and added a fourth item about students' perceived recognition by classmates.

3. Background variables

The students' previous experience with the content areas in school was assessed using seven items each for mechanics (e.g., "force," "velocity," and "energy of motion") and particle physics (e.g., "elementary particles," "particle detector," and "electron"). For all items, the question was: "How exhaustively was this content covered in class?" The students expressed their degree of experience with the content presented in each item on a five-category rating scale ranging from *very exhaustively* (= 5), *exhaustively* (= 4), *medium* (= 3), *just briefly* (= 2), to *not at all* (= 1).

We also assessed students' sex ["Please tick your sex": *female* (= 1), *male* (= 2), and *prefer not to specify* (= 3)]; age ["How old are you?": *14 years* (= 1), *15 years* (= 2), *16 years* (= 3), and *other* (= 4)]; and language most spoken at home ["Which language do you speak most at home?": *German* (= 1), *another language* (= 2), and *both equally* (= 3)].

Moreover, each participating class was assigned to a class code consisting of three characters. The first is a letter, indicating the country (A = Austria, C = Switzerland, and D = Germany). The second and third are digits, representing the consecutive numbers of the classes. For example, "A01" is the class code of class number one from Austria. Using a class code system enables a class-wise comparison of the data later. The students' class code was collected using one item ("What is your class code?") and a free text field limited to three characters. Students received their class code together with the link to the questionnaire in an email invitation forwarded to them by their teachers.

Finally, the students could express further comments or feedback in a free text field using one item ("Your opinion matters!").

B. Participants

We sent out an email invitation to participate in the study to more than 100 teachers in Austria, Germany, and German-speaking Switzerland. As a result, the questionnaire was filled in by 62 school classes from different urban and rural areas of the three countries. The teachers who agreed to participate in the study with their classes

TABLE II. Descriptive statistics of the valid sample.

Category	Austria	Switzerland	Germany	Total
Grade ^a				
8	140 (18%)	111 (61%)		251 (21%)
9	626 (78%)	72 (39%)	233 (100%)	931 (77%)
Mixed (8 and 9)	17 (2%)			17 (1%)
10	15 (2%)			15 (1%)
Physics class in current year ^a				
Yes	659 (83%)	116 (63%)	233 (100%)	1008 (83%)
No	128 (16%)	67 (37%)		193 (16%)
Mixed	11 (1%)			11 (1%)
Age				
14 years	236 (30%)	80 (44%)	125 (54%)	441 (36%)
15 years	403 (50.5%)	79 (43%)	91 (39%)	573 (47%)
16 years	91 (11%)	14 (8%)	10 (4%)	115 (9%)
Other	68 (8.5%)	10 (5%)	7 (3%)	85 (7%)
Sex				
Female	368 (46%)	87 (48%)	140 (60%)	595 (49%)
Male	373 (47%)	83 (45%)	73 (31%)	529 (44%)
Prefer not to specify	57 (7%)	13 (7%)	20 (9%)	90 (7%)
Language spoken most at home				
German	554 (69%)	128 (70%)	189 (81%)	871 (72%)
Another language	117 (15%)	34 (19%)	22 (9%)	173 (14%)
Both equally	127 (16%)	21 (11%)	22 (9%)	170 (14%)

^aInformation provided by the teacher and associated with the class code.

were asked for some background information about their classes, namely, number of students, grade, and whether they have physics lessons in the current school year. The teachers were provided with an email invitation specific for each class and asked to send it to their students. In this email invitation, the students were provided with the class code and told that they will need to enter this class code at the end of the questionnaire. Moreover, the students received the link to access the questionnaire in the email. The participating school classes were grade 9 ($N = 48$, 77%), grade 8 ($N = 12$, 19%), grade 10 ($N = 1$, 2%), and grade 8 and 9 mixed ($N = 1$, 2%). In total, 1219 students participated in the study. The collected data is openly available [93]. Five students did not write an identifiable class code, e.g., “819.” We considered these cases invalid and excluded them from the data (cases 954, 2665, 3081, 3141, and 3506). Table II provides an overview of the participants in the data. There was no missing data since all questions were marked as mandatory. According to their self-report, the study participants were 49% female ($N = 595$), 44% male ($N = 529$), and 7% of the students ($N = 90$) preferred not to specify their sex. Of the participating students 36% were aged 14 years ($N = 441$), 47% aged 15 years ($N = 573$), 10% aged 16 years ($N = 115$), and 7% had a different age ($N = 85$).

IV. DATA ANALYSIS

To answer our three research questions, we first prepared the collected data for analysis. Students who completed the questionnaire in less than 3 min were excluded, as it is highly unlikely they engaged with the instrument in a meaningful way. Instead, they may have responded at random or not read the introductory texts. Based on this criterion, 27 students were removed from the data, resulting in a final sample size of $N = 1187$.

A. (Mixed) Rasch models

We answered RQ1 (“Into which different types of interest in physics can German-speaking students aged 14–16 years be categorized, while comparing a classical and a modern physics content area, namely, mechanics and particle physics?”) using (mixed) Rasch model analyzes and RQ2 (“To what extent can students’ types of interest be described in terms of a hierarchy of students’ levels of interest?”) using the answer profiles resulting from the (mixed) Rasch models.

In recent years, international educational assessment programs, such as PISA (e.g., in 2006; [94]), have brought increased attention to item response theory models, including Rasch models.

Analyzing data using a Rasch model allows for the estimation of linear measures for both persons and items. The person measure represents the extent to which a student possesses the latent construct being assessed [95], while the item measure indicates the level of the construct required for a person to have a 50% probability of endorsing the item. Both measures are expressed on the same linear scale and use the unit of logits (log-odds unit). To visualize the distribution of person and item measures, Wright Maps can be generated as part of Rasch analysis [95].

Building on simple Rasch models, there are three principles underlying mixed Rasch models [95,96]: (1) The sample consists of a mix of several groups of students with qualitatively different answer profiles. Within a group of students, the same items are more (or less) endorsed relative to each other by the students. (2) The students are categorized into one of these groups based on their most probable group assignment, as in a latent class analysis (LCA; [97]). (3) Within each group, the Rasch model is applied. Hence, students of one group may differ in their degree of the measured construct, that is, in their quantitative person measures, which is unlike LCA.

We conducted mixed Rasch model analyses to investigate the students' types of interest in mechanics and particle physics, respectively. That is, we examined whether students not only differ in their quantitative degrees of the measured constructs but also qualitatively in their answer profiles (RQ1). The answer profiles show how interesting different items on mechanics and particle physics, respectively, are relative to each other (RQ2).

There are several (mixed) Rasch models, and the choice of the right model needs to be based on the nature of the data. Since our measurement instrument for both interest and self-concept consisted of rating-scale items, we used the (mixed) Rasch rating-scale model [96]. We conducted the (mixed) Rasch analysis separately for the data on students' interest in mechanics, interest in particle physics, physics-related self-concept, and previous experience with the content areas in school using the software "Winnmira" [98,99]. Consistent with our conceptualization of interest at the content-area level, we applied the mixed Rasch model separately to the data about the two content areas rather than to the combined dataset. This approach follows the procedure used in the IPN study to ensure comparability of results [17]. Moreover, analyzing the content areas separately allowed for a clearer identification and interpretation of latent interest types within each content area. At the same time, this approach enabled the examination of content-area-overarching patterns, that is, of structural invariance of interest types across content areas.

For each dataset, we estimated models with varying numbers of latent groups. Specifically, we calculated four mixed Rasch models per dataset, ranging from a one-group model (i.e., the sample is not divided into groups of students with different answer profiles) to a four-group

model. Models with more than four groups were not considered, as models with relatively more groups are less restrictive and hence tend to have lower Bayesian information criterion (BIC) values (see below). Moreover, having more than four groups would result in relatively small group sizes, which would limit the practical relevance of describing interest types for educational practice.

As a criterion for model validity, we combine qualitative and quantitative methods. Qualitatively, we analyze whether the retrieved model (e.g., a model consisting of three different groups of students with different particle physics interest profiles) is interpretable in a sound manner. Quantitatively, we use the BIC values since previous studies suggest that this is the most reliable approach when conducting mixed Rasch model analyses [17,28,100–102]. The BIC value approximates the Bayes factor for large sample sizes. Hence, we follow Kass and Raftery's [103] guideline for the Bayes factor; that is, a smaller BIC value indicates that the corresponding model describes the collected data better than other models with higher BIC values. With reference to the lowest BIC value, delta-BIC values are calculated. We consider delta-BIC values above 150 to indicate very strong evidence in favor of the model with a smaller BIC value, above 20–150 strong evidence and above 3–20 positive evidence [103].

B. Evaluation of the obtained Rasch person and item measures

After calculating different mixed Rasch models and choosing the best-fitting models, the obtained Rasch person and item measures were evaluated separately for all groups of all chosen models.

The fit of the items was evaluated using the Q index, which ranges from 0 to 1. A Q index of 0 indicates a perfect fit, 0.5 indicates independence of the trait and the item (i.e., random response behavior), and 1 indicates a perfect misfit [96,104]. The standardization of the Q index, ZQ , can be assumed to be asymptotically normally distributed with a zero mean. To check for item fit, we used the items' ZQ values and apply a 2-sigma (95%) confidence interval; that is, we considered items with ZQ values ranging from -1.96 to 1.96 as having a good fit.

Persons were excluded from further analyses when at least one of the following criteria was met:

- (1) The fit of the persons was evaluated using the newfit values, which are "almost normally distributed" [105]. Persons whose newfit 1 and/or 2 value is less than -3 or greater than 3 , following the rule-of-thumb guideline provided by Boone *et al.* [106], were excluded, as well as persons for whom no newfit values were calculated because their person measures are extreme values.
- (2) To detect multivariate outliers, we conducted a linear regression on the Rasch person measures for interest in mechanics, particle physics, and

physics-related self-concept. Using Mahalanobis distance [107], as recommended by Tabachnick and Fidell [108], we compared each case to a chi-square distribution with three degrees of freedom. Values less than 0.001 for the probability that a value from the chi-square distribution with the same degrees of freedom will be less than the Mahalanobis distance indicate multivariate outliers and were excluded from further analyses.

- (3) We excluded the data of the students who did not indicate their sex (option: “prefer not to specify”) because the reasons why they did not indicate their sex are unknown. For example, students might think that their sex does not matter, or they might not see themselves as either female or male.

The reduced sample size following these exclusions is referred to as N_{red} .

C. Logistic regression models

To answer RQ3 (“To what extent is physics-related self-concept a better independent variable than sex for distinguishing between the different types of interest in mechanics and in particle physics?”), we conducted logistic regression analyses complemented by linear regression and t test analyses.

Logistic regression models allow for the dependent variable to be categorical and for the independent variables to be both continuous and categorical. In our study, the dependent variables were the student’s most probable type assignment obtained from the best-fitting mixed Rasch model for the data about students’ interest in mechanics and particle physics, respectively. The independent variables were the student’s sex (categorical) and physics-related self-concept (continuous Rasch person measure). This enabled us to investigate the correlational relationship between the independent variables (e.g., students’ self-concept) and the likelihood of the event (e.g., students being assigned to a certain interest type).

