Development, evaluation, and gender differences in a novel workshop intervention to narrow the physics gender gap at postcompulsory level

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To address the issue of gender disparity in participation in the physics state matriculation exam, a novel school visit program was designed. The program was facilitated by undergraduate university students of physics and related courses who visited schools providing lower secondary education and delivered a single-session workshop including hands-on demonstrations of physics principles, presentations about famous female scientists, information on physics-related careers, and the importance of adopting a growth mindset. In this paper, we present a detailed description of the principles underlying the workshop's design and its final outline. Participants' responses to a pre-post questionnaire are analyzed to assess the immediate effects of the workshop, particularly as regards changes in their opinions about physics and students' intention to study it for their state matriculation exam. Female and male responses are analyzed separately to establish differences in the intervention's effect between the two genders. Results show an increase among female students with positive perceptions of their physics knowledge and familiarity with physics role models. Our attempt to boost confidence, enjoyment, and perceptions of the relevance of physics proved challenging but yielded some positive results. Strikingly, girls reported positive change in their ability to imagine themselves as physicists and their intention to study physics for their matriculation exam. The intervention was more successful among younger girls. Results obtained from boys were positive but to a lesser extent. The study demonstrates an encouraging and strong positive impact of a uniquely designed, single-session intervention, especially on adolescent girls, and contributes to research on the effectiveness of gender equality-oriented science outreach interventions.

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I. RESEARCH BACKGROUND AND CONTEXT

For decades, researchers and educators have documented a gender disparity in the uptake of physics at state exams and the ensuing serious underrepresentation of females in university-level physics courses and further on in related industries, labeling the phenomenon the "leaky pipeline." An intervention, called the SOPHia Project, aiming to encourage young women and girls to form positive perceptions of physics, and to help address the gender imbalance in physics at the Irish state matriculation exam was designed at the University of Limerick, Ireland (UL).[1]

The intervention's success is evaluated against three overarching objectives. The first is to change perceptions of physics, especially to break down stereotypes of physics as an exclusive and masculine field of study, best suited to inherently brilliant people who work in a solitary fashion in a very mathematics-related and abstract discipline. The second is to introduce students to physics role models to whom they can relate [1–7]. The third objective is an aspirational aim that through the breaking down of the stereotypes and the introduction of relatable physics role

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[1]The SOPHia Project was designed by the Physics Department at UL, in partnership with the Science Learning Centre, and the Institute of Physics Ireland. It was named the SOPHia Project, an acronym for "Science Outreach for Promoting Physics for Female Students" but also referencing *sophia*—wisdom in Greek.

models, there will be a compound effect of an increase in the number of girls sitting the state examination for physics. In accordance with contemporary understandings in science, technology, engineering, and mathematics (STEM) education research emphasizing the need for ecosystemic interventions (see [8]), the SOPHia Project adopted a multimodal approach comprising a science competition for pupils, a repository of resources for experimental teaching of lower secondary level physics, regular teacher showcase events and interactive school visit workshops.[2] In this paper, for clarity, we investigate and discuss only the latter component: the novel, interactive school visit workshop.

This paper opens by discussing the global issues underlying the gender gap in physics education. We present a breakdown of the intervention goals and the theoretical insights that guided them. Next, the content of the intervention session is set out by examining the workshop schedule. We then discuss the methodological approach to the evaluation of the project's impact, the survey instrument employed, and the data collected while situating those decisions in the specific issues arising in the national context in which this intervention was deployed. Finally, the results of the analysis are discussed. We explore the intervention's impact on girls while comparing it with its effects on boys within the sample population, aiming to determine any gender-specific effects and establish the suitability of the design for enhancing gender parity in the field.

The majority of studies reflecting on gender differences obtained during interventions in physics relate to transformative teaching techniques [9–12]. There is a scarcity of studies presenting the gender effects of interventions aimed at removing the gender gap in physics uptake since the majority are delivered to females only. Studies examining the gender effects analyze attitudes toward science, related self-concept, and sense of belonging at different stages of development, retrospectively or longitudinally [13–15]. Interventions in mathematics and general science or STEM career aspirations often investigate their effects on females separately from males [16–18]. However, as pointed out by Jansen *et al.* [19] since student self-concept needs to be always examined as subject specific, interventions in order to be successful must be subject specific too (p. 19). Physics is an outlier among other science subjects both with respect to its popularity and gender disparity and thus warrants additional attention. Among peer-reviewed manuscripts analyzing the effects of interventions aimed at narrowing the gender gap in physics on boys and girls, we identified the following. The works of Häusler and Hoffman report on a complex multilevel intervention in the provision of physics [20,21]. A study of transnational European cohorts of adolescents participating in science outreach lab intervention at CERN (S'Cool LAB) found that the gender gap in the physics-related interest and self-concept closed among participants after the intervention [22]. Wulff *et al.*'s study of physics identity development intervention aimed at participants of the German Physics Olympiad [23] and a report on a psychological intervention called "values affirmation" by Miyake *et al.* [24]. Sasson and Cohen report on the results of an academic enrichment intervention, which interestingly, generated a gender gap in favor of boys, not recorded beforehand, decreasing the interest and self-efficacy of girls toward physics [25]. Therefore, this manuscript initiates the process of filling a gap in the existing knowledge, which is likely to be of great interest to readers and can hugely benefit the community of physics educators.

The clearly visible gender disparity in the undergraduate physics course at UL, which was typical for physics courses in Ireland, was raised as a problem by one of its female students with one of the coauthors of this paper (G.W.), who at that time was a director of the Science Learning Centre (SLC) at UL. The ensuing conversations prompted the development of the intervention, which involved combined efforts of students, faculty, and staff members at the university, predominantly, but not limited to its physics department.[3] It was unanimously agreed that since the gender imbalance in physics was documented as early as the state matriculation exam, the intervention should focus on fostering interest in studying physics among female students in secondary schools. Our motivation to increase the number of females in physics has also been driven by the hope that once the gender imbalance in courses and professions utilizing physics is reduced, so too will the mistreatment and harassment that some females currently experience [27]. It is important to clarify that the aim of the SOPHia Project was never to recruit participants for the host department or institution but rather to create a space where a passion for physics learning can be ignited.

II. DETAILED DESCRIPTION OF STEPS UNDERTAKEN TO DESIGN AND EVALUATE THE WORKSHOP

A. Step 1. Identifying barriers to girls choosing physics: Initial considerations and theoretical grounding

In this section, we present a summary of our considerations taken at the first step of designing the intervention. The strategy employed in designing this workshop is broken into nine steps that we describe in the following

[2]For details, see website http://sophiaphysics.ie/.

[3]This student was Elora McFall, now a graduate of the BSc in Applied Physics course. Given the ambitious shape of the intervention, students and faculty members in the Education Department and Mathematics and Statistics provided their expertise and time. For the full list of acknowledgments, see the Readme file for the published dataset [26].

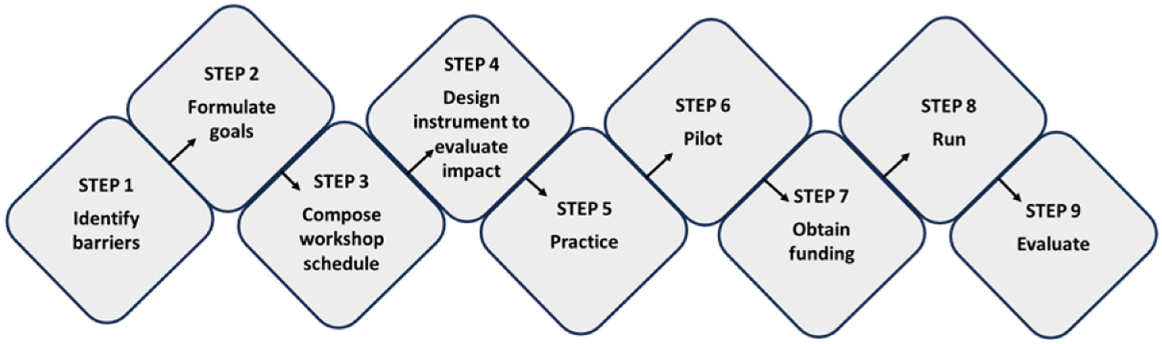


FIG. 1. Schematic visualization of the strategy employed for the development of the workshop intervention.

sections and outlined in Fig. 1 where a tile indicates each consecutive step. Liben and Coyle [28] warn of unintended consequences of STEM interventions aimed at increasing gender parity, which may also "promote or reinforce gender stereotypes in the society more broadly" (p. 108). This can especially happen when the intervention delivery occurs with the separation of females and males in a normally mixed environment since attention to gender distinctions in classroom settings has been found to reinforce stereotypes and limit cross-gender interactions [29,30]. To mitigate such inadvertent results, an inclusive approach was adopted, meaning that workshops are consistently presented to the entire age cohort in coeducational settings (rather than exclusively to girls) and all-boys schools are also presented with a workshop upon their request. Whenever possible, workshops are delivered by facilitators of different genders with at least one being female. These strategies aim to minimize the risk of perpetuating gender stereotypes and promote intergender collaboration among the facilitators.

1. Evidence-informed barriers

Research increasingly highlights how women's interest and persistence in physics hinge on their sense of belonging [6,13,31–33]. Thus, to develop the workshop intervention, the project team decided to focus on the theories of female science identities and synthesize them with evidence-based practices to promote increased identification with and participation in physics.

Stereotypes surrounding physics are found to negatively affect a sense of belonging among girls in physics classrooms [6,34]. One such stereotype characterizes physics as another version of mathematics, and the mechanisms found to affect the sense of belonging in mathematics also affect physics. Mathematics ability relative to verbal ability is a factor influencing decisions to pursue "math-intensive fields," to which physics belongs [35]. Mathematics preparation was found to be "the strongest predictor of university physics performance" [36]. Both disciplines are often perceived, both by pupils and teachers, as masculine: they are characterized as "boys' subjects" [37–41].

The pool of characteristics stereotypically associated with those who do physics is small and restrictive. Across cohorts of all genders, the stereotypical scientist is imagined as innately brainy and clever, male, white, wearing a lab coat, working indoors, and often transgressing the standards of "normality," visibly marked by their crazy hair [42]. Young people's opinions about scientists, and more specifically physicists, have been analyzed for decades with successive iterations of the Draw-A-Scientist-Test as well as qualitative research. The responses in those studies remain remarkably stable [43–47]. They are reflected in the pupils' opinions about those who are good at physics in school, translating into ideas about who can and who cannot do it. Archer *et al.* [48] dissect the complexities of the phenomenon of the "'brainy', 'middle-class masculinity' (…) associated with science" in multiple works (p. 21; also see [1,46–50]).