Prior to the analyses, we verified necessary assumptions, such as the adequacy of expected frequencies and absence of outliers, in line with Tabachnick and Fidell’s recommendations [108], to ensure that the data were suitable for logistic regression.

We calculated several logistic regression models using the software “IBM SPSS statistics 28.” We examined the likelihood ratios of the baseline model (i.e., a model in which the independent variables are 0, the constant-only model) and the different comparison models to find the models that are significantly better than the baseline model using logarithmic likelihood ratio tests. After choosing the best model, we interpreted the odds ratio of the included independent variables. While researchers often erroneously report the odds ratio as the ratio of probabilities, it only indicates the direction of the relationship [109]. Moreover, we evaluated the p values of the corresponding

correlation coefficients to assess statistical significance. Most statistical software provides the odds ratio and the p value of the corresponding correlation coefficient as the standard output of a logistic regression analysis. After determining the direction and the significance of the relationships, we examined their strength in terms of probabilities by “manually” calculating the relative risk [109].

Complementing the logistic regression analyses to better understand mean-level differences in self-concept and interest by sex and interest types, we conducted independent-samples t tests. Moreover, we examined correlations between self-concept and interest to show the strength of their association on the continuous level, not only via the dichotomized interest types.

To account for the inflation of the overall α level when multiple significance tests are conducted, corrections such as the Bonferroni correction can be applied [110]. Hence, we used a Bonferroni-corrected α level of $p = 0.001$, corresponding to 50 significance tests when controlling the family-wise α level at $p = 0.05$. Only outcomes with a p value smaller than this α level were considered statistically significant.

V. RESULTS

A. RQ1: Students’ types of interest in physics

1. Mechanics

We estimated four mixed Rasch models to describe students’ interest in mechanics, ranging from a one-group model (i.e., no division into groups with different answer profiles) to a four-group model. The four-group model had the smallest BIC, with delta-BIC values providing very strong evidence against the one- and two-group models and strong evidence against the three-group model (see Table III).

Qualitative analysis also indicated that the four-group model sufficiently represented students’ interest in mechanics, as models with more groups included one extremely small group with a profile similar to another. Students were therefore classified into groups 1_M (37%), 2_M (31%), 3_M (18%), and 4_M (14%), where “M” denotes Mechanics. Each student was assigned to the group for which the probability of membership was highest. Throughout the following, the terms “assigned to” and “categorized into” refer to this most probable group assignment.

When conducting (mixed) Rasch analyses, evaluating the obtained item and person measures is essential for assessing the quality of the chosen model. First, we

TABLE III. Delta-BIC values of the four calculated models to describe the students’ interest in mechanics relative to the model with the lowest BIC.

Number of groups	1	2	3	4
ΔBIC	812	277	66	0

examined the Rasch item measures. Item fit statistics showed that all items fit well in all mechanics groups 1_M (ZQ values: -1.01 to 1.43), 2_M (-1.34 to 1.63), 3_M (-1.26 to 1.78), and 4_M (-0.88 to 1.30). These results indicate that the data support interest in mechanics as a single latent trait across all four groups, indicating unidimensionality of the IPN instrument for measuring this construct. Second, person fit analysis led to the exclusion of 28 students with extreme or missing fit values.

Figure 1(a) presents the relative interestingness of the items for all four groups. Apart from differences in threshold spacing, the interest profiles of groups 1_M , 2_M , and 3_M are similar. In contrast, group 4_M 's interest profile differs from the others.

To examine differences among groups 1_M , 2_M , 3_M , and 4_M , we analyzed how students used the rating-scale categories. Figure 1(b) presents the probabilities of selecting each rating-scale category for all groups. The groups showed distinct patterns in their category use. Group 1_M predominantly selected nonextreme categories, especially the category “medium,” and rarely used the extreme category “very low” across the 11 items. Group 2_M also favored nonextreme categories but, depending on the item, occasionally used both negative and positive extremes. Group 3_M very frequently used the negative and positive extremes, depending on the item. The different category uses of the groups can also be seen in the threshold measures [Fig. 1(a)]. Thresholds for group 1_M are more widely spaced than those for group 2_M , which in turn are more widely spaced than those for group 3_M . In group 3_M , the thresholds are unordered. Group 4_M used all categories relatively evenly across the 11 items.

To characterize students' types of interest in mechanics, we compared the item hierarchies of the four groups, in which items are ranked by their item measure (i.e., their interestingness; Fig. 2). This analysis revealed two distinct patterns of interest in mechanics. The first pattern, shared by groups 1_M , 2_M , and 3_M , was characterized by clear differences in item measures. For example, in all three groups, item M07 (artificial organs and joints in medicine) has the lowest item measures, indicating high interestingness, whereas items M05 (calculating the energy of motion from the speed of a car) and M10 (calculating the braking path from the speed of a car) have relatively high item measures, indicating low interestingness. The second pattern was found in group 4_M . Here, all items were rated similarly interesting, with no clear hierarchy, except for items M07 and M11, which were rated as the least interesting, as indicated by the high item measures.

Based on these findings, groups 1_M , 2_M , and 3_M , representing 86% of the students, can be described as forming a single type of interest in mechanics (TIM1), while group 4_M , which comprised 14% of the students, represents a second, distinct type of interest (TIM2). To further characterize the different types of interest in

mechanics, we calculated descriptive statistics for the reduced sample size N_{red} for the two types: TIM1 (groups 1_M , 2_M , and 3_M) and TIM2 (group 4_M ; see Fig. 7 and Table X in Appendix B). Compared to TIM2 students, TIM1 students reported higher mean interest in mechanics but lower mean experience with mechanics in school and lower physics-related self-concept. Type TIM1 comprised 81% of all male and 93% of all female students.

2. Particle physics

We estimated four mixed Rasch models to describe students' interest in particle physics, ranging from a one-group model (i.e., no division into groups with different answer profiles) to a four-group model. The three-group model had the smallest BIC, with delta-BIC values providing very strong evidence against the one- and two-group models and strong evidence against the four-group model (see Table IV).

Qualitative analysis also indicated that the three-group model sufficiently represented students' interest in particle physics, as the four-group model included one extremely small group with a profile similar to another group. Students were therefore classified into groups 1_{PP} (46%), 2_{PP} (33%), and 3_{PP} (21%), where “PP” denotes particle physics. Each student was assigned to the group for which the probability of membership was highest.

Item fit statistics indicated that all items fit well in group 1_{PP} (ZQ values: -1.27 to 1.18) and 3_{PP} (ZQ values: -0.82 to 1.47). In group 2_{PP} , all items also fit well (ZQ values: -1.91 to 0.61) except for item PP07 (medical diagnostics; ZQ = 3.57). This misfit is likely due to PP07's medical context, which differs from that of the other items and may therefore appear less directly related to the latent trait (interest in particle physics). However, this trait is broad, as particle physics can be presented in many different contexts (cf. [111] on mathematics as a broad domain). Hence, we argue that the item fit statistics overall support interest in particle physics as a single latent trait in all three groups. Consistent with findings from our first study [34], these results support the unidimensionality of the IPPI. Analysis of the person fit statistics led to the exclusion of 39 students with extreme or missing fit values.

Figure 3(a) shows the interest profiles of groups 1_{PP} , 2_{PP} , and 3_{PP} . Apart from differences in threshold spacing, the interest profiles (i.e., the relative interestingness of the items) were similar for groups 1_{PP} and 2_{PP} . The interest profile of group 3_{PP} differs from those of the other groups.

To examine differences among groups 1_{PP} , 2_{PP} , and 3_{PP} , we analyzed their use of the rating-scale categories. Figure 3(b) presents the category probabilities, showing clear differences between groups. Group 1_{PP} predominantly selected the nonextreme categories and, additionally, the extreme category “very high.” Group 2_{PP} used the full range of categories, including both extremes, depending on the item. The different category uses of the groups can also be

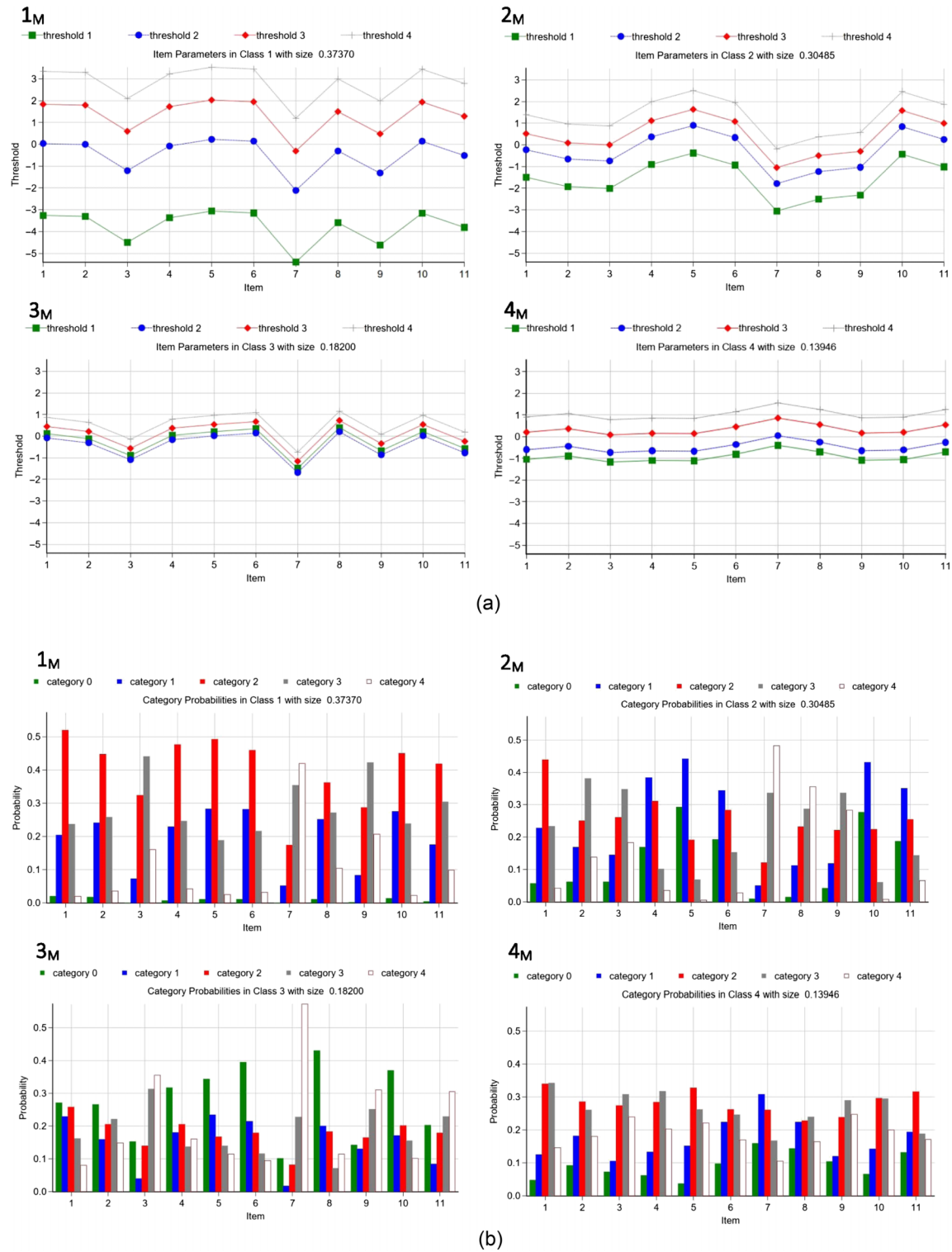


FIG. 1. Interest profiles and category probabilities for the four mechanics (M) interest groups (1_M, 2_M, 3_M, and 4_M). (a) Interest profiles, that is, how interesting the different items are relative to each other. Note: On the *x* axis, the items are shown, and on the *y* axis, the threshold measures are shown in logit units, each marking the threshold between one rating scale category and another. For example, threshold 1 is between the categories “very low” and “low.” The line between the data points does not have a meaning but helps to observe some patterns. (b) Category probabilities, that is, the probabilities to choose the different categories of the rating scale. Note: The students expressed their degree of interest in each item on a five-category rating scale [“My interest in this is...” very high (= 4), high (= 3), medium (= 2), low (= 1), or very low (= 0)].

Item	Group 1 _M	SE	Group 2 _M	SE	Group 3 _M	SE	Group 4 _M	SE
M05	0.68	0.07	1.17	0.07	0.43	0.07	-0.20	0.08
M10	0.60	0.07	1.11	0.07	0.43	0.07	-0.14	0.08
M06	0.60	0.07	0.61	0.06	0.56	0.07	0.11	0.08
M01	0.49	0.07	0.05	0.06	0.34	0.07	-0.13	0.08
M02	0.45	0.07	-0.38	0.06	0.11	0.07	0.03	0.08
M04	0.38	0.07	0.64	0.06	0.26	0.07	-0.18	0.08
M08	0.15	0.07	-0.97	0.06	0.62	0.09	0.22	0.08
M11	-0.06	0.07	0.53	0.06	-0.35	0.07	0.21	0.08
M03	-0.75	0.07	-0.47	0.06	-0.67	0.07	-0.26	0.08
M09	-0.87	0.07	-0.77	0.06	-0.45	0.07	-0.17	0.08
M07	-1.66	0.07	-1.52	0.07	-1.27	0.09	0.52	0.08

FIG. 2. Item IDs, corresponding Rasch item measures (reflecting their interestingness), and standard errors (SE) for the four mechanics (M) interest groups (1_M, 2_M, 3_M, and 4_M). The Rasch item measures and standard errors are listed in logit units. Lower and higher item measures represent more and less interesting items, respectively. The mean item measure of each group is set to zero in mixed Rasch analysis. The items are ordered according to their measures in group 1_M. The colour scale represents the interestingness across all groups; dark blue is the most interesting item and dark red is the least interesting item.

seen in the threshold measures [Fig. 3(a)]. The threshold measures for group 1_{PP} are more widely spaced than those for group 2_{PP}, with the largest gap occurring between the first and second thresholds. In group 2_{PP}, the thresholds are unordered, likely due to low response frequencies in one or more rating-scale categories (as discussed below). Group 3_{PP} mainly selected “medium,” “high,” and very high, and hence, thresholds 1, 2, and 3 are widely spaced, whereas thresholds 3 and 4 are closely clustered.

To characterize students’ types of interest in particle physics, we compared the item hierarchies of the three groups, in which items are ranked by their item measure (i.e., their interestingness; Fig. 4). This analysis revealed two distinct patterns of interest in particles. The first pattern, shared by groups 1_{PP} and 2_{PP}, was characterized by clear differences in item measures. For example, item PP07 (medical diagnostics) has very low item measures, indicating high interestingness, whereas items PP05 (masses of particles) and PP10 (energy of a particle collision at the speed of light) have very high item measures, indicating low interestingness. The second pattern was found in group 3_{PP}, which differed in its item hierarchy; for example, item PP07 (medical diagnostics) was the least interesting item, whereas it was among the most interesting in the other groups. Given the equivalent

item hierarchies, students in groups 1_{PP} and 2_{PP}, representing 79% of the sample, can be described as forming a single type of interest in particle physics (TIPP1). In contrast, students with the most probable group assignment to group 3_{PP} (21% of the sample) differ in their item hierarchy and are considered to represent a second type of interest in particle physics (TIPP2).

To further characterize the different types of interest in particle physics, we calculated descriptive statistics for the reduced sample size N_{red} for the two interest types: TIPP1 (groups 1_{PP} and 2_{PP}) and TIPP2 (group 3_{PP}; see Fig. 8 and Table XI in Appendix C). The mean experience with particle physics in school was similar for both types. The mean interest in particle physics and the mean physics-related self-concept was lower for TIPP1 than for TIPP2 students. Type TIPP1 consisted of 89% of all female students and 69% of all male students.

In summary, TIPP2 students (group 3_{PP}) were more likely to be male and to have a higher physics-related self-concept compared to TIPP1 students (groups 1_{PP} and 2_{PP}), consistent with the findings for the mechanics interest types. In contrast to the mechanics interest types, where TIM1 students had higher mean interest in mechanics, TIPP2 students had higher mean interest in particle physics than TIPP1 students.

3. Comparison

To unveil common and diverging aspects across the two content areas, we compared the most probable type assignments for students in mechanics and particle physics (Table V). Overall, 76% of students had matching assignments across the two content areas. Most students fell into

TABLE IV. Delta-BIC values of the four calculated models to describe the students’ interest in particle physics relative to the model with the lowest BIC.

Number of groups	1	2	3	4
ΔBIC	905	230	0	41

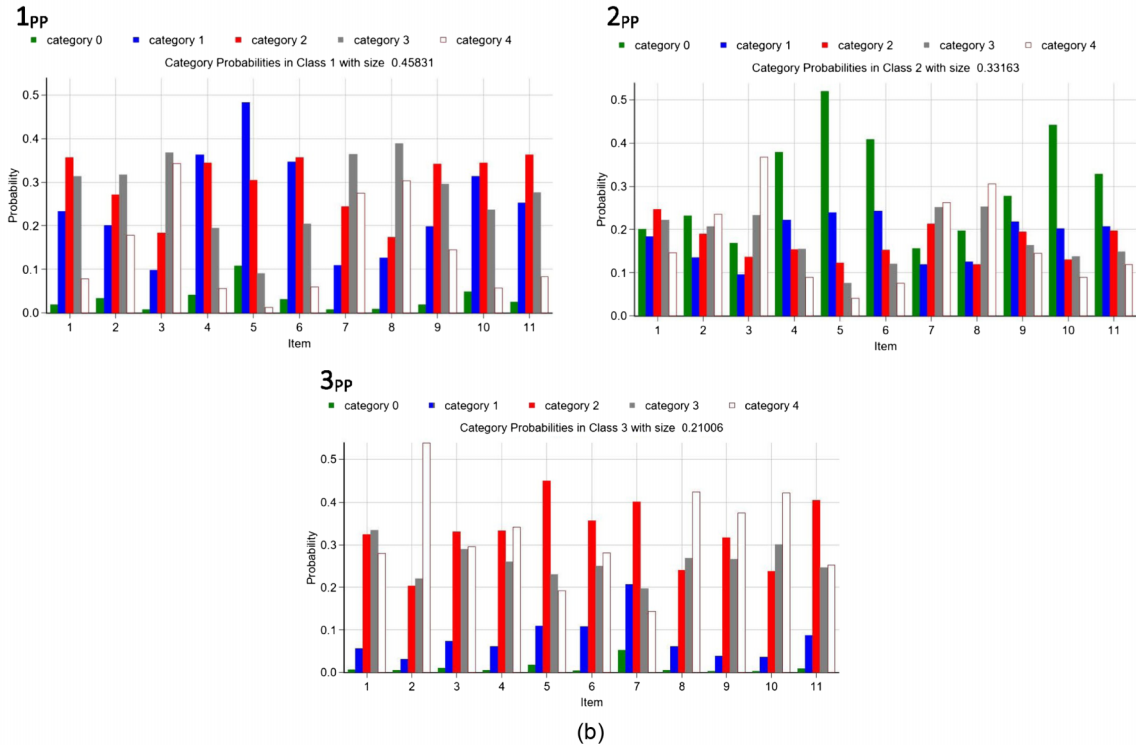
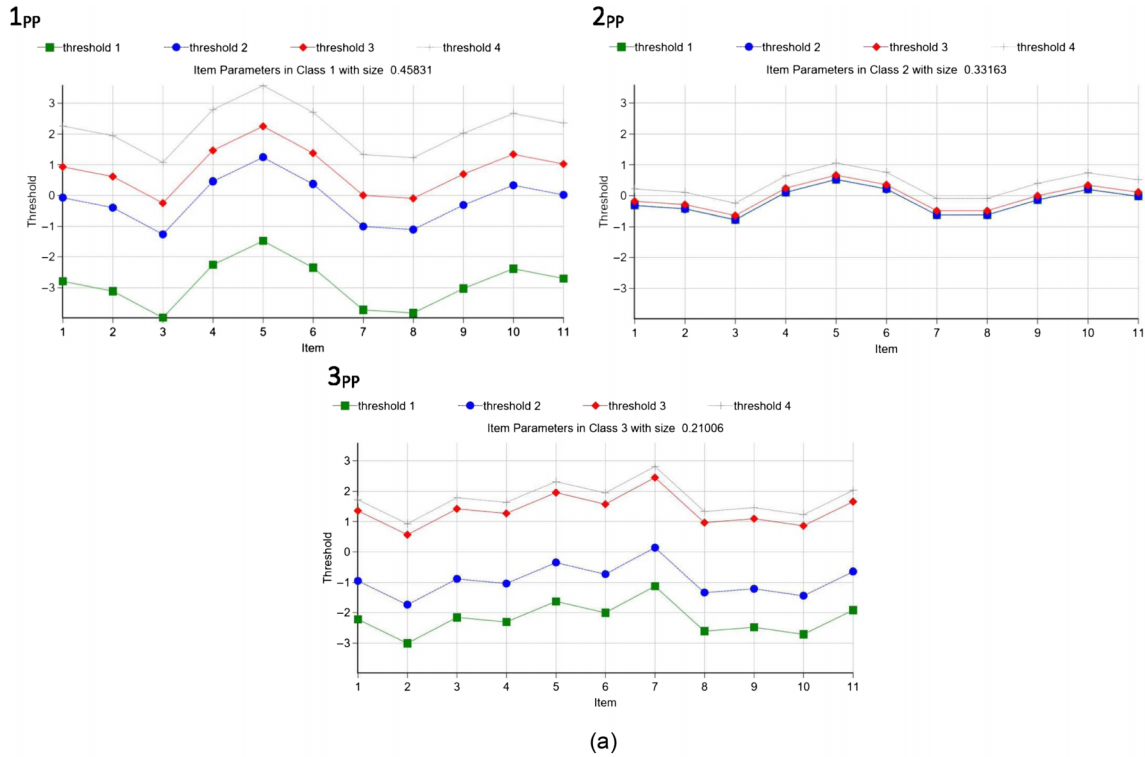


FIG. 3. Interest profiles and category probabilities for the three particle physics (PP) interest groups (1pp, 2pp, and 3pp). (a) Interest profiles, that is, how interesting the different items are relative to each other. Note: On the x axis, the items are shown, and on the y axis, the threshold measures are shown in logit units, each marking the threshold between one rating scale category and another. For example, threshold 1 is between the categories “very low” and “low.” The line between the data points does not have a meaning but helps to observe some patterns. (b) Category probabilities, that is, the probabilities to choose the different categories of the rating scale. Note: The students expressed their degree of interest in each item on a five-category rating scale [“My interest in this is...” very high (= 4), high (= 3), medium (= 2), low (= 1), or very low (= 0)].