Good *et al.* [51] prove that the combination of gender-related stereotypes with the belief in a fixed mindset (belief in brilliance as a prerequisite to study a subject) leads to decreased interest in pursuing mathematics and math-based disciplines, such as physics or engineering, among women. Deiglmayr *et al.* found that students within ETH Zurich[4] in the most math-intensive fields (physics and mathematics) endorse belief in brilliance much more than students in fields of lower math intensity with low female participation (computer science and mechanical engineering; see p. 5 in Ref. [52]). The potential of a growth mindset has been meticulously studied and documented [53,54]. Lewis *et al.* [6] and Good *et al.* [51] encourage educators to counteract stereotypes by replacing a fixed mindset with a growth mindset and introducing praise for hard work to improve women's sense of belonging.

Physics applicability can be difficult to imagine outside a research lab [45,55,56]. It is perceived as dull, as is mathematics, whereas a perceived lack of relevance separates physics from other science subjects (such as biology) which are more popular, especially among girls. Physics is seen as "important but not for me" by adolescent pupils and more so by female ones. Multiple studies highlight the need

[4]ETH Zurich is the Swiss Federal Institute of Technology Zurich, a public research university in Zürich, Switzerland.

TABLE I. Barriers to female participation in physics: stereotypes, opinions, and facts. The positioning of barriers in rows reflects only the connections that we considered the strongest and most obvious. For example, the stereotype of innate cleverness is a very powerful belief that could also be associated with the "female achievement vs confidence" paradox.

Facts	Stereotypes	Opinions
There are more men in physics.	Physics is a boys' subject.	
Mathematics ability is linked to the choice of physics.	Physics is a version of mathematics.	Physics is boring.
Teaching of physics can be theory-heavy.		
Achievement in physics is not linked with the subject's continuation—for girls only.	Physics is difficult.	I will not be able to succeed in physics.
Pupils do not know what physics is—what the subject deals with.		Physics is irrelevant—for me now.
Pupils do not know what careers require or benefit from physics knowledge.		Physics is irrelevant—for my future.
	Cleverness or brain type required.	
	Image of a physicist.	

to improve both conceptual understanding and contextual relevance in the teaching of the subject to decrease the gender gap in physics [32,57,58]. Cleaves [55] argues that the "vast majority of students enjoy practical aspects of science" and yet "facts, principles and theories (…) become dominant" as children progress through their science education (p. 483). Siegel and Ranney [59] have shown that opinions about the relevance of science can be positively changed with a meaningful intervention. Female pupils' self-efficacy[5] in physics can be much lower than warranted by their attainment compared to their male peers of similar achievement [61–65]. Even good attainment in lower-level physics is not a predictor of continuation for girls [37,63]. It has also been documented that students with a physics role model in their close environments are more likely to choose physics [66,67]. The scarcity of female role models in physics reflects and reinforces the gender imbalance within the field. Since it is suggested to create challenges in the development of a female physics identity, it is often proposed as a factor in perpetuating the gender gap in physics [68,69]. Observing other women perform physics tasks and hearing about their career journeys can help them "visualise their own success in comparable roles" and thus offset the shortage of female physics role models and boost their self-efficacy (see p. 020116–8 in Ref. [70]).

Based on the review of the literature, all the above barriers were deemed crucial in understanding a female sense of belonging/not belonging in the physics classroom and in the construction of the workshop intervention. To address these barriers, which are multiple, interrelated, and operating at many levels, careful untangling had to be done. The barriers were classified into three categories: stereotypes, opinions, and facts. This classification helped us design the specific elements of the intervention. In our classification, stereotypes and opinions are both beliefs about physics, which are passed on informally both in institutionalized schooling and outside of it. We consider stereotypes to be general beliefs about what physics is whereas opinions are of a more affective and subjective nature. A stereotype can be conveyed in a statement stating that "it is widely known that physics is x," whereas an opinion: "I feel that physics is x." Stereotypes can be disrupted either by discussion or a demonstration of the counterfact. Opinions are the most intrinsic of all the three types of barriers, thus the most challenging to influence, and are only subject to change with sustained effort, if at all [18]. Research shows that some facts can be candidly called out to inspire change (e.g., "explicit discussion of underrepresentation of women in science" has been shown to have positive impact on female adolescents [13] p. 993). In Table I, we present how we classified the barriers.

[5]Defined by the term's creator, Albert Bandura, as one's beliefs about their capabilities to produce designated levels of performance in areas that are considered important to the person undertaking them [60].

B. Step 2. Formulating goals and means

Step 2 involved deciding what goals the intervention will strive to achieve and what means will be employed to obtain them. The goals were selected to balance logistical feasibility with reasonable expectations of impact. Acknowledging the national context, outlined subsequently (section F9.2), the focus was placed on addressing the lack of knowledge about physics, as the foremost determinant of students' lack of engagement with the subject. Stereotypes, notably affecting young female students, as previously discussed, arise in knowledge gaps. Table II shows the breakdown of the goals and means.

C. Step 3. Designing the means to achieve goals: Workshop components and delivery

It was decided that "what" is presented to pupils and "how" it is done would be equally important for the success

TABLE II. Breakdown of goals with means to achieve them.

Goal	Way to achieve it
G1: Show what physics is.	Quote, discussion + demos, and questions throughout.
G1a: Show that physics is the investigation of the world around us.	Demos and questions refer to natural phenomena. Demos are based on standard household items; students can repeat them at home.
G1b: Show that physics is not mathematics.	Demos and questions show the experimental nature of physics and participants are actively encouraged to participate and think out loud.
G2: Discuss the stereotypical traits associated with physicists.	Facilitators: 1. Break down every stereotypical trait. 2. Talk about themselves as physicists, they are young and relatable.
G2a: Frame physics (discipline) and its learning (school subject) as accessible and possible "for people like me".	Facilitators' short bios together with a message of not needing "a special brain type, cleverness, or mathsiness to do physics" serve as embodied evidence of physics being suitable and attainable for young people, including girls.
G3: Discuss gender discrimination in the sciences.	Gender discrimination has many faces and creates a self-fulfilling prophecy but physics is for everyone. Physics appears as a masculine subject (which in the feminist reading means that not only is it a boys' subject but also that it has the properties of the dominant group: white, middle class, appearing effortlessly clever). Explicit talk about gender discrimination in sciences—found to have a positive effect [13].
G4: Offset apparent lack of relevant role models.	Create foundations for identification with role models via 1. Facilitators: young undergraduate students. They deliver information about physics as a science discipline, as a school subject but also as their own chosen path. 2. Bios of famous female physicists from marginalized backgrounds or transgressing the usual expectations of masculine, coat-wearing, lab-based physicists.
G5: Show where studying physics can lead to (career opportunities).	Information about the applicability of physics in various disciplines and professions, supported by specific examples of industry careers of physics graduates from our university.
G6: Show what studying physics for the physics state matriculation exam entails (curriculum).	Toward the end of the workshop: linking the workshop contents to the syllabus.
G7: Dismantle the negative stereotypes about what physics is, who does physics, and what can you do with physics knowledge.	By combining all the above means for a positive experience of an engaging and informative workshop, hopefully transforming the student-physics relationship.
G7a: Lay foundations for informed subject choice, possibly of physics, as their state matriculation exam subject.	By providing relevant information.

of the intervention. Below, we present the rationale for a single-session workshop intervention mode, its components, and then details of delivery deemed crucial for reaching the goals.

1. Choice of a workshop format

Since the roots of gender underrepresentation in STEM are multidimensional and multicontextual, likewise, the range of the interventions rolled out to combat the issue

TABLE III. Detailed outline of a workshop. [a]Boomwhackers are plastic tubes of the same circumference but different lengths, which, when hit against a surface, produce sounds of different pitch. They are color-coded and have additional marking about the notes they represent.

Workshop component	Description of the component
Introduction, setup, and prepart of the survey.	While facilitators are setting up, participants are asked to answer the metric and pre-part of the survey.
Draw a scientist.	Participants are asked to use the empty space at the back of the survey form and draw a scientist.
Facilitators.	At least one facilitator is female. All facilitators are close in age to the school students, with the majority being undergraduate students and some postgraduates.
One of the facilitators sets up Alka-Seltzer explosions.	Facilitators shake an Alka-Seltzer tablet in a bit of water inside a closed container. As the tablet fizzes inside, the closed container is placed on the ground, away from the audience but within their sight. The container explodes and zooms through the air as facilitators talk. They ask the audience “what happened?” (to explain what they saw).
The facilitators introduce themselves briefly.	They provide a very brief introduction: “My name is … and I study …”
They ask about the Draw—A—Scientist task.	Then facilitators ask specific questions: Who drew a man with crazy hair? Who drew a man in a lab coat? Or walk around the classroom to look at the drawings and then refer to them. There is a direct statement made that not all scientists look like Albert Einstein. In fact, the facilitators are scientists: they name the courses they study and declare that “I am a physicist” adding that they do not have crazy hair and/or that they are a girl and that they only sometimes wear a lab coat.
What is physics?	Definition of physics (Lene Hau quote) is given: “Physics is about questioning, studying, probing nature. You probe, and, if you’re lucky, you get strange clues” “Physics describes how things behave: From the biggest objects in the universe… To the smallest….”
Physics questions (throughout):	Facilitators ask the following questions: How did the universe begin? How does the Sun keep on shining? Why did this apple just fall on my head?! (+A short mention of Newton, leading to information about his book being locked away in a secret location in Marsh’s Library in Dublin—locally relevant.) Why is the sky blue? How long can you survive in space without a spacesuit? Why do you spin faster with legs/arms tucked in?
Demos (throughout):	Facilitators alternate between questions and demos: poking a ziplock bag filled with water with sharp pencils, Alka-Seltzer, spinning a cup of water in the air, spinning on an office chair, sucking cup with water upside down to cardboard-defying gravity.
More questions.	A CERN outline drawn on a satellite picture is shown. What is it? Explanation leads to questions about space. Sometimes it is linked to a short bio of Jocelyn Bell Burnell.
Facilitators present a chosen physics figure from a marginalized background.	Example figures are Jocelyn Bell Burnell; Hedy Lamar; Marie Curie-Skłodowska; Merritt Moore; Nora Patten.
Why did I choose physics?	Each facilitator gives a personal account of their path to becoming a physicist.
Boomwhackers[a]	Each student in the audience has a boomwhacker and they make music together: they play a popular song following the notes projected on the board.
Overview of the physics curriculum at the state matriculation exam.	Facilitators link the curriculum to demos and questions from the workshop.
What can you do with a physics degree?	The workshop also contains information about career options available for those with qualifications in physics.
Postpart of the survey.	Participants are asked to answer the postpart of the survey.