Item	Group 1 _{pp}	SE	Group 2 _{pp}	SE	Group 3 _{pp}	SE
PP05	1.40	0.06	0.70	0.05	0.57	0.09
PP04	0.62	0.06	0.28	0.05	-0.11	0.09
PP06	0.53	0.06	0.39	0.05	0.19	0.09
PP10	0.49	0.06	0.37	0.05	-0.52	0.09
PP11	0.17	0.06	0.15	0.05	0.28	0.09
PP01	0.08	0.06	-0.15	0.05	-0.02	0.09
PP09	-0.15	0.06	0.03	0.05	-0.28	0.09
PP02	-0.24	0.06	-0.26	0.05	-0.81	0.09
PP07	-0.85	0.06	-0.46	0.05	1.07	0.09
PP08	-0.95	0.06	-0.45	0.05	-0.41	0.09
PP03	-1.10	0.06	-0.61	0.05	0.04	0.09

FIG. 4. Item IDs, corresponding Rasch item measures (reflecting their interestingness), and SE for the three particle physics (PP) interest groups (1_{pp}, 2_{pp}, and 3_{pp}). The Rasch item measures and standard errors are listed in logit units. Lower and higher item measures represent more and less interesting items, respectively. The mean item measure of each group is set to zero in mixed Rasch analysis. The items are ordered according to their measures in group 1_{pp}. The colour scale represents the interestingness across all groups; dark blue is the most interesting item and dark red is the least interesting item.

type 1 across both content areas ($\text{TIM1} \cap \text{TIPP1} = 71\%$), whereas concordant type 2 assignments were rare ($\text{TIM2} \cap \text{TIPP2} = 5\%$). This substantial overlap in type assignment is also reflected on the continuous level in the strong positive correlation between students' interest in particle physics and mechanics, $r(999) = 0.62$, 95% CI [0.58, 0.65], $p < 0.001$.

B. RQ2: Hierarchy of students' levels of interest in physics (HOLIP)

In our first study, we developed the HOLIP originally for particle physics (see Sec. II B, Ref. [34]). In the present study, we adopted a complementary approach aimed at strengthening the framework's external validity. Specifically, we examined whether different interest types exhibit interest profiles that are consistent with the HOLIP. Interest types were therefore not used to revise the framework, but rather to assess whether the previously established hierarchy remains valid for students of different interest types. In particular, to examine whether students' types of interest can be described using the HOLIP, we analyzed the item hierarchies of the interest types, focusing on item measures and wording. If this hierarchy applies, items set, for example, in contexts with

societal relevance (e.g., medicine) should rank among the most interesting, while those set, for example, in purely scientific contexts (e.g., qualitative or quantitative science) should rank among the least interesting.

1. Interest in mechanics

For mechanics, groups 1_M, 2_M, and 3_M had equivalent item hierarchies (see Fig. 2) and were combined into type TIM1, that is, students whose interest depends on the contexts in which physics content is set.

The most interesting items for TIM1 students involved contexts related to the human body (M07: artificial organs and joints and M09: designing a safety car for severe accidents) and socio-scientific issues (M03: probability and consequences of car accidents and M11: accident statistics and speed limits), consistent with the definition of the level of focused interest in the HOLIP. However, existential questions that are also part of this level were not represented in the mechanics items. Items linked to everyday life, defining the level of open interest, were restricted to car-related contexts (e.g., M04: transformation of kinetic energy into other forms of energy, M05: calculating the energy of motion based on car speed, M06: force-saving devices in a car repair shop, and M10: calculating braking distance based on car speed). These items were among the least interesting (unlike the ones linking to car accidents M03, M09, and M11). Similarly, the context of crude oil was also one of the least interesting. We argue that the contexts “car” and “crude oil” primarily reflect technology, that is, the level of broad interest, rather than everyday life, that is, the level of open interest. The context “science” was not addressed through

TABLE V. Most probable type assignments: TIM1 and TIM2 vs TIPP1 and TIPP2 (total %).

Interest types	TIPP1	TIPP2
TIM1	840 (71%)	190 (16%)
TIM2	97 (8%)	60 (5%)

the mechanics items, making it unclear how interesting this would have been. Overall, TIM1 students' hierarchy fits the HOLIP conceptualization well, although several aspects (existential questions, broader everyday life, and science) were not covered by the mechanics items.

For type TIM2 (group 4_M), interest was generally similar across all items. However, items M07 (artificial organs and joints in medicine), M08 (constructing different pulleys and trying them out), and M11 (accident statistics and speed limits) were slightly less interesting, despite being highly interesting to the other type. The relatively more interesting items were those set in car-related contexts: M01 (devices that amplify forces, e.g., pulley, lifting platform), M03 (increase of probability and consequences of a car accident with speed), M04 (transformation of kinetic energy into other forms of energy), M05 (calculating the energy of motion based on car speed), M06 (force-saving devices in a car repair shop), and M10 (calculating braking distance based on car speed), as well as item M02 (pumping oil from great depths, context crude oil). Thus, the conceptualization does not adequately describe type TIM2, since these students' interest was similar across most items and did not depend on the contexts in which physics content is set.

2. Interest in particle physics

For particle physics, groups 1_{PP} and 2_{PP} had equivalent item hierarchies (see Fig. 4) and were combined into type TIPP1, that is, students whose interest depends on the contexts in which particle physics content is set.

The most interesting items for TIPP1 students involved contexts related to existential questions of humankind (PP02: particle physics and the big bang), socio-scientific issues (PP03: particle detectors and smuggled arms), and health (PP07: medical diagnostics). These contexts and their interestingness align with the level of focused interest. Unlike in mechanics, the aspect existential questions of humankind was explicitly represented in the particle physics items. Items linked to everyday life [PP01: devices that detect particles (e.g., digital camera) and PP11: particle physics has changed our daily life] were less interesting, aligning with the level of open interest. The least interesting items (PP04: particles in the nucleus space of an atom, PP05: masses of particles, PP06: accelerators in industry, and PP10: calculating the energy of a particle collision) reflected purely scientific or technical contexts and corresponded to the level of broad interest. Overall, the HOLIP conceptualization described TIPP1 students' interest well.

For students of type TIPP2 (group 3_{PP}), however, the conceptualization did not capture their interest. Most students of this type were interested in the special aspects of particle physics as a content area and a scientific endeavor, that is, its focus on the existential questions of humankind (PP02: particle physics and the big bang and

PP04: particles in the nucleus space of an atom) and on experiments (PP08: transforming a mobile phone into a particle detector, PP09: planning an experiment on particle acceleration, and PP10: calculating the energy of a particle collision at the speed of light). Socio-scientific, everyday life, and technological contexts were less interesting. Hence, TIPP2 students' interest focused directly on particle physics itself rather than on broader contextual connections.

3. Comparison

In sum, we found that the item hierarchy of the type of students whose interest in physics depends on the contexts in which it is set, that is, types TIM1 and TIPP1, comprising most students' interest in mechanics (86%) and particle physics (79%), respectively, can be described with our conceptualization of interest as a hierarchy of levels of interest in physics (HOLIP, see Fig. 6, adapted to both content areas, mechanics and particle physics).

C. RQ3: Physics-related self-concept vs gender as independent variables for interest type assignment

We prepared the dataset by excluding students with a person measure misfit in mechanics interest (28), particle physics interest (39), and self-concept analyses (73), with overlaps resulting in 115 total exclusions ($N = 1072$). We then removed three multivariate outliers (Mahalanobis distance, $p < 0.001$) and 68 students without sex information, yielding $N_{\text{red}} = 1001$ (540 female, 54% and 461 male, 46%).

Next, we recoded most probable group assignments into the broader mechanics ($1_M, 2_M, 3_M \rightarrow \text{TIM1}$; $4_M \rightarrow \text{TIM2}$) and particle physics interest types ($1_{PP}, 2_{PP} \rightarrow \text{TIPP1}$; $3_{PP} \rightarrow \text{TIPP2}$).

Using these, we ran three logistic regression models per content area, with type assignment as the dependent variable and physics-related self-concept (continuous Rasch measures) and/or sex (categorical) as independent variables, comparing models via the likelihood ratio test, Nagelkerke's R^2 , and classification accuracy.

For mechanics interest (Table VI), the best-fitting model (B) included physics-related self-concept, sex, and their interaction as independent variables ($\chi^2 = 45$, $p < 0.001$, $df = 3$), correctly classifying 87% of cases. This matched the baseline prediction of assigning all students to TIM1, with Nagelkerke $R^2 = 0.08$, indicating poor improvement in fit compared to the baseline model [112]. Female students were 62% less likely to be in type TIM2 (OR = 0.33, RR = 0.38). For male students, physics-related self-concept almost reached the Bonferroni-corrected significance level ($p = 0.004$), suggesting that each unit increase in self-concept raised the odds of being in type TIM2 by 20% (OR = 1.2). The interaction between sex and physics-related self-concept was not significant ($p = 0.336$), indicating that the

TABLE VI. Regression model analyses of the interest types in mechanics (two types, reference type is TIM1). *** $p < 0.001$, ** $p = 0.004$ | B is the correlation coefficient, SE is the standard error, OR is the odds ratio, CI is the confidence interval, and df is the degrees of freedom.

Model	A ($df = 1$)		B ($df = 3$)		C ($df = 1$)	
Measure	B (SE)	OR [95% CI]	B (SE)	OR [95% CI]	B (SE)	OR [95% CI]
Constant	-1.430** (0.118)	0.239	-1.435*** (0.120)	0.238	-1.876*** (0.096)	0.153
Self-concept			0.175** (0.060)	1.191 [1.058, 1.341]	0.187*** (0.048)	1.206 [1.098, 1.324]
Sex (female)	-1.179** (0.207)	0.307 [0.205, 0.461]	-1.109** (0.217)	0.330 [0.215, 0.505]		
Self-concept ** sex			-0.100 (0.104)	0.905 [0.739, 1.109]		
Correctly classified cases		87.4%		87.4%		87.4%
Nagelkerke's R^2		0.066		0.083		0.030
Likelihood ratio test		35.560**		45.086**		15.940**

TABLE VII. Regression model analyses of the interest types in particle physics (two types, reference type is TIPP1). *** $p < 0.001$, ** $p = 0.002$ | B is the correlation coefficient, SE is the standard error, OR is the odds ratio, CI is the confidence interval, and df is the degrees of freedom.

Model	A ($df = 1$)		B ($df = 3$)		C ($df = 1$)	
Measure	B (SE)	OR [95% CI]	B (SE)	OR [95% CI]	B (SE)	OR [95% CI]
Constant	-0.820*** (0.101)	0.441	-0.853*** (0.108)	0.426	-1.304*** (0.081)	0.272
Self-concept			0.377*** (0.059)	1.458 [1.299, 1.636]	0.306*** (0.042)	1.359 [1.251, 1.476]
Sex (female)	-1.260*** (0.170)	0.284 [0.203, 0.396]	-1.143*** (0.181)	0.319 [0.224, 0.455]		
Self-concept *** sex			-0.277** (0.090)	0.758 [0.636, 0.904]		
Correctly classified cases		79.9%		81.7%		80.1%
Nagelkerke's R^2		0.091		0.164		0.089
Likelihood ratio test		59.564***		109.961***		58.167***

association between self-concept and TIM2 assignment did not differ significantly between sexes.

For particle physics interest (Table VII), the best-fitting model (B) also included self-concept, sex, and their interaction as independent variables ($\chi^2 = 110$, $p < 0.001$, $df = 3$), correctly classifying 82% of cases. The classification accuracy (82%) improved only slightly compared to the baseline model, with Nagelkerke $R^2 = 0.16$,

indicating poor improvement in fit [112]. Female students were 61% less likely to be in type TIPP2 (OR = 0.32, RR = 0.39), and for male students, each unit increase in self-concept raised the odds of being in type TIPP2 by 50% (OR = 1.5). Importantly, the interaction between sex and physics-related self-concept almost reached the Bonferroni-corrected significance level ($p = 0.002$, OR = 0.76), suggesting that the association between

self-concept and TIPP2 assignment differed across sexes. The positive effect of self-concept was significantly weaker for female students (10%, OR = 1.1).

Complementing the logistic regression analyses to better understand mean-level differences in self-concept by sex and interest type, we conducted independent-samples t tests. Female students had significantly lower physics-related self-concept than males across the full sample (-1.00 ± 2.04 vs -0.19 ± 2.04 logits, $t(999) = 6.27$, $p < 0.001$, $d_C = 0.4$, 95% CI [0.27, 0.52]). This pattern held within the interest types TIM1 (-1.02 ± 2.03 vs -0.32 ± 1.95 logits, $t(873) = 5.10$, $p < 0.001$, $d_C = 0.3$, 95% CI [0.21, 0.48]) and TIPP2 (-0.63 ± 2.35 vs 0.77 ± 1.97 logits, $t(96.21) = 4.07$, $p < 0.001$, $d_C = 0.70$, 95% CI [0.36, 0.98]). For TIPP1, the difference almost reached the Bonferroni-corrected significance level (-1.05 ± 2.00 vs -0.61 ± 1.92 logits, $t(798) = 3.05$, $p = 0.002$). For the interest type TIM2, the difference was not significant (-0.71 ± 2.17 vs 0.38 ± 2.31 logits, $t(124) = 2.45$, $p = 0.016$).

Moreover, we calculated the correlations between self-concept and interest to show the strength of their association on the continuous level, not only via the dichotomized interest types. Self-concept correlated positively with interest in mechanics ($r = 0.38$, 95% CI [0.32, 0.43], $p < 0.001$) and particle physics ($r = 0.47$, 95% CI [0.42, 0.52], $p < 0.001$) for the full sample, with similar associations for females and males across the interest types TIM1 ($r_f = 0.39$, 95% CI [0.31, 0.46]; $r_m = 0.41$, 95% CI [0.32, 0.49]), TIPP1 ($r_f = 0.42$, 95% CI [0.35, 0.50], $r_m = 0.38$, 95% CI [0.28, 0.47]), and TIPP2 ($r_f = 0.44$, 95% CI [0.21, 0.62], $r_m = 0.46$, 95% CI [0.32, 0.58]), all $p < 0.001$. For the interest type TIM2, the correlation reached the Bonferroni-corrected significance level for male students ($r_m = 0.34$, 95% CI [0.14, 0.51], $p = 0.001$), but not for female students ($r_f = 0.35$, 95% CI [0.02, 0.60], $p = 0.036$).

Finally, to better understand mean-level differences in interest by sex, we conducted independent-samples t tests. No significant sex difference was found in mechanics either overall ($p = 0.568$) or within TIM1 ($p = 0.465$) and TIM2 ($p = 0.457$). In contrast, particle physics interest was slightly higher among males overall (0.67 ± 1.09) than females (0.38 ± 0.98 ; $t(934.6) = 4.36$, $p < 0.001$, $d_C = 0.3$, 95% CI [0.27, 0.52]), but this difference did not reach the Bonferroni-corrected significance level for the interest types TIPP1 ($p = 0.798$) and TIPP2 ($p = 0.008$).

VI. DISCUSSION

A. RQ1: Students' types of interest in physics

1. Mechanics

We found that the groups 1_M , 2_M , and 3_M have very similar item hierarchies and can be described with one single type of interest in mechanics (TIM1), whose interest

depended on the contexts in which physics content is set (a more detailed discussion follows in Sec. VI B). However, some small differences in the item hierarchies warrant discussion: For group 2_M , items M11 (accident statistics and speed limits) and M04 (transformation of energy of motion into other forms of energy) were less interesting compared to items M09 (designing a safety car for severe accidents) and M03 (increase of probability and consequences of a car accident with speed), while for group 1_M and 3_M , all “car accident” items were highly interesting. Possible reasons are that M11 (accident statistics and speed limits) involved a potentially less interesting discussion task and a less explicit description of the context car accident compared to the other car accident items. Moreover, the item M04 (transformation of energy of motion into other forms of energy) presents the content “qualitative physics,” whereas item M03 (increase of probability and consequences of a car accident with speed) presents the content “quantitative physics.” Although both items are set in the context car accident, M04 may have been less interesting than M03 because M03's quantitative aspect is a measure for the severity of accident consequences. M08 (constructing pulleys and trying them out) was relatively more interesting for groups 1_M and 2_M but least interesting for group 3_M , possibly due to lower interest in the hands-on task or in the pulley content.

Apart from the discussed differences, the three groups' item hierarchies were equivalent. When conducting mixed Rasch model analyses, one may interpret all the different groups as different types of interest, as done, for example, in the initial publications of the IPN study [17,19,25]. However, the overall similarity in item hierarchies suggests that the separation into three groups reflects differences in response style rather than fundamentally different interest types. As shown in Fig. 1(a), group 1_M exhibits a nonextreme response style (NERS), characterized by “widely spaced first and fourth thresholds while the second and third thresholds are close together” [113]. In contrast, group 3_M shows an extreme response style (ERS), with thresholds that are “nearby each other, sometimes even overlapping” [113]. The presence of nonordered threshold measures indicates that some categories of the rating scale are never the most probable. While some researchers (e.g., [114,115]) have interpreted this as a violation of the intended category ordering, others (e.g., [116–118]) have shown that nonordered thresholds result from low frequencies of responses in one or more categories. The category probability plots [Fig. 1(b)] further support these interpretations: group 1_M primarily used nonextreme categories with occasional use of the extreme category very high, group 3_M mainly used both extreme categories, and only group 2_M demonstrated a “normal” response style by making relatively balanced use of both extreme and nonextreme categories.

In contrast, group 4_M students rated all items similarly interesting, except for M07 (artificial organs and joints), M08 (constructing different pulleys and trying them out), and M11 (accident statistics and speed limits), which were least interesting. Their category use resembled a normal response style. This group (14% of students) forms a second mechanics interest type (TIM2), whose interest did not depend on the contexts in which physics content is set.

2. Particle physics

For the content area particle physics, 79% of the sample, that is, groups 1_{pp} and 2_{pp}, have a highly similar interest profile and can be described with one single type of interest (TIPP1), whose interest depends on the contexts in which physics content is set (a more detailed discussion follows in Sec. VI B). Although groups 1_{pp} and 2_{pp} were categorized separately, this was due to different response styles rather than different item hierarchies. As can be seen in the category probability plots [Fig. 3(b)] and interest profiles [Fig. 3(a)], group 1_{pp} students used the nonextreme categories and additionally the extreme category very high (= 5), resulting in widely spaced first thresholds and slightly more closely spaced higher thresholds, resembling a NERS [113]. Group 2_{pp} students, by contrast, used all categories, including the extreme category very low, which produced very closely spaced thresholds overall and even overlapping thresholds at 1 and 2, resembling an ERS [113].

In comparison, 21% of the students (group 3_{pp}) showed a different item hierarchy and formed a second type of interest in particle physics (TIPP2). Group 3_{pp} tended to use only the more positive categories [medium to very high; see Fig. 3(b)], and hence, thresholds 3 and 4 are very close together, and thresholds 1 and 2 are widely spaced [Fig. 3(a)]. Since these students were interested in the special aspects of particle physics as a content area and a scientific endeavor, that is, its focus on the existential questions of humankind (PP02: particle physics and the big bang and PP04: particles in the nucleus space of an atom) and on experiments (PP08: transforming a mobile phone into a particle detector, PP09: planning an experiment on particle acceleration, and PP10: calculating the energy of a particle collision at the speed of light), we referred to them as the “particle physics lovers.”

3. Comparison

For both content areas two different types of interest in physics were distinguished. The first (TIM1 for mechanics and TIPP1 for particle physics) comprises students whose interest in physics content depends on the context in which it is embedded. Hence, we referred to this type as a context-oriented interest type (a more detailed discussion follows in Sec. VI B). Most students (71%) were categorized into this type for both content areas. Whereas this type is overarching (i.e., content-area independent), the second type of interest differs across content areas: in mechanics, TIM2 students were rather equally interested in all items, suggesting that their mechanics interest does not depend on specific contexts. In particle physics, TIPP2 students were interested in the special aspects of particle physics as a content area and a scientific endeavor. What TIM2 and TIPP2 share as a common characteristic is that their interest is oriented toward mechanics and particle physics, respectively, as content areas. Therefore, we refer to them as content-oriented types.