internationally is equally layered and complex. Some aim to modify institutional practices or influence parental attitudes toward science [71–73]. Others aim to transform school culture holistically and tackle biases and stereotyping as exemplified by the "Improving Gender Balance" initiative in the United Kingdom and Ireland [4,7]. Extracurricular interventions have proven successful in providing career information and subject choices [74,75]. An outreach intervention, where undergraduate facilitators directly engage with secondary school pupils, was chosen as the most appropriate means of influencing the physics identity of students. Evans strongly advocates for extracurricular interventions as they offer students "opportunities to observe role models and to gain realistic views of the world of work" (cited in Ref. [76]). The SOPHia Project intervention does not intend to teach physics, but rather teach about it, by illuminating aspects of physics beyond the national syllabus and enhancing the female pupils' sense of belonging by redirecting the focus from mathematical calculations to the experimental aspect of physics [6,34,77]. Therefore, the single-session workshop model aligns with similar projects targeting various actors or topics, such as professional development for science teachers [78], learning strategies for biology students [79], addressing impostor syndrome among students in the healthcare sector [80], and combatting microaggressions in science and engineering [81]. Such an intervention proved successful among girls at reversing their gender stereotypical views about technology being for boys only [82].

2. Workshop outline and delivery

A schedule for a workshop session is presented in Table III. The workshops are delivered to students in their schools during their regular school day, replacing one of their classes, in a laboratory, demonstration room, or science classroom, depending on availability and the school's resources. Each session is delivered by a team of two or three facilitators, with at least one being female. While the organization of workshops can be challenging, as school visits must align with the busy timetables of physics undergraduates, it remains a non-negotiable aspect of the workshop that all new facilitators must belong to the undergraduate student cohort, to minimize the age difference between the facilitators and the audience, enhancing relatability and fostering an engaging learning experience. Some facilitators continue their involvement with the project even after commencing their postgraduate studies, ensuring a seamless transfer of knowledge, but they are then accompanied by undergraduates during each session. All facilitators are financially remunerated for their contributions to the project.

To maximize the impact of the workshops, pupils are continuously encouraged to share their knowledge or speculate about all presented phenomena ("What just happened?," "Why?"). They are rewarded for their active participation, irrespective of the merit of their contributions, and for engaging in practical activities. These rewards are provided by the Institute of Physics (IOP) and include items such as physics comic strips, stickers, pens, erasers, or booklets containing physics formulas, among others. Each workshop is accompanied by a slideshow, which serves to anchor both the audience and facilitators in the content of the workshop, ensuring that even reserved participants remain engaged and that the facilitators maintain the workshop's rich content and demanding pace. A set of standard slides is included in the Supplementary Material [83], comprising two slides contributed by former facilitators which they used while presenting themselves during the workshops.

D. Step 4. Designing the instrument to evaluate the impact

1. Introduction

The studied intervention does not aim to teach physics curriculum content but rather achieve a complex set of goals. Hence its evaluation answers the questions "what happened" as well as "how it happened" [84], specifically "'Did participation in the workshop have an effect on females' beliefs about the possibility of studying physics?" but more importantly "What part of the workshop made a lasting impression?" and "What was the impression?"

Since the facilitators change from session to session, the content is delivered in their own unique ways, and workshop comparability is limited.[6] All these factors mean that explanations of the causal relationships need to be based "on both empirical and substantive knowledge gained on the program and its setting" ([86] p. 5), rather than on the randomized controlled studies. The latter is a "gold standard" in educational research yet has been contested by several researchers, campaigning instead for both the need for and value of insight coming from qualitative inquiry [75,87].

The chosen model of evaluation follows the five principles of the extended term mixed method (ETMM) approach, as formulated by Chatterji [86]. It is, *inter alia*, based on a long-term research plan, measuring immediate and long-term impact with the use of mixed methods. The early phase stems from the review of literature which informed the intervention design. The use of a pre-post-type feedback survey was found to best measure the intervention's immediate impact since it captures the change in sentiments reported before and after the event. Thus, the survey was designed as a set of quantitative, closed-ended, Likert-type questions and one general open-ended question about participants' changes in attitudes, probing the dynamics of the student-physics

[6]This is due to the considerable time and effort required for workshop preparation and execution, complicated by the busy schedules of undergraduate students in hands-on, lab-driven courses. Additionally, this approach provides many students with the opportunity to participate in the outreach project and thus develop their physics identity and contribute to the morale of the students and staff of the participating departments [85].

relationship. The quantitative questions in the survey which are analyzed in this paper ask the participants pre- and postworkshop about their knowledge of what physics is, their enjoyment of physics, and its relevance, their feelings about physics role models, and their confidence in learning about physics as well as their intention to choose the subject for their matriculation exam. Data were collected on site, with a pen-and-paper method.

Recognizing that changing deeply ingrained perceptions takes time and sustained effort, the workshop's primary goal is to provide honest and reliable information and showcase perspectives often overlooked in physics education, thus addressing stereotypes that fill the gaps in knowledge. Therefore, the evaluation of the immediate effect focuses on participants' reported changes in their sentiments rather than their sentiments reported postworkshop as stand-alone measures. For example, the question on intention to study physics for the matriculation exam does not measure the numbers of participants who will pursue it but rather if the workshop has made it conceivable for participants who previously could not envision themselves doing physics to now see it as an imaginable option.[7]

The second, ongoing, phase is guided by the qualitative data collected with the pre-post questionnaire (open question) as well as in-depth group discussions with participants conducted at least a year after the intervention. During this stage, both the sustained impact of the intervention and the more transient attitudes and complex areas (especially stereotypes and career opportunities) are investigated.[8] This qualitative research is led by the workshop design principles and the insights gained from the analysis of the survey results, presented herein. The data collection for this second phase is ongoing, and results will be presented in a separate publication.

2. Research questions

Through the use of the pre-post survey instrument, the following questions are answered:

1. What immediate impact, if any, does participation in the workshop have on students' perceptions of physics, including filling in gaps in their knowledge about physics and in removing negative stereotypes about the subject? Can workshop participation influence students' enjoyment of learning physics, confidence in performing physics-related tasks, and appreciation of the relevance of physics in daily life?
2. How does participation in the workshop influence male students' perceptions of physics compared to those of female students'? Are there differences in the effects of the workshop on male and female students?
3. What immediate impact, if any, does participation in the workshop have on students' declared intention to study physics for their leaving certificate?[9] Are there differences in the effects of the workshop on male and female students' intentions to study physics for their leaving certificate?

3. Survey instrument

An overview of the questions and possible answers is presented in Table IV. Responses to the quantitative questions were measured on a five-point scale, ranging from 1 (not at all confident/not much) to 5 (very confident/a lot).

The questionnaire intentionally adopts a concise format with Likert scale labels, to accommodate data collection within the confines of a single workshop time slot, which, in some schools, may be as short as 40 min. Given these time constraints, there is no provision for elaborate scales measuring attitudes or identity formation. Importantly, this survey was designed to measure changes in specific attitudes or opinions resulting from workshop participation, rather than assessing overall attitudes or intentions. Therefore, the postworkshop results should not be viewed in isolation as stand-alone measures of opinion or intention; rather, it is the change that is being measured. The consistency of question and answer scales before and after the intervention ensures that participants ascribe the same meaning to each question. For the purposes of measuring immediate change imprinted by the workshop, the slight differences in specific interpretation assigned to each question are not critical. The results demonstrate that the distribution and range of answers for each question remain diverse within and across waves of data collection (including the pilot phase), indicating that students provide individualized responses to each question rather than consistently selecting the same answer. This variability in responses across questions, especially in the size of change, supports the reliability of the survey's results.

The dataset containing the responses can be downloaded from the institutional repository of the University of Limerick [26] along with a Readme file with a detailed description of the questionnaire and its measures. Some qualitative questions were included in the questionnaire; however, only the fully quantitative survey items were made publicly available and these are analyzed in this paper.

[7]It should be noted that the original plan included an additional assessment of the workshop's impact on postcompulsory physics uptake the following year through teacher feedback. Disappointingly, we could not retrieve this information from some schools. However, the workshop has been consistently delivered annually in several schools (all of them are all girls) that report that physics uptake increased following the initial workshop, has since remained stable, and therefore the workshop has been incorporated into the schools' annual schedule.

[8]Note: The cohorts who participated in the workshops for which feedback is analyzed left the schools before all the COVID-19 related restrictions were lifted. The qualitative research taking place now involves pupils who participated in the Project workshops during COVID-19 (online) and soon after.

[9]The state matriculation exam in Ireland. More information about the Irish educational system is provided in Sec. II (National context) of Step 6.

TABLE IV. List of closed-ended questions in the pre-post workshop questionnaire. Sections "A" (A1–A4) and "B" (B1–B6) were answered before the intervention, section "C" (C1–C6) directly afterward. [a]TY = Transition Year, explained below in subsection F.2; [b]leaving certificate = state matriculation exam.

Question	Range of answers
A1. Have you studied physics at Junior Cycle Science?	No, yes
A2. Have you studied physics during Transition Year?	No, yes
A3. Select your gender	Male, female, other, prefer not to say
A4. What year are you in?	1, 2, 3, 4 ([a]TY)
B1/C1. Do you think you know much what physics is about?	Not much, below average, average, above average, a lot
B2/C2. Do you enjoy learning about physics and physics-related topics (astronomy, electricity, the weather)?	Not much, below average, average, above average, a lot
B3/C3. Do you feel confident about doing and learning about physics at school?	Not confident at all, not confident, average, confident, very (much) confident
B4/C4. Do you feel like there are good physics role models for someone like you?	Not much, below average, average, above average, a lot
B5/C5. Do you think physics is interesting and important in your life?	Not much, below average, average, above average, a lot
B6/C6. Do you think you are likely to take physics as a subject for your [b]leaving certificate?	No, maybe, yes

E. Steps 5–8. Pilot study and rollout

The workshop was piloted in 2018. Its evaluation was based on answers to open-ended questions from teachers who witnessed the workshop and on the pre-post feedback forms from students. The project was granted funding and started providing workshops in January 2019, continuing until March of 2020. During this phase, workshops were delivered to 14 secondary schools, 10 of which were all girls and 4 coeducational, in the Mid-West of Ireland.