However, only a small fraction of students (5%) were assigned to both of these second types, indicating that they are content-specific, in contrast to the overarching context-oriented type. Notably, there are students who, depending on the content area, belong to either the context-oriented or the content-oriented type (see Fig. 5). Our description of the two interest types, derived from the groups revealed by the mixed Rasch analysis, is supported by past findings (Rost *et al.* [27]). The students' context-oriented interest type concerning both content areas is in line with type C found in the IPN study, which describes students who are highly interested in physics as it relates to humans, nature, applications, and society [26–28]; with category A found in the HOPE study, which describes students' “curiosity to understand the world, natural phenomena and the universe” [30]; and with the interest category living systems found by Drechsel *et al.* for PISA 2006 data [29]. Slightly more female than male students were assigned to this type.

In mechanics, the type TIM2, rather equally interested in all items, only partly aligns with IPN type A, that is, students that are generally and highly interested in physics [26–28]. Although all items were similarly interesting for TIM2 students, which aligns with IPN type A, their mean

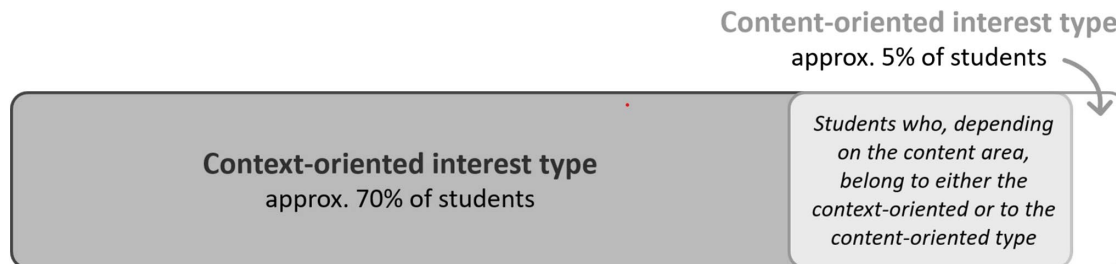


FIG. 5. Distribution of students across the context- and content-oriented interest types.

interest was lower than that of TIM1 students, which does not align with IPN type A. However, type TIM2 somewhat resembles the group of students referred to as practical inquirers (1.5%) by Radišić *et al.* in their analysis of PISA 2015 data from Italy [86]. These practical inquirers showed high self-efficacy and instrumental motivation and engaged in leisure science activities but had the lowest interest in science topics. Similarly, the TIM2-type students in our study had the highest mean physics-related self-concept.

In particle physics, the particle physics lovers type (TIPP2) also only partly aligns with IPN type A [26–28], as not all items were equally interesting for them. Quantitative items without context were less interesting for them, while items on existential questions (where do we come from? → big bang and what are we made of? → “particles in the nucleus”) or spectacular experiments (particle collisions, detectors, and accelerators) were more interesting. This finding corresponds with category B identified in the HOPE study, which describes students’ “interest in physics knowledge as a special way of knowing, investigating, questioning and thinking” [30], and with the interest category “physical/technology systems” reported by Drechsel *et al.* [29]. Olsen and Lie further emphasized that within the cluster physical/technological systems, items related to fires and pure or frontier science are central [119]; particle physics may be considered a prime example of such frontier science. The particle physics lover type of students also resembles the group labeled scientists (12%) in Radišić *et al.*’s analysis of PISA 2015 data from Italy [86]. These students demonstrated the highest mean levels of self-efficacy, instrumental motivation, and enjoyment of science, as well as interest in both school and leisure science activities. Consistently, the particle physics lover type reported the highest mean interest in particle physics. This pattern is further supported by Habig *et al.*, who found that students with high individual interest tend to show stronger interest in unique contexts [120]; particle physics, as a scientific endeavor, can be regarded as such a unique context. The particle physics lover type consisted predominantly of male students. This aligns with findings from the ASPIRES study, which showed that among students aged 12–14 years, notably fewer females (37%) than males (63%) were classified as “science keen” [68].

Overall, the resulting description does not fully replicate the IPN types (A, C, and NG) as defined in the latest analyses of the data [26–28]. In the IPN study all groups resulting from the mixed Rasch rating-scale model were described in terms of interest types. In contrast, we considered the item hierarchies of the different groups when describing interest types. Given an equivalence (i.e., absence of qualitative differences) of their item hierarchies, we combined different groups to form an interest

type. We argue that, given the overall similarity in item hierarchies across groups, labeling them as fundamentally different interest types would overstate their substantive distinctiveness. While the mixed Rasch model statistically differentiates latent classes, the practical explanatory value of such classes depends on whether they reflect qualitatively different interest profiles rather than differences in response style. Notably, this concern is not unprecedented within the mixed Rasch tradition. In the reanalysis of the IPN data, Sievers [28] questioned whether the type NG should be interpreted as a distinct interest type because it consisted of students whose interest profiles resembled either type A or type C depending on the content area. The defining characteristic of this type was not a unique item hierarchy but a specific response style: students predominantly used the extreme categories of the rating scale, which resulted in disordered (German: nicht geordnet) thresholds between the rating-scale categories. Therefore, we used a different approach when defining interest types: only if a group had a unique item hierarchy did we consider this group as a separate interest type. Using this approach, we naturally could not replicate the type NG. We could replicate IPN type C across both content areas. IPN type A could only be partially replicated, with distinct forms in mechanics and particle physics. Thus, type A is not universal but depends on the content area.

B. RQ2: Hierarchy of students’ levels of interest in physics (HOLIP)

We found that the item hierarchy of the type of students who are only interested in physics when it is set in certain contexts, referred to as “context-oriented,” representing the majority of students, can be described using our HOLIP framework, originally introduced for particle physics in our first study [34]. Past empirical studies provide a rationale for why the HOLIP framework remained valid not only for the particle physics type TIPP1 but also for the mechanics type TIM1 in this study. As argued by Fechner *et al.*, the effect of a context on interest is more distinct when the context can be clearly distinguished from the content, and the positive effect of a context on interest is stronger when the content itself is less interesting [55]. Based on this, we argue that for students of the context-oriented type, (1) a clear distinction existed between the content areas mechanics and particle physics, respectively, and the contexts in which they were embedded, and (2) the content areas themselves were perceived as less interesting than the contexts.

In contrast, we found that for the content-oriented interest types, representing only a small fraction of students (TIM2: 14% in mechanics and TIPP2: 21% in particle physics), the HOLIP did not fit. In mechanics, the content-oriented type (TIM2) consisted of students

similarly interested in all items. In particle physics, the content-oriented type (TIPP2) comprised students most interested in particle physics as a content area and as a scientific endeavor. We labeled them particle physics lovers. The HOLIP could not be applied to these content-oriented types. The difference in applicability between the context-oriented interest type (TIM1, TIPP1) and the content-oriented ones (TIM2, TIPP2) may again be explained with reference to Fechner *et al.* [55]: for TIM2 students, no clear distinction may have existed between the content area mechanics and the contexts in which it was embedded (mainly car-related contexts). Similarly, for TIPP2 students, particle physics itself may not have been distinguishable from the contexts in which it was embedded or may have been more interesting than the contexts in which it was set. In both cases, the positive effect of contexts is less pronounced [55].

In sum, the HOLIP framework, originally introduced in our previous study, was successfully applied to describe the relative interestingness of different contexts for the first type of students (context-oriented) across both content areas, that is, type TIM1 (86% of students in mechanics) and type TIPP1 (79% of students in particle physics), with 71% of students concordantly assigned across both content areas. Hence, the present study specifies, based on a large sample, that the HOLIP is valid for the context-oriented interest type and strengthens the framework's external validity by demonstrating that it remains valid across different physics content areas.

As outlined in Sec. II B, the HOLIP comprises three levels of interest. First, we characterized the level of focused interest as interest arising when physics is set in contexts related to one's own body, socio-scientific issues, or existential questions of humankind. We argue that these three aspects can be grouped into the same level of interest because they all arouse positive or negative emotions. This corresponds to the first phase of interest development, "triggered situational interest," in which the emotional component prevails [43]. Second, students at the level of open interest were additionally interested when physics was presented in the broader context of "everyday life." Our definition of open interest aligns with the second phase of interest development, "maintained situational interest," in which a person begins to recognize personal value based on existing positive feelings; that is, the value-related component of interest gains in importance [43]. Third, we defined the level of broad interest as interest in physics even when presented in purely scientific or technical contexts. This broad level corresponds to the third and fourth phases of interest development, "emerging" and "well-developed individual interest," in which the cognitive-epistemic component of interest predominates [43]. Importantly, these levels are cumulative: the broad level encompasses the open level, which in turn encompasses the focused level (see Fig. 6).

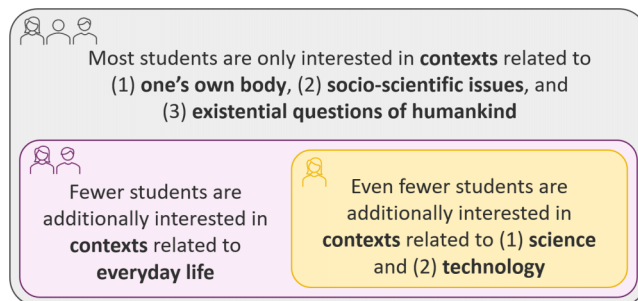


FIG. 6. Hierarchy of levels of interest in physics (HOLIP) for the context-oriented type of interest.

C. RQ3: Physics-related self-concept vs gender as independent variables for interest type assignment

A direct logistic regression examined whether students' physics-related self-concept (continuous Rasch person measure) and/or sex (categorical) predicted their interest type in mechanics (TIM1 vs TIM2) and particle physics (TIPP1 vs TIPP2). In both content areas, the best-fitting models included self-concept (continuous) and sex as significant predictors. Female students were less likely to be in types TIM2 and TIPP2, respectively, and a higher self-concept increased odds of being in TIM2 and TIPP2, respectively. For particle physics, the association between self-concept and TIPP2 assignment differed across sexes. In particular, the positive effect of self-concept was significantly weaker for female students. However, the interpretability of odds ratios in logistic regression models is limited to the direction of the effect, as the effect size itself cannot be interpreted in a sound manner. Moreover, to our knowledge, it is not possible to calculate probabilities for a one-unit increase in a continuous variable, and thus the relative risk cannot be derived. Due to these limitations, we were not able to compare the effect sizes between the categorical variable sex and the continuous variable physics-related self-concept using logistic regression models in our study.

Complementing the logistic regression analyses to better understand mean-level differences in self-concept and interest by sex, we conducted independent-samples *t* tests. Overall, female students had lower self-concept than males (small effect), with larger differences for students with higher mean self-concept (e.g., TIPP2; medium effect). This finding is somewhat surprising and suggests that for students with higher mean self-concept, sex differences are even more pronounced. Similarly, Bucchieri *et al.* analyzed the PISA 2006 data of four different countries and found that "female high-performers have a significantly lower [ability] self-concept in sciences than their male colleagues" [80]. Interest in mechanics did not differ significantly between sexes, either overall or by type. In contrast, for particle physics (overall), male students reported slightly higher interest. This effect appears to be primarily driven by the TIPP2 type, although

the difference did not reach the Bonferroni-corrected significance level ($p = 0.008$). Thus, we argue that sex differences in interest are present only within the high-interest, high-self-concept group of particle physics lovers. Complementing findings based on the dichotomized interest types, we found that correlations between self-concept and interest on the continuous level were moderate ($r \approx 0.4$) and similar across sexes in all types, indicating that the self-concept–interest link is stable. Consequently, the lower mean self-concept observed among female students is mirrored by lower mean interest. Hence, meaningful descriptions of students' interest in physics require considering both sex (or gender) and self-concept jointly.