1. Participating schools

Initial school recruitment targeted physics teachers in schools previously engaged with UL Department of Physics outreach. Invitations for workshops were extended, with further outreach facilitated through a snowball effect, and new schools contacting the project and expressing interest after hearing about the program.

2. Data collection recruitment process

Teachers were informed about the data collection and were responsible for securing parental consent from the pupils. It was communicated to the pupils that their participation in the survey was voluntary. We stress that regardless of parental consent, all pupils present in the class were handed the questionnaire. The inclusion criteria for this study, however, encompassed pupils who attended the workshops and had obtained parental consent. Thus, questionnaires from pupils who did not provide parental consent were separated after collection and were not included in the published dataset.

Demographics of the studied population. Detailed demographic information and participant breakdown can be found in Table V, which illustrates the distribution of female and male pupils across different years of study. There were 668 consented responses collected. Among them, 562 participants (84.53%) identified as "female," indicating the predominant representation of female pupils. A number of respondents, 76, (11.4%) identified as "male," while 30 pupils (4.5%) chose the option "other" or left the answer blank.

3. Ethical considerations

Ethical approval (reference no. 2018_11_09_S&E) was obtained from the relevant institutional ethics committee for data collection throughout the SOPHia Project, ensuring compliance with ethical considerations.

F. Step 9. Analysis of the data obtained with the survey instrument

1. Introduction and methodology

The study was conducted to verify if, and to what extent, the design of the intervention aligned with its objectives. The data analysis was performed via an interactive web application created in the R environment (3.6.3) using the

TABLE V. Distribution of pupils who participated in the SOPHia workshops broken down by their school year and gender. Note that TY is the Transition Year.

Student gender	School year					Total
	Unknown	1st	2nd	3rd	4th (TY)	
Female	3	64	101	152	242	562
	0.5%	11.4%	18.0%	27.0%	43.1%	100.0%
Male	1	0	13	27	35	76
	1.3%	0.0%	17.1%	35.5%	46.1%	100.0%
Unknown	2	1	7	7	13	30
	6.7%	3.3%	23.3%	23.3%	43.3%	100.0%
Total	6	65	121	186	290	668
	0.9%	9.7%	18.1%	27.8%	43.4%	100.0%

Shiny framework (version 1.4.0.2)[10] for statistical computations and visualizations. Microsoft Excel was utilized to conduct parallel analysis and generate graphs and charts.

To examine shifts in participants' attitudes and perceptions before and after the workshop, Wilcoxon signed-rank tests were employed, chosen for their suitability with ordinal data. Answers pre- and postintervention from each participant were cross tabulated and categorized as one of the following changes: positive (higher postworkshop response), no change, and negative (lower postworkshop response) (see Tables VII–XI below for females and the Appendix, Tables XIV–XVII for males). The obtained changes were subsequently cross tabulated with school years. Sankey plots were generated to visualize the transfers of responses between pre- and postintervention. All tests were conducted separately for female and male participants.

2. National context

In Ireland, once children complete primary school, around the age of 12 or 13, they enter the lower secondary education program,[11] called the Junior Cycle (JC), at a second-level school, encompassing three years of study. We refer to these years of study in this paper as school years 1 to 3. Next, pupils (around 15 or 16 years of age) have an option (although in some schools it is compulsory) to take a Transition Year (TY). It is a one-year program bridging the Junior and Senior Cycle (SC). During this year, students are expected to reflect upon "possible future careers or areas of study" (see Ref. [88] p. 3) TY steers away from traditional curriculum-based learning and offers a more flexible and diverse educational experience. Its focus is on personal, social, vocational, and educational development [89]. We refer to it as school year 4. The ensuing 2 years of higher secondary education in Ireland (at the same school) are called Senior Cycle (SC) and are highly focused on preparation for the standardized state exam, which additionally serves as an entry exam to third-level courses, called the leaving certificate (LC). Pupils typically choose subjects they wish to study in SC in the Spring preceding their first year of their SC (in school year 3 or 4, i.e., TY).

Pupils in the JC study a general "Science" subject with five strands: The Nature of Science, The Physical World, The Chemical World, The Biological World, and Earth and Space [90]. The teachers have considerable flexibility to focus on their favorite subject in the delivery of the JC Science curriculum and thus cover very briefly the part for which they have little liking or confidence [91,92].

[10]In conjunction with other packages such as plyr (1.8.6), tsoutliers (0.6–8), moments (0.14), nortest (1.0–4), and stats (3.6.3) and XLConnect (1.0.1) to permit the importation of Microsoft Excel files into the R working environment.

[11]As per the UNESCO's International Standard Classification of Education (ISCED, 2011) https://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-isced-2011-en.pdf.

TABLE VI. Number of teachers currently registered with the teaching council of Ireland to teach each science subject (June 2023). Source: private communication between the teaching council Ireland and the Department of Physics at the University of Limerick. [a]Biology, chemistry, physics, agricultural science, and physics and chemistry are all subjects taught for the leaving certificate, i.e., for the senior cycle in Irish schools providing secondary education.

Subject[a]	Number of teachers
Biology	4882
Chemistry	2664
Physics	1406
Agricultural science	1075
Physics and chemistry	49

As shown in Table VI, few science teachers are registered to teach physics. This distribution of science subject specializations suggests that a majority of Irish students are introduced to physics during the JC by teachers who lack a formal education in physics that meets the minimum requirements for registration as a physics teacher. And yet, to study physics as a stand-alone subject, in SC, pupils need to make a deliberate choice. Their knowledge of physics hinges on the physics instruction received in JC and TY and how much it resonated with them.

The school visit workshop was originally aimed at pupils in the Transition Year and 3rd year (last year of JC), when pupils are choosing their subjects for LC. Additionally, during the Transition Year, pupils are expected to participate in career workshops. However, some schools asked for the project to be presented to students in other school years so workshops were delivered to pupils across school years 1 to 4.

III. FINDINGS

A. Effects on female respondents

In this section, we present the effects of the intervention on the female participants. Table VII presents the results of a Wilcoxon signed-rank test conducted on populations of female and male participants ($N = 562$ and $N = 76$, respectively). It can be seen that for females, there are strong grounds for the confident rejection of the null hypothesis, which had a probability of far less than the significance level (α) of 0.05 for all tests.

In the pre-post survey, the workshop participants were asked to describe their knowledge of what physics is, with answers on a five-point scale ranging from "Not much" (1) to "A lot" (5) (as described in Table IV). Results from this question are presented in Table VIII and Figs. 2 and 3.

As illustrated in Fig. 2, the frequency distribution of responses before the workshop is slightly skewed to low levels of knowledge and after the workshop becomes skewed in the direction of higher levels, with the mode answer changing from midpoint "average" to a higher level

TABLE VII. Results of Wilcoxon signed-rank test for gender subgroups. Note: L. Cert. = leaving certificate. [a]w_s Smaller of the absolute value of signed ranks. [b]Small reduced sample size criteria used. [c]Null hypothesis only rejected on the basis of a threshold of less than 5%. All other values rejected based on a threshold of less than 1%.

Question	Sample size (N)	Reduced sample size (n)	Sum of positive ranks	Sum of negative ranks	z Test statistic	Probability of H_0	Conclusion
Females							
Knowledge	550	398	77661.0	1740.0[a]	−16.53	1.11^{-61}	Reject H_0
Role models	543	415	84482.5	1837.5[a]	−16.90	2.20^{-64}	Reject H_0
Confidence	547	282	33523.5	6379.5[a]	−9.90	2.05^{-23}	Reject H_0
Enjoyment	547	316	45659.5	4426.5[a]	−12.68	3.64^{-37}	Reject H_0
Appreciation	544	329	48573.0	5712.0[a]	−12.41	1.13^{-35}	Reject H_0
Physics for L. Cert.	542	172	13943.0	935.0[a]	−9.94	1.33^{-23}	Reject H_0
Males							
Knowledge	75	45	947.5	87.5[a]	−4.85	6.06^{-7}	Reject H_0
Role models	74	35	549.0	81.0[a]	−3.83	6.34^{-5}	Reject H_0
Confidence	74	27	307.5	70.5[a]	−2.85	$n < 30$	[b]Reject H_0 (for $w_s < 83$; $z < 1\%$)
Enjoyment	75	32	372.0	156.0[a]	−2.02	2.17^{-2}	[c]Reject H_0 (for $z < 5\%$)
Appreciation	74	30	370.0	95.0[a]	−2.83	2.34^{-3}	Reject H_0
Physics for L. Cert.	74	13	56.0	35.0[a]	−0.73	$n < 30$	[b]Fail to reject H_0 (for $w_s < 21$; $z < 10\%$)

"above average." There is a considerable increase in the highest positive responses, choosing "a lot" (+56 cases). Figure 3 shows that there are multiple transfers to higher levels from across the whole range of answers to the question. Only very small numbers report a negative change, where the answer post is at a lower level than pre. The predominance of positive change is most strongly demonstrated in Table VIII where almost all data are on or below the primary diagonal of the matrix shown in the table (and a scarcity of responses recorded above the primary diagonal). Overall, 70% of female students in the sample reported a positive change in their knowledge of what physics is. This shows an encouraging impact of the SOPHia Project intervention but also highlights the initial low levels of knowledge about what physics is among the secondary school students.

Participants answered a question "Do you feel like there are good physics role models for you?" using a five-point scale where 1 is "Not much" and 5 is "A lot." Results are shown in Table IX and Figs. 4 and 5.

As illustrated in Fig. 4, the frequency distribution of responses preworkshop is skewed toward the lowest levels of awareness of physics role models, with a modal answer at the lowest point "not much" (337 respondents). Postworkshop the answers become more normally distributed, with only slight skewness to the left (low levels). Figure 5 highlights that the intervention had a positive effect on the participants but to varied degrees. Although 61

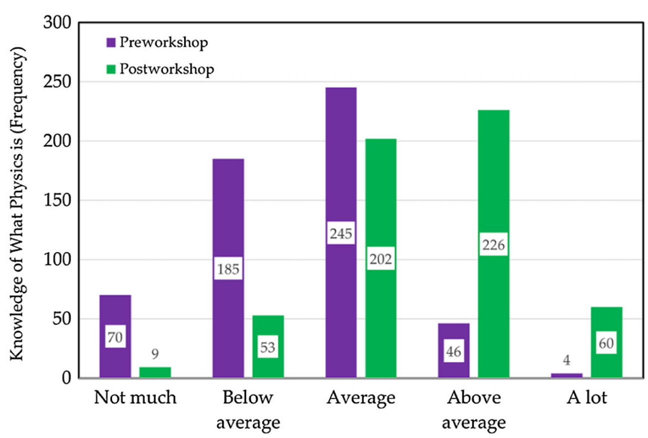


FIG. 2. Bar chart of responses by female students to question B/C1 (knowledge of what physics is), pre and post the workshop, with response values ranging from 1 = Not Much to 5 = A Lot. $N = 562$.

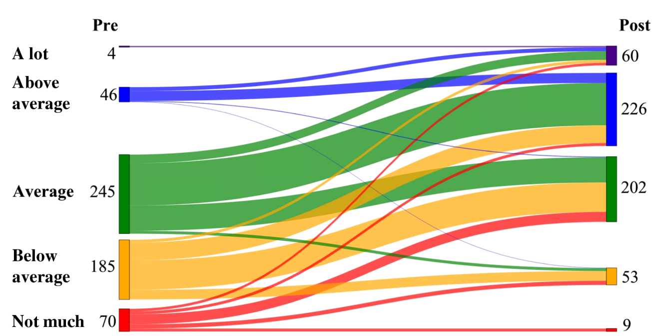


FIG. 3. Sankey plot showing transfers of answers from pre- to postworkshop to question B/C1 (knowledge of what physics is) from female students. $N = 562$. Missing answers are not included.

TABLE VIII. Cross tabulation of answers from female students to question B/C1 (Do you think you know what physics is about?) pre/postintervention. $N = 562$.

Pre ⇓	Post ⇒ (5)	(4)	(3)	(2)	(1)	(0)
A lot (5)	4	0	0	0	0	0
Above average (4)	12	31	2	1	0	1
Average (3)	27	131	78	9	0	8
Below average (2)	9	55	91	30	0	2
Not much (1)	8	9	31	13	9	1
No answer (0)	0	0	0	0	0	0

TABLE IX. Cross tabulation of answers from female students to question B/C4 (Do you feel like there are good physics role models for someone like you?) pre/postintervention. $N = 562$.

Pre ⇓	Post ⇒ (5)	(4)	(3)	(2)	(1)	(0)
A lot (5)	6	0	1	0	0	1
Above average (4)	5	6	2	0	0	0
Average (3)	6	23	12	1	2	3
Below average (2)	12	34	46	43	7	4
Not much (1)	24	51	79	122	61	6
No answer (0)	0	1	2	2	0	0

of those respondents who chose "not much" preworkshop did not change their opinion afterward, 276 of them changed their answer to a more positive response postworkshop. It can be noted that 140 of those students assessed their awareness of physics role models postworkshop as "average," 114 as "above average," and 53 changed to "a lot," an increase from 44, 13 and 7, respectively (as can be seen in Table IX). Overall, three-quarters (74%) of respondents reported a positive change in their feelings following the SOPHia intervention.

Workshop participants were also asked about their confidence in, enjoyment of, and appreciation of physics,

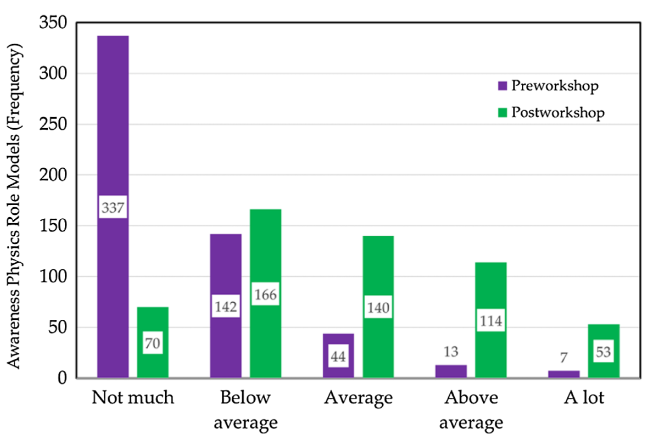


FIG. 4. Bar chart of responses by female students to question B/C4 (awareness of physics role models) with response values ranging from 1 = Not Much to 5 = A Lot. $N = 562$.

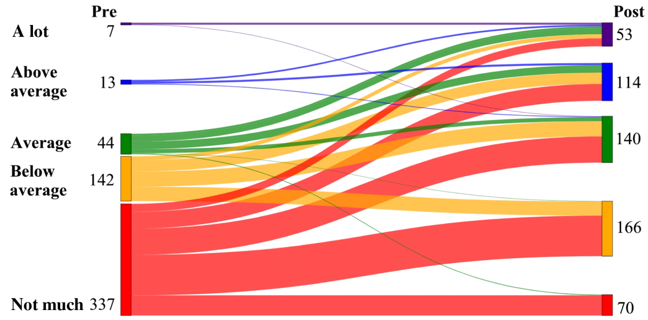


FIG. 5. Sankey plot showing transfers of answers from pre to post for question B/C4 (Awareness of role models) from female students. $N = 562$. Missing answers are not included.

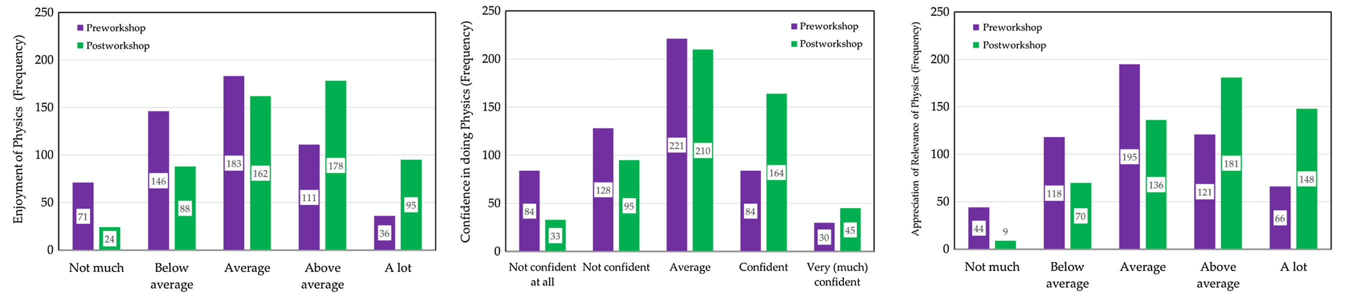
also using the five-point scale, where 1 is "Not confident at all" or "Not much" and 5 is "Very much confident" or "A lot" (as described in Table IV).

These measures were less amenable to change among the female students in the sample. Figs. 6(a)–6(c) show that although positive, the effects are smaller than for measures of self-assessed knowledge and access to role models. Similarly, the overall positive changes recorded for these items are not as high: for each of the three questions, approximately half of the sample reports a positive change (Table X). The corresponding Sankey diagrams highlight that the intervention had a positive effect on the participants (see Fig. 7). For all three questions, there are strong net flows to more positive opinions regarding enjoyment of physics [Fig. 7(a)], confidence in doing physics [Fig. 7(b)], and appreciation of the relevance of physics [Fig. 7(c)], and corresponding much weaker flows to less positive opinions.

Table XI and Figs. 8 and 9 show results for the question "Do you think you would likely take physics at Leaving Cert?" (national matriculation exam), with a three-point scale of 1 for "No," 2 for "Maybe," and 3 for "Yes."

There was a decrease in No responses and an increase in both Maybe and Yes postworkshop (see Fig. 8). A total of 30% of female students reported a positive change in their declared intentions to study physics for the exam after the intervention (see Table XII). Postintervention, 19% of the sample (103 girls) stated their intention to study physics for the purposes of matriculation, up from 63 girls before the workshop (see Fig. 8). The postworkshop values are not only significantly higher than the national average for girls (7.6%) but also comparable to the percentage of boys nationally studying physics for the LC (19.7%).[12] We would like to clarify that the answers to this question are treated as a measure of the overall dynamics of the participant-physics relationship. Despite certain limitations, such as the lack of outcomes for respondents completing the survey, and the varying timelines for subject

[12]Only 7.6% of girls and 19.7% of boys studied physics for the LC in 2021 [93].



(a) Enjoyment (b) Confidence (c) Relevance

FIG. 6. Bar charts of responses by female students to questions (a) B/C2 (enjoyment of physics), (b) B/C3 (confidence in doing physics) and (c) B/C5 (appreciation of relevance of physics), with response values ranging from 1 = Not Much to 5 = A Lot. $N = 562$.

choice (imminent for those in years 3 and 4, but distant for those in years 1 and 2), these results provide crucial insights into the possibilities of reimagining oneself as a girl pursuing physics. While a substantial portion of girls (68%) expressed no change in their intention to study physics for LC, Fig. 9 shows that a minimal number of participants who initially answered Maybe shifted to No (only eight girls). Only three (5%) of those who initially answered Yes changed to Maybe, and no one moved from Yes to No. Notably, 118 girls (47%) who initially responded No shifted to Maybe, indicating the intervention's potential to foster reconsideration (see Table XI).

TABLE X. Cross tabulation of answers from female students to question (a) B/C2 (Do you enjoy learning about physics (…)?) (b) B/C3 (Do you feel confident about doing and learning about physics at school?) and (c) B/C5 (Do you think physics is interesting and important in your life?) pre/postintervention. $N = 562$.