VII. STRENGTHS, LIMITATIONS, AND DIRECTIONS FOR FUTURE RESEARCH

This study examined students' types of interest in mechanics and particle physics and their relation to the students' sex, physics-related self-concept, and previous experience with the content areas in school.

Measurement instruments: Interest in two different physics content areas was assessed using items that systematically varied context. Although different tasks were included, their variation was less systematic, and the learning environment was not specified. Both tasks and learning environments could be more deliberately included in future research to provide a more comprehensive understanding of students' types of interest. Moreover, the instrument primarily targeted the cognitive component of interest. Incorporating also the emotional and value-related components would yield a representation more consistent with interest theory. Finally, interest was assessed using nonembedded items, although embedded items, as in PISA 2006 [31] or [121,122], could better resemble classroom situations and reduce school subject aversion effects [70]. Physics-related self-concept was measured in terms of both ability beliefs and perceived recognition as a “physics person.” Future research could additionally include students' self-perception as a physics person to capture all elements of the physics identity framework. A limitation concerns the use of different rating scales for interest (five-category) and self-concept (four-category), which restricted direct comparison of response styles across the two constructs. Previous research suggests that having a midpoint (e.g., in a five-category scale) decreases ERS compared to even-numbered scales because both truly neutral respondents who would otherwise be forced into arbitrary directional choices and ambivalent respondents who might otherwise resolve internal conflict by selecting extreme options can use the midpoint [123,124]. Ensuring consistent scaling in future instruments would facilitate comparative analyses of response styles. Our instrument to measure sex was somewhat ambiguous, as the German term *Geschlecht* can

mean both sex and gender. However, because the item read “Please tick your sex” and provided the response categories: female, male, and not specified, we assume that students interpreted it as referring to sex rather than gender. Future research should explicitly focus on gender and unambiguously measure it by using other instruments, such as Dockendorff and Geist's [125] scale for feminine and masculine self-perception and perceived recognition. This would also enable future studies to explore links between gender self-concept, physics-related self-concept, and interest.

(Mixed) Rasch models: A key strength of our study is the use of mixed Rasch models to analyze students' interest. By analyzing mixed Rasch rating-scale models, we identified groups of qualitatively different interest. Mixed Rasch models are particularly suited to identifying such qualitative differences because, unlike multilevel analyses, they do not rely on predefined categories. In our study, this approach provided unique insights into how students' interests vary across groups and how interesting different contexts are relative to one another.

We recommend the use of mixed Rasch models to prevent overgeneralization of findings that may apply only to specific groups of students. For instance, our results suggest that widely held claims, such as boys are more interested in physics than girls, results from the gender differences of the small group of students assigned to the second, small type of interest in mechanics and particle physics, respectively.

We also recommend the use of mixed Rasch models to test for differential item functioning (DIF; [101]). Standard DIF tests rely on predefined categories such as sex or age, which might inadvertently reinforce stereotypes. The advantage of mixed Rasch models over standard DIF testing lies in their ability to detect unexpected forms of DIF, for example, we detected DIF related to students' response styles [101]. We therefore recommend that future studies test for DIF using mixed Rasch models. Constrained mixed Rasch models could confirm the detected DIF related to response style in future work as suggested by Wetzel *et al.* [113].

We used ability point estimates for the secondary analyses, and it would be an interesting idea for future studies to use, for example, plausible values instead, as recommended by Lechner *et al.* [126] and Christensen [127].

A limitation of our approach concerns the treatment of mechanics and particle physics interest as separate unidimensional constructs. The substantial correlation between the two content areas ($r = 0.62$, corresponding to approximately 38% shared variance) indicates the presence of a common underlying component and suggests that the content areas may not be entirely distinct. Future research should therefore extend the present work by applying multidimensional mixed Rasch models. Such models would allow the shared and content area-specific variance

in students' interests to be estimated simultaneously and would provide a more rigorous test of the underlying dimensionality of physics interest.

Logistic regression models: While researchers often erroneously report the odds ratio as ratio of probabilities, it only indicates the direction of the correlational relationship [109]. After determining the direction of the relationships, one can examine the strength of statistically significant relationships in terms of probabilities by manually calculating the relative risk. However, to our knowledge, it is not possible to calculate the probabilities of a one-unit increase on a continuous variable, and hence to calculate the relative risk. Due to these limitations, we could not compare the effect sizes between the categorical variable sex and the continuous variable physics-related self-concept using logistic regression models in our study.

Sample: A limitation of our study is that the sample may be biased toward a higher proportion of particle physics lovers than in the general population. Participating school classes received a CERN-related thank you after participation, particularly a CERN-hosted science show related to particle physics or an overview talk about CERN. This may have attracted teachers who are personally interested in particle physics and inclined to foster this interest in their students. Consequently, the sample may overrepresent students with a strong affinity for particle physics compared to the general population. The observed proportion of TIPP2 students (particle physics lovers, 21%) should therefore be interpreted as an upper-bound estimate rather than a population parameter. Importantly, this potential bias does not affect the HOLIP describing TIPP1 and TIM1 students, nor the associations between interest types, physics-related self-concept, and sex. In addition, teachers who volunteer for a physics education research project may be more dedicated than average, which may have also potentially influenced their students' interest in physics, an aspect relevant for both mechanics and particle physics.

A strength of our sample is the age group (14–16 years, mostly grade 9). Since students' interest in science often declines between ages 10 and 14 [16], we were able to study interest after this critical phase. This also makes our results comparable to large-scale studies such as PISA and ROSE, which focus on 15-year-olds. However, particle physics usually appears only in higher grades, so an older sample might have allowed a more balanced comparison with mechanics. Nevertheless, our aim was to compare interest in two content areas that differ in students' prior school experience.

Although our sample consisted only of German-speaking students, it included participants from Austria, Germany, and Switzerland, supporting generalisability within this linguistic context. Another strength is the large sample size ($N > 1200$), which provides a robust basis for statistical analyses.

Replication and innovation: One strength of our study is that it combines both replicative and innovative elements, (a) a partial replication of the IPN study on the classical physics content area mechanics and (b) an extension to the modern physics content area particle physics. We showed that the IPN findings regarding students' interest types in mechanics can only be partially replicated and that these findings can only partly be transferred to particle physics. An interesting direction for future research would be to examine whether the newly defined interest types can be extended to additional physics content areas.

Hierarchy of levels of interest in physics (HOLIP): One strength of our study lies in the proposed conceptualization of students' interest as a Hierarchy of Levels of Interest in Physics (HOLIP). We were able to interpret these levels through the three components of interest (emotional, value-related, and cognitive-epistemic), aligned with the four-phase model of interest development [43]. Future studies could further investigate students' interest in physics by systematically varying content and contexts while explicitly assessing the emotional, value-related, and cognitive-epistemic components. This would provide additional evidence for the HOLIP conceptualization as a hierarchical structure and its alignment with the phases of interest development. Moreover, longitudinal studies could test whether the hierarchy indeed reflects a developmental process.

A further strength of the HOLIP framework is its practical utility: it offers educators a concise overview of which contexts are more or less interesting and can guide the design of interesting learning activities.

A limitation of our study is that, although tasks were included in the measurement instruments, they were not explicitly considered in the hierarchy of interest levels. We decided against doing so because the variation of tasks was too limited to allow meaningful conclusions. There were four different tasks, of which receiving information (e.g., reading and listening) was represented by seven items, hands-on tasks (e.g., conducting experiments) by one item, minds-on tasks (e.g., calculating) by two items, and evaluating and discussing by one item. Our focus on contexts is supported by the findings of Blankenburg *et al.*, [58] who showed that students reporting higher interest in a specific context also tend to express greater interest in all tasks within that context. Future studies could nevertheless combine systematic variations in both contexts and tasks to extend the HOLIP framework.

VIII. CONCLUSIONS AND IMPLICATIONS

To answer our research questions, we conducted a cross-cohort study with German-speaking students aged 14–16 years ($N = 1219$). We assessed students' interest in mechanics and particle physics, their physics-related self-concept, previous experience with both content areas in school, and sex.

Applying mixed Rasch rating-scale models, we found that most students could be assigned to a single type of interest across both content areas (86% for mechanics and 79% for particle physics): students whose interest in physics depends on the contexts in which it is set, referred to as the context-oriented interest type. Smaller groups emerged as the content-oriented types in mechanics (14%) and particle physics (21%), respectively. While the former was rather equally interested in all mechanics items, the latter showed strong interest in particle physics as a scientific endeavor. Although originally developed for particle physics, we found that the context-oriented interest type can be described with our HOLIP regarding both content areas.

Comparing our results to the IPN study [17,27,28], we observed that the definition of interest types in the IPN study was based on individual groups resulting from a mixed Rasch analysis. We found that not all groups represented actual interest types but rather occurred due to differences in students' use of the rating scale. Hence, two or more groups with similar interest profiles but differing in rating-scale use could be combined into one type of interest. In this sense, also in the reanalysis of the IPN study conducted by Sievers [28], only two types of interest were actually found, one type comprising students who are only interested in physics set in certain contexts and a second type of students who are rather equally interested in all items. Using the original IPN instrument for mechanics, we could partially replicate these findings and extend them to particle physics, indicating that interest structures are comparable across classical and modern physics content areas.

Furthermore, through logistic regression model analyses, we found that students' membership in one or the other interest type of both content areas was better explained by a model including both sex and physics-related self-concept than by the respective baseline models.

Overall, we found no significant gender differences in mean interest, except for particle physics overall, where boys reported higher interest than girls. This effect appears to be primarily driven by the particle physics lover type (TIPP2), although the difference did not reach the Bonferroni-corrected significance level (TIPP2: $p = 0.008$). While focusing on sex or gender differences may appear practical by yielding straightforward recommendations for teaching, such an approach risks unintentionally reinforcing stereotypes (e.g., portraying girls as less interested or in need of special support). Moreover, it overlooks the role of other characteristics such as physics-related self-concept. In our study, girls reported lower mean physics-related self-concept than boys, with this difference being even more pronounced for the interest types associated with higher mean self-concept (e.g., TIPP2). Taken together, our results suggest that students'

interest in physics is shaped not only by their sex but also, more importantly, by their physics-related self-concept, particularly their perceived recognition as a physics person. Hence, for education research, we recommend deemphasizing sex or gender as explanatory variables and instead combining it with physics-related self-concept, as suggested by Höft and Bernholt [128]. Moreover, for educational practice, we recommend that efforts to increase female students' interest should additionally aim at improving their physics-related self-concept, especially their perceived recognition as a physics person. Indeed, previous studies indicate that students may differ in how they develop their self-concept: male students (who typically report higher levels of self-concept) tend to draw on mastery experiences, whereas female students (who typically report lower levels of self-concept) rely more on social persuasion and vicarious experiences [129].