(a) Enjoyment of physics

Pre ⇓ Post ⇒	(5)	(4)	(3)	(2)	(1)	(0)
A lot (5)	31	2	1	2	0	0
Above average (4)	38	66	6	1	0	1
Average (3)	18	84	67	13	1	3
Below average (2)	5	21	68	48	4	6
Not much (1)	3	5	20	24	19	3
No answer (0)	0	0	0	1	1	0

(b) Confidence in doing physics

Pre ⇓ Post ⇒	(5)	(4)	(3)	(2)	(1)	(0)
Very (much) confident (5)	21	6	2	1	0	0
Confident (4)	12	57	12	2	1	3
Average (3)	8	77	117	16	3	6
Not confident (2)	3	18	58	45	4	4
Not confident at all (1)	1	6	21	31	25	2

(c) Appreciation of relevance of physics

Pre ⇓ Post ⇒	(5)	(4)	(3)	(2)	(1)	(0)
A lot (5)	53	12	1	0	0	5
Above average (4)	53	54	12	1	1	2
Average (3)	31	85	65	14	0	2
Below average (2)	7	23	51	36	1	5
Not much (1)	4	7	7	19	7	0
No answer (0)	0	3	1	0	0	0

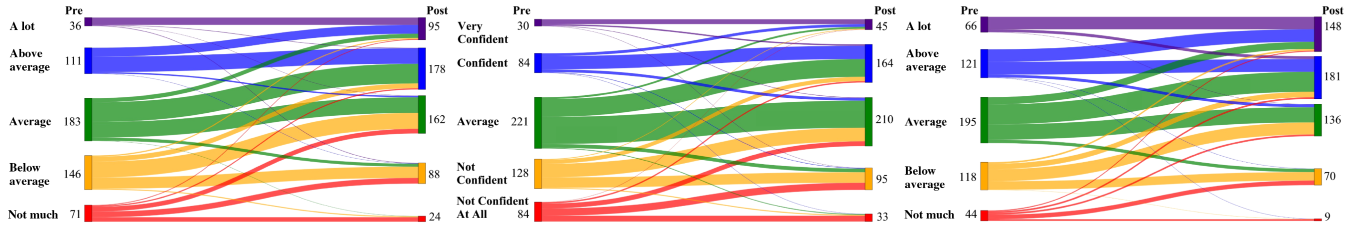
1. Changes in responses by the school year

Table XII presents changes calculated for each of the aforementioned items, categorized as negative, no change, or positive, by school year. The data presented relate to years 1 to 4 of secondary school. A table showing the frequency of responses provided by female students in each school year can be found in the Appendix (Table XIII).

In respect to the question of whether the intervention produced a change in girls' intentions to take physics for their matriculation exam, 30% of the female participants positively changed their intentions. The lowest percentage change was among fourth-year female students, the cohort who are most likely to be engaged in finalizing their choices regarding their matriculation subjects. The fraction of respondents with a positive change in intention decreased as the years progressed: 39% in the first year, declining to 35% and 30% in the second and third years, with only 25% of females in fourth year positively changing their intention to study physics.

The female students in first year report their highest positive change when asked about access to physics role models: 80% report a positive change in this regard, whereas 62% of them show a positive change when self-assessing their knowledge of what physics is. Across other items, they return moderate positive changes: 57% for enjoyment of physics, 40% for confidence in doing physics, and 38% for appreciation of the relevance of physics.

Girls in their second year report the highest positive change across all age cohorts. Positive change was reported by the following fractions: 85% for knowledge of what physics is, 81% for awareness of physics role models, 69% for enjoyment of physics, and 48% for confidence in doing



(a) Enjoyment (b) Confidence (c) Relevance

FIG. 7. Sankey plots showing transfers of answers from pre- to postworkshop for questions (a) B/C2 (enjoyment of physics), (b) B/C3 (confidence in doing physics), and (c) B/C5 (appreciation of relevance of physics) from female students. $N = 562$. Missing answers are not included.

physics. Also, a positive change was recorded at 55% for appreciation of the relevance of physics, however, for this item, it was the female students in fourth year who reported the highest fraction of positive change: 60%. Female respondents in the third year reported high positive changes in their knowledge of what physics is and access to physics role models: 68% for both items. For other questions, positive change is moderate but consistent: 40% for confidence, 43% for enjoyment, and 45% for appreciation of the relevance. Fourth-year females' positive changes range from 67% for their knowledge of what physics is, to 73% and 60% for access to physics role models and appreciation of the relevance of physics respectively, to 50% and 43% for enjoyment and confidence, showing an overall positive effect of the workshop on the opinions about physics of this age cohort. However, these positive changes do not translate to as large a change in the intention to study physics, as was recorded for earlier years.

B. Effects on male respondents

1. Introduction

In this section, we present the results of the analysis of data from the male participants. Boys attended the same workshops as girls and were handed the same questionnaire, yet the sizes of the two gender subgroups were very different. The population of boys totals only 76, compromising the generalizability of findings and the ability to draw definitive conclusions regarding the gender-specific effects of the intervention. Notwithstanding, the analysis offers an interesting indication of the effects achieved by an intervention designed to address female underrepresentation in physics on male participants. Thus, our study's inclusive approach provides substantial added value by allowing for the comparison of effects on both genders, an aspect that has received limited attention in existing literature on interventions aimed at addressing gender disparities in physics or related disciplines [9,16,20,94]. While many interventions in this domain focus solely on girls, our study's reach extends to boys as well, presenting a valuable opportunity to examine gender effects more comprehensively.

TABLE XI. Cross tabulation of answers from female students to question B/C6 (Do you think you are likely to take physics as a subject for your leaving certificate?) pre/postintervention. $N = 562$.

Pre ⇓	Post ⇒	(3)	(2)	(1)	(0)
Yes (3)		60	3	0	2
Maybe (2)		40	180	8	4
No (1)		3	118	130	9
No answer (0)		0	3	1	1

2. Gender effects

As mentioned before, Table VII provides results of the Wilcoxon signed-rank test for both genders with significance level α set to 0.05. The median in answers from boys pre- and postintervention is statistically different for all the questions bar the one about their intention to study physics for their LC (for which the obtained test statistic $w_s = 35$, $n = 13$, $w_{\text{critical}} = 17$). That is, since $w_s > 17$, the null hypothesis cannot be rejected. The null hypothesis can be rejected for the question about the enjoyment of physics,

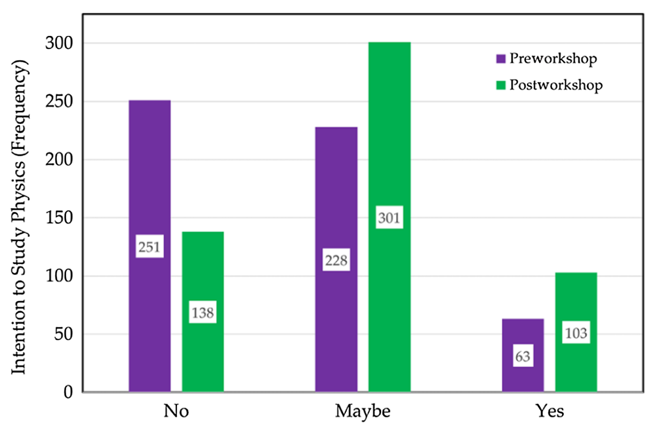


FIG. 8. Bar chart of responses by female students to question B/C6 (intention to study physics for leaving certificate) with response values 1 = No, 2 = Maybe, 3 = Yes. $N = 562$.

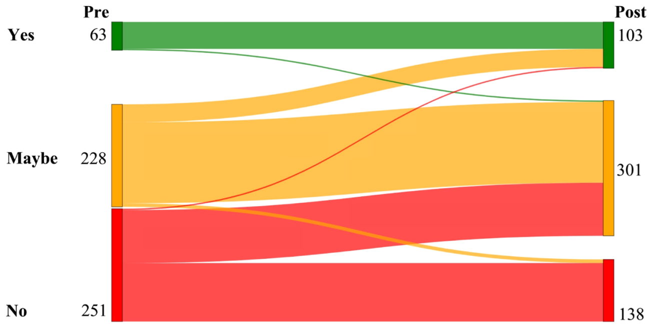


FIG. 9. Sankey plot of transfers of responses for the question B/C6 (intention to study physics for leaving certificate, i.e., state matriculation exam) by female pupils. $N = 562$. There is a clear immediate increase in intention to study physics as impressed by the workshops on many students who previously had no intention to do so or were hesitant.

although it has to be noted that there is 2% possibility of the change occurring randomly. Results from male participants' answers to the question about their knowledge of what physics is are presented in Figs. 10 and 11 (the frequencies are shown in Table XIV in the Appendix). As illustrated in Fig. 10, before the workshop, the frequency distribution of responses of the male participants shows a dominance of average and low levels of knowledge about physics and after the workshop becomes flatter and skewed in the direction of higher levels, with the mode answer changing from midpoint average to a higher level above average. Thus, the general trend is similar to the females yet not so overwhelming; there still remain relatively big fractions of boys reporting low levels of knowledge about physics. Figure 11 shows that there are multiple transfers to higher levels across the whole range of answers, observed also among female students. Only very small numbers report negative change, where the answer post- is at a lower level than preintervention. As shown in Table XVIII, 58% of male students in the sample reported positive change in their knowledge of what physics is (compared to 73% of females). While there was nearly no negative change among females (1%), a small fraction of

TABLE XII. Magnitude and direction of changes in responses pre- and postintervention by school years for female pupils ($N = 562$). Values calculated for participants who did not declare their year of study are not shown. Frequencies of responses are included in Appendix Table XIII.

School year ⇒	1st	2nd	3rd	4th (TY)	All
Knowledge of what physics is					
Negative change	8%	0%	2%	2%	2%
No change	30%	15%	30%	31%	28%
Positive change	62%	85%	68%	67%	70%
Physics role models					
Negative change	3%	1%	3%	3%	2%
No change	16%	18%	30%	24%	24%
Positive change	80%	81%	68%	73%	74%
Confidence in doing physics					
Negative change	18%	7%	14%	3%	9%
No change	42%	44%	46%	53%	48%
Positive change	40%	48%	40%	43%	43%
Enjoyment of physics:					
Negative change	11%	7%	7%	2%	5%
No change	31%	24%	49%	49%	42%
Positive change	57%	69%	43%	50%	52%
Appreciation of relevance of physics					
Negative change	20%	5%	7%	6%	8%
No change	43%	40%	48%	34%	40%
Positive change	38%	55%	45%	60%	53%
Intention to study physics for leaving certificate					
Negative change	5%	2%	3%	0%	2%
No change	56%	63%	67%	74%	68%
Positive change	39%	35%	30%	25%	30%

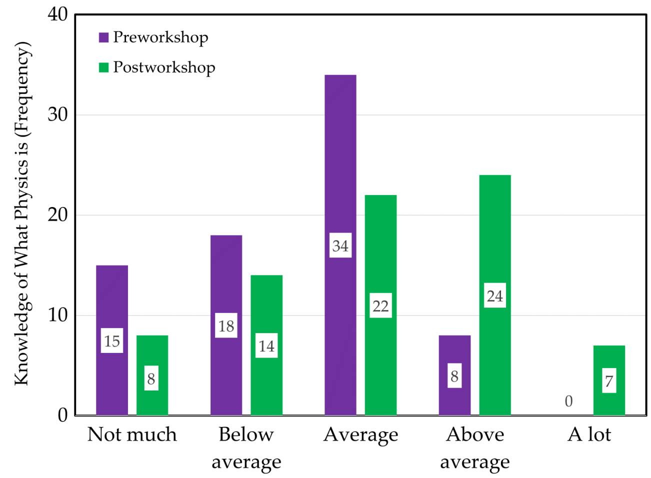


FIG. 10. Bar chart of responses by male students to question B/C1 (knowledge of what physics is), pre and post the workshop, with response values ranging from 1 = Not Much to 5 = A Lot. $N = 76$.

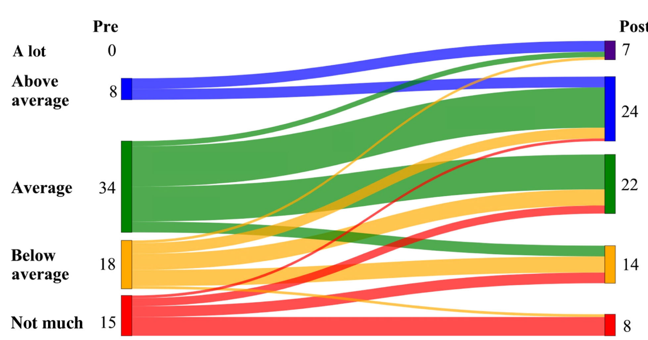


FIG. 11. Sankey plot showing transfers of answers from pre- to postworkshop to question B/C1 (knowledge of what physics is) from male students. $N = 76$. Missing answers are not included.

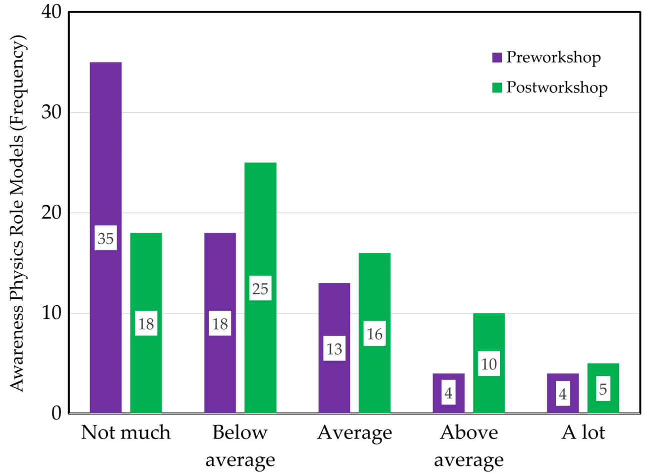


FIG. 12. Bar chart of responses by male students to question B/C4 (awareness of physics role models) with response values ranging from 1 = Not Much to 5 = A Lot. $N = 76$.

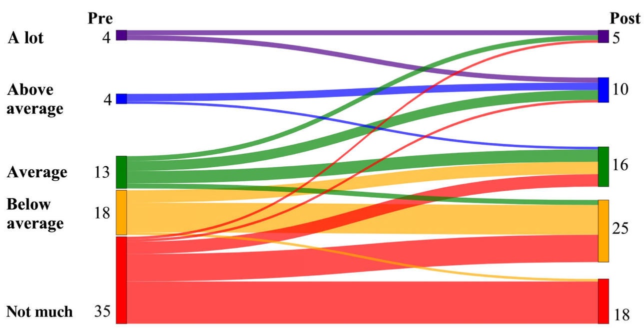


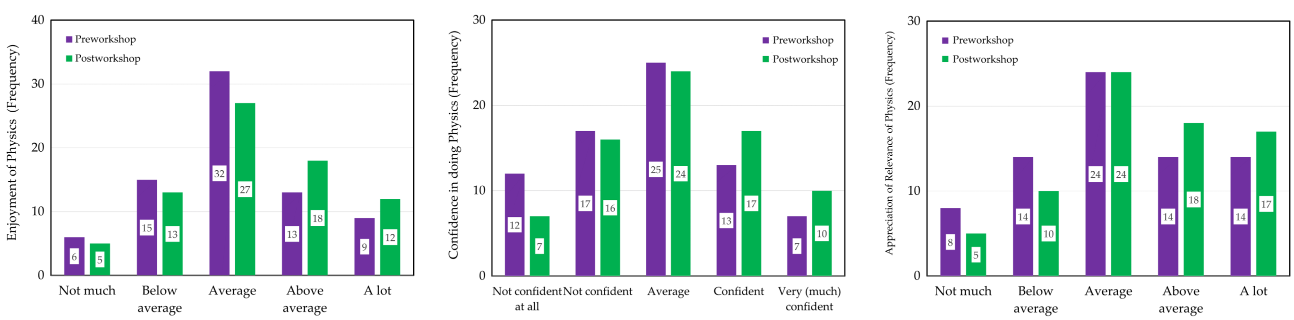
FIG. 13. Sankey plot showing transfers of answers from pre to post for question B/C4 (awareness of role models) from male students. $N = 76$. Missing answers are not included.

boys, 7%, reported negative change. A third of the boys, 35%, reported no change. The goal of filling in gaps in knowledge about physics is achieved with the intervention also for the boys, although not to such an extent as for the girls. Since the initial levels of knowledge are similarly low to those reported by the girls, it can be concluded that the workshop's overall design is more effective in supplying the girls with knowledge about physics than the boys.

Results from male participants to a question 'Do you feel like there are good physics role models for you?' are shown in Figs. 12 and 13 (and the frequencies of responses in Table XV). As illustrated in Fig. 12, before the intervention, the modal answer is the lowest point "not much." This is similar to the female participants, among whom the overwhelming majority chose the lowest answer "not much" prior to the workshop (see Fig. 4). The intervention had a positive effect on male participants with numbers of lowest answers decreasing and the positive answers increasing. Figure 11 shows that very few boys reported a negative shift in responses. However, when comparing the average change among male participants, only 42% report positive change, compared to 74% of females) and 49% report "no change" (compared to 24% of females). The workshop was designed with female belonging in physics as a guiding concept, therefore these findings do not come as a surprise but rather as a testimony to its effectiveness.

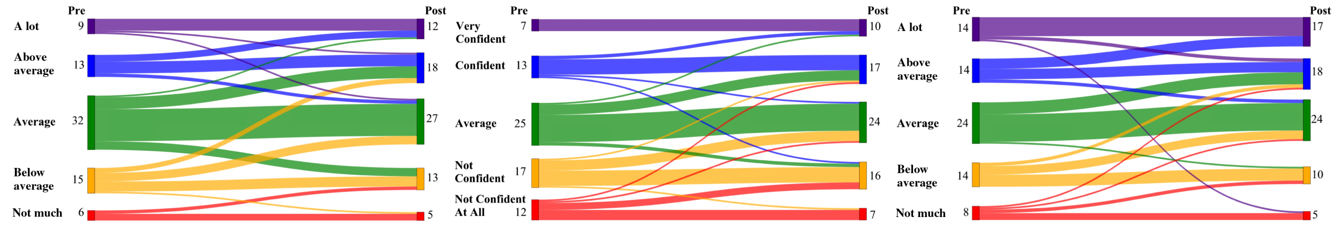
When asked about their confidence in, enjoyment of, and appreciation of relevance of physics, the male respondents provided answers as shown in Figs. 14 and 15 (the frequencies can be found in the Appendix, see Table XVI). Just like in the case of the female workshop participants, these measures proved less amenable to change for boys relative to other items. Fractions of male students reporting positive change for these questions oscillate between a quarter and a third, with 27% of boys changing their feelings about the enjoyment of physics, 29% about the relevance of the subject, and 31% about confidence.

The frequency distribution of responses to the question about declared intention to study physics for the LC exam preworkshop shows that the boys in the studied sample consider physics as an option to a higher degree than the girls. This aligns our population with the national statistics



(a) Enjoyment (b) Confidence (c) Relevance

FIG. 14. Bar charts of responses by male students to questions (a) B/C2 (enjoyment of physics), (b) B/C3 (confidence in doing physics), and (c) B/C5 (appreciation of the relevance of physics), with response values ranging from 1 = Not Much to 5 = A Lot. $N = 76$.



(a) Enjoyment (b) Confidence (c) Relevance

FIG. 15. Sankey plots showing transfers of answers from pre- to postworkshop for questions (a) B/C2 (enjoyment of physics), (b) B/C3 (confidence in doing physics), and (c) B/C5 (appreciation of the relevance of physics) from male students. $N = 76$. Missing answers are not included.

for the uptake of subjects at the state matriculation exam. Both the bar chart (Fig. 16) and the Sankey plot (Fig. 17) demonstrate that there is very little change among the boys as a result of participating in the workshop regarding considering studying physics. Table XVIII shows that 83% of them report no change with 7% reporting a negative change and 10% positive change. It has to be noted, that just like in the case of females, no one changed their declared intention from "yes" to "no."

3. Gender differences in changes in responses

Table XVIII (in the Appendix) presents changes calculated for each of the aforementioned items, categorized as negative, no change, or positive, by school year, and gender. Since there were no boys in school year 1 in our study, we removed answers from females in this school year (one) from this comparison and the data presented relate to years 2 to 4 of secondary school (leading to slight changes in the distribution of fractions reporting types of change for females as compared to Table XII). A table showing the frequencies of responses provided by male students in each school year can be found in the Appendix (Table XIII). When comparing the average magnitude and direction of change calculated for the two genders for each measured item, both similarities and differences are in evidence.

1. Workshop participation had the same main effect in magnitude and direction of change:
   - For knowledge about physics, with both genders predominantly reporting positive change.
   - For confidence in doing physics, with both genders predominantly reporting no change.
   - Similarly, no change is the most frequent effect on the intention to do physics, although the effect is not statistically significant for boys.
2. The intervention bore different main effects in magnitude and direction of change on the two genders for questions about
   - Identification with role models, where 74% of girls reported positive change and 49% of boys no change.
   - Enjoyment, with 54% of girls recording positive change and 59% of boys recording no change.
   - Relevance, with 53% of girls recording positive change and 61% of boys no change.