Moreover, we note that current physics education still focuses heavily on scientific and technological contexts, although initiatives such as Science-Technology-Society in the 1970s and 1980s already aimed to bring societal contexts into physics classrooms [130,131]. Our results confirm that the contexts science and technology are interesting to only a few students.

We recommend that educators align their learning activities with the HOLIP conceptualization. The HOLIP can serve as a practical tool for educators to design learning activities that are interesting for most students, regardless of sex or self-concept. In particular, the HOLIP suggests in line with the four-phase model of interest development [43] that contexts addressing the emotional and value-related components of interest are crucial for fostering interest among the context-oriented students. By matching the design of learning activities to the interests of the context-oriented type, educators can also maintain the interest of the content-oriented types. For example, for the particle physics lovers (TIPP2), learning about this content within a scientific context (e.g., quantitative analyses of particle collisions; addressing the cognitive-epistemic component) may be more interesting than everyday-life contexts (e.g., a digital camera as a particle detector). Nevertheless, these students also show strong interest in particle physics when it is embedded in everyday contexts (addressing the value-related component). In contrast, particle physics within the scientific context tends to be interesting only to the particle physics lover type and not to most students.

We therefore suggest that educators apply the HOLIP framework across all physics content areas—provided that the content can be presented within the suggested contexts. In doing so, they can design learning activities that align with the interests of most students, regardless of sex, gender, or physics-related self-concept. Emphasizing similarities, that is, contexts that are interesting for most

students regardless of sex, gender, or self-concept, can support most teachers, as it reflects the typical heterogeneous classrooms they encounter in practice. Finally, we recommend preparing differentiated tasks from time to time, whereby the students can choose the context in which they want to learn a content themselves, and also include contexts that are particularly interesting for students of the smaller interest type.

Our results are also relevant for particle physics outreach, where it is often assumed that the public shares the same enthusiasm for physics as scientists do. Instead, outreach efforts should focus on the contexts in which particle physics can be set and that are interesting for most students.

IX. ETHICAL STATEMENT

The study met the ethics and human subject requirements of the authors' institutions at the time the data was collected. All teachers who were invited to participate in the study with their school classes received an information sheet for their students' parents explaining that

participation was voluntary and that the collected data would be collected anonymously.

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DATA AVAILABILITY

The data that support the findings of this article are openly available [93].

APPENDIX A: MEASURING INTEREST IN MECHANICS AND PARTICLE PHYSICS

TABLE VIII. Original German wordings and English paraphrases of the items to measure mechanics interest.

Item ID	Original German wording	English paraphrase
M01	Mehr darüber erfahren, wie Geräte funktionieren, die Kräfte verstärken (z. B. Flaschenzug, Hebebühne)	Devices that amplify forces (e.g., pulley, lifting platform)
M02	Mehr darüber erfahren, wie man Erdöl aus sehr großen Tiefen (z. B. aus 3000 Metern) herauspumpen kann	Pumping oil from great depths
M03	Mehr darüber erfahren, wie die Wahrscheinlichkeit eines Autounfalls und die Schwere der Unfallfolgen mit zunehmender Geschwindigkeit wachsen	Increase of probability and consequences of a car accident with speed
M04	Mehr darüber erfahren, wie die Bewegungsenergie (Wucht) eines Fahrzeugs in andere Energieformen umgewandelt werden kann (z. B. in den Bremsen oder in der Knautschzone)	Transformation of energy of motion into other forms of energy
M05	Mehr Einblick erhalten, wie die Bewegungsenergie eines Fahrzeugs aus seiner Geschwindigkeit berechnet werden kann	Calculating the energy of motion based on the speed of a car (quantitative)
M06	Mehr Einblick erhalten, welche kraftsparenden Geräte in einer Autowerkstatt verwendet werden	Force-saving devices in a car repair shop
M07	Mehr Einblick erhalten, welche künstlichen Organe (z. B. Herz als Blutpumpe) und Gelenke heute in der Medizin zur Verfügung stehen	Artificial organs and joints in medicine
M08	Mit Rollen und Seilen verschiedene Flaschenzüge bauen und ausprobieren	Constructing different pulleys and trying them out (hands-on)
M09	Sich ein Sicherheitsfahrzeug ausdenken, in dem auch bei schweren Unfällen Fahrer und Beifahrer wenig oder nichts passiert	Designing a safety car for severe accidents (minds-on)

TABLE IX. Original German wordings and English paraphrases of the items to measure particle physics interest.

Item ID	Original German wording	English paraphrase
PP01	Mehr darüber erfahren, wie Geräte funktionieren, die Teilchen detektieren (z. B. Digitalkamera)	Devices that detect particles (e.g., digital camera)
PP02	Mehr darüber erfahren, wie Teilchenphysik zum Verständnis des Urknalls beiträgt	Particle physics and the big bang
PP03	Mehr darüber erfahren, wie mithilfe von Teilchendetektoren geschmuggelte Waffen in einem Container entdeckt werden können	Particle detectors and smuggled arms
PP04	Mehr darüber erfahren, welche Elementarteilchen man im Atomkern-Bereich findet	Particles in the nucleus space of an atom
PP05	Mehr darüber erfahren, wie groß die Massen der Elementarteilchen im Vergleich zueinander sind	Masses of particles (quantitative)
PP06	Mehr Einblick erhalten, wie in der Elektronik-Industrie mit Teilchenbeschleunigern gearbeitet wird	Particle accelerators in the electronics industry
PP07	Mehr Einblick erhalten, wie in einem medizinischen Diagnose-Zentrum gearbeitet wird	Medical diagnostics
PP08	Ein Handy in einen Teilchendetektor umbauen und ausprobieren	Transforming a mobile phone into a particle detector (hands-on)
PP09	Ein Experiment planen, um zu zeigen, wie Teilchen beschleunigt werden	Planning an experiment on particle acceleration (minds-on)
PP10	Berechnen, wie groß die Energie beim Zusammenstoß zweier Teilchen ist, die sich mit nahezu Lichtgeschwindigkeit bewegen	Calculating the energy of a particle collision at the speed of light (minds-on)
PP11	Darüber diskutieren, wie Erkenntnisse im Bereich der Teilchenphysik unser Alltagsleben verändert haben	Particle physics has changed our daily life (discussion)

APPENDIX B: INTEREST IN MECHANICS

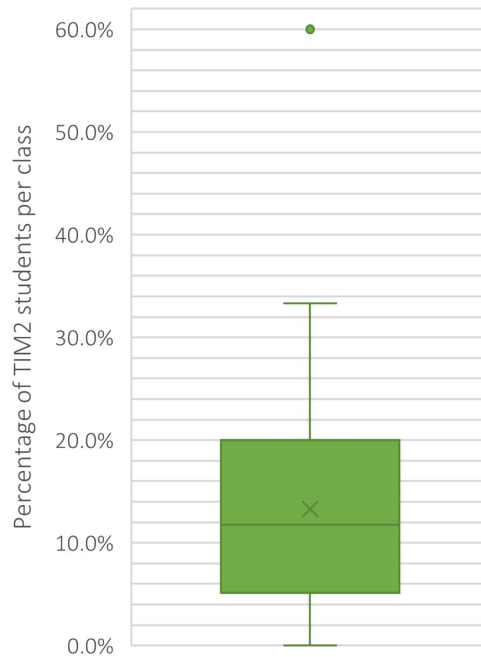


FIG. 7. This boxplot illustrates the distribution of percentage values of the TIM2 across all 62 participating school classes, highlighting the median, mean, and overall spread (incl. one notably high 60% value class).

TABLE X. Characteristics of mechanics interest types.

Type	TIM1 (<i>groups</i> 1 _M , 2 _M , 3 _M)	TIM2 (<i>group</i> 4 _M)
Interest in mechanics (<i>Rasch person measures</i>)		
Mean (SD)	0.46 (0.95)	0.31 (0.75)
Min–Max	–2.15–3.71	–1.26–3.06
Previous experience with mechanics (<i>Rasch person measures</i>)		
Mean (SD)	–0.30 (0.84)	–0.13 (1.01)
Min–Max	–3.57–4.52	–2.73–4.52
Physics-related self-concept (<i>Rasch person measures</i>)		
Mean (SD)	–0.72 (2.02)	0.06 (2.31)
Min–Max	–6.16–5.10	–6.16–4.41
Sex		
Female count (row %, column %)	503 (93.1%, 57.5%)	37 (6.9%, 29.4%)
Male count (row %, column %)	372 (80.7%, 42.5%)	89 (19.3%, 70.6%)

APPENDIX C: INTEREST IN PARTICLE PHYSICS

TABLE XI. Characteristics of particle physics interest types.

Type	TIPP1 (<i>groups</i> 1 _{pp} and 2 _{pp})	TIPP2 (<i>group</i> 3 _{pp})
Interest in particle physics (<i>Rasch person measures</i>)		
Mean (SD)	0.30 (0.95)	1.37 (0.95)
Min–Max	–2.92–3.42	–1.30–3.92
Previous experience with particle physics (<i>Rasch person measures</i>)		
Mean (SD)	–0.69 (0.96)	–0.57 (1.61)
Min–Max	–3.38–4.00	–3.38–4.00
Physics-related self-concept (<i>Rasch person measures</i>)		
Mean (SD)	–0.87 (1.98)	0.35 (2.18)
Min–Max	–6.16–5.10	–6.16–4.41
Sex		
Female count (row %, column %)	480 (88.9%, 60.0%)	60 (11.1%, 29.9%)
Male count (row %, column %)	320 (69.4%, 40.0%)	141 (30.6%, 70.1%)

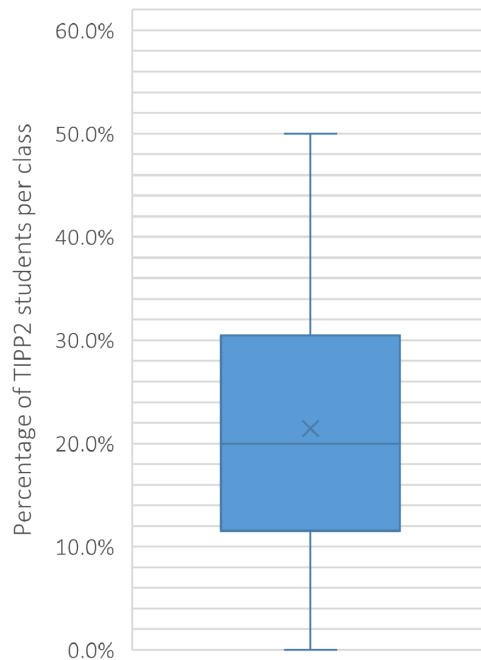


FIG. 8. This boxplot illustrates the distribution of percentage values of the TIPP2 across all 62 participating school classes, highlighting the median, mean, and overall spread.

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