For females, a highly encouraging effect was demonstrated with an average of over 70% reporting positive

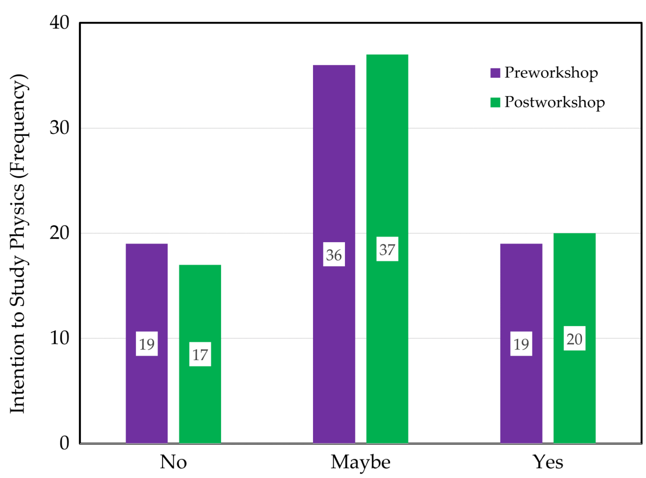


FIG. 16. Bar chart of responses by male students to question B/C6 (intention to study physics for leaving certificate) with response values 1 = No, 2 = Maybe, 3 = Yes. $N = 76$.

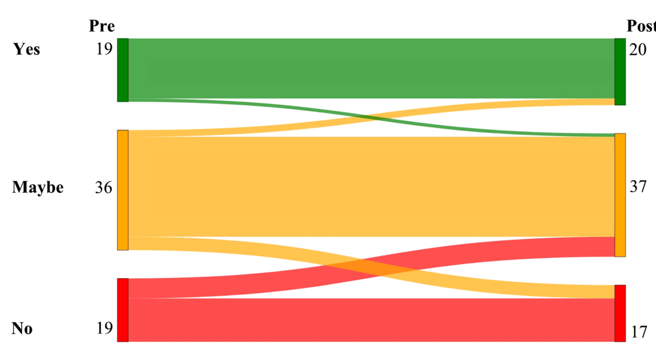


FIG. 17. Sankey plot of transfers of responses for the question B/C6 (intention to study physics for leaving certificate, i.e., state matriculation exam) by male pupils. $N = 76$.

change (questions about knowledge about physics and physics role models; see Tables XI and XVIII) and over 50% for moderately successful achievements (enjoyment and relevance of the subject). In the male population, the highest positive average change is 58% (knowledge about physics; see Table XVIII). The second highest value is 42% (physics role models) with the remaining three oscillating around 30% and intention to study physics for LC at the lowest—10%.

4. Changes in responses from male participants by the school year

We compared the effects of the workshop on each measured item between genders for school year, see Table XVIII. In regard to knowledge about physics, there is no significant effect, but there is a striking enthusiastic reaction among males in the second year, with 83% reporting positive change, which then drops to 37% in third year and goes to 54% in fourth (TY). The girls in second year are similarly the most enthusiastic in the female subgroup (85% positive change) but for the females, the following years also evidence high levels of positive change (68% and 67%, respectively). Similarly, for the question about physics role models, boys in their second year are the most receptive to the workshop, with 50% of them reporting positive change, compared to 81% of girls in the same school year.

For enjoyment and appreciation of relevance of physics, the school year has a reverse effect, meaning that the higher the school year, the higher the proportion of boys reporting positive change. The positive change in enjoyment is reported by 17% of boys in second year, 30% in third, and 34% in fourth (TY). The positive change in the appreciation of relevance of physics is reported by 17% of boys in second year, 33% in third, and by 38% of boys in fourth (TY). However, compared to girls, smaller fractions of boys report positive change and "no change" is the predominant answer (no change in enjoyment: 67% in second, 56% in third, and 54% in fourth (TY); no change in appreciation of relevance: 67%, 63%, 53% respectively). The intervention has an effect on boys' sense of enjoyment and appreciation of relevance of physics but to a smaller degree than for the females and it is more successful in influencing these values among boys in their higher school years.

Confidence in physics is predominantly unchanged with no school year effect observed either, for either gender. However, the frequencies of answers to the question about confidence provided before the workshop look very similar for both genders, despite research demonstrating that boys are more confident about their physics-related abilities than their female peers.

Interestingly, the females in the sample were solidifying their intention whether to study physics for LC as they progressed through school. The predominant effect among boys is no change in their intention to study physics for the LC and this lack of effect is almost independent of school year, except for 4th year, where 15% of the 34 boys expressed a positive change. As mentioned before, the difference in the distributions pre- and postintervention for the boys is not statistically significant for this question and this is also true for the 4th year boys (i.e., the null hypothesis also cannot be rejected; Wilcoxon signed-rank test statistics: $w_s = 8$, $n = 7$, probability of $H_0 > 0.15$).

IV. DISCUSSION

In this section, we discuss the results of our analysis in the light of the conceptual framework underlying the intervention's design. The results demonstrate the success of the intervention design, although with varying degrees of effectiveness for different measured items in the female population with some successes among the male participants. Of the specific stated goals of the SOPHia school visit workshop, the greatest success was evidenced with respect to enhancing students' perceptions of their knowledge of what physics is and their access to physics role models. The levels of knowledge about physics increased for both genders but for boys to a smaller extent. Girls (70%) and boys (58%) experienced positive change in their self-reported knowledge of what physics is and 74% of girls experienced positive change in their self-reported awareness of physics role models, while only 42% of boys did. In the context of students in Ireland lacking a basic understanding of physics, and recognizing the importance of role models for a choice of physics for girls [44,95], these are laudable successes but also highlight the initial low starting points.

Of great import, the intervention achieved on average, across all years, a 30% positive change in stated intention to study physics. Moreover, it achieved a 25% positive change among girls in their fourth year—the year in which they are most likely to have their last opportunity to make their exam subject selections for matriculation. While this is an important achievement, particularly given that the sample consists of female students, it is of concern that the research also found that the oldest cohort in the sample was least likely to change their views. Sadler *et al.* [14] demonstrated that interest in a physics career, as opposed to careers in other science disciplines, is more likely to remain stable throughout high school. In general, research has consistently highlighted the declining interest in science as individuals grow older, particularly among girls [14,96,97]. Our research confirms that with increasing years of study, comes a solidifying of attitudes toward physics education among females. It thus contributes to research highlighting the need for early interventions for girls to attract them to the field.

According to the situated expectancy value theory (SEVT) [98] and the social cognitive career theory (SCCT) [99], career aspirations significantly influence individual subject choices and gender disparities in career plans are associated with gender gaps in STEM outcomes [88,95,100]. Individual career choice is the most influential predictor of subject selection, and the strongest predictor for selecting a career in science is utility and enjoyment, with career plans still evolving during high school. According to the SEVT, adolescence represents a rich period marked by changes in multiple achievement-related domains, including STEM and career expectations, which depend on the social context and the specific support students receive [101]. Ozulku and Kloser [102] examined middle schoolers and found that the perceived utility value of the subject is most impactful in increasing STEM career interests, particularly among females and students from higher years. The SOPHia intervention succeeded in achieving 60% positive change for girls in the oldest cohort's appreciation of the relevance of physics and 53% positive change across all girls in the study. These findings support the value of demonstrating the applicability of physics to a diverse range of careers as was done in the studied workshop. We concur with Drymiotou *et al.*'s [103] recommendation for interventions to incorporate the "authentic use of science practices" through career-based scenarios and interaction with STEM experts to influence STEM career aspirations. However, given the limited resources available to fund extracurricular educational interventions, the question asked by Sadler *et al.* [14], "Which years are the most important to focus on to effect substantial change?" (in fostering science career aspirations among girls), is crucial. Anderhag *et al.* [104] demonstrated that the decline in interest in science (affecting girls at higher rates than boys) often occurs during the transition from primary to secondary school, regardless of the age of pupils in a particular educational system. Our results support the contention that the time of transition is a tumultuous one: first-years in our study are significantly more likely than other years to report negative change in their views of physics following the workshop. This prompts the question, of whether in a context of sparse funding, outreach interventions such as the SOPHia Project should avoid the transitional, first year of secondary school. Sadler *et al.* [14] emphasize the necessity for precollege intervention, indicating that interventions in the latter years of secondary school (at the crucial point of deciding matriculation exam subjects) can still be highly effective. However, Ozulku and Kloser's [102] recommendation to differentiate interventions according to the specific needs of year cohorts warrants further consideration. Students in their final year of choosing subjects were least likely to change their position postintervention across the majority of measured items and thus targeting of earlier cohorts is recommended. However, they also report the most positive changes in appreciation of the relevance of physics compared to other age cohorts (60% positive, 34% no change, and 6% negative). Research discussed in this paper emphasizes the importance of fostering girls' awareness of careers in physics and the vocational relevance of the field. While our results show positive outcomes, they leave room for improvement in this regard. Thus, synthesizing these observations, we propose that the SOPHia workshop and similar interventions should dedicate more time to presenting careers utilizing physics skills when reaching students in older cohorts, who base their subject choice also on perceived utility of each subject. Although small, there are some negative shifts in responses from female participants, worth discussing. The highest negative change is reported for confidence in doing physics (9% across all school years) and appreciation of its relevance (8% on average), substantially due to the greatest negative change which is reported by female students in their first year (18% and 20%, respectively). Since participation in the workshop could be their first-ever interaction with the subject of physics, we speculate that they could be overwhelmed and slightly confused with the material covered. Alternatively, they could be disappointed by their learning experience from the general science subject so far. Helga Stadler *et al.* [105] demonstrated the differences in understanding (and learning) physics between boys and girls, especially between the viewpoints on the importance of context, coherence, and connections to the world outside of physics concepts. The SOPHia school visit workshop was designed with female sense of belonging in physics as a guiding framework and our results show that such an intervention also has different effects on girls and boys. To summarize, it is successful for female participants while moderately beneficial for boys. The observed gender differences not only highlight the effectiveness of the intervention design but also reveal a notable disparity in the attitudes toward physics between male and female students in our sample. Prior to the intervention, male respondents held less negative opinions about physics compared to their female counterparts, suggesting a narrower scope for change among male students. However, when asked about their intention to study physics for their state matriculation exam (LC), the boys were adamant about their choices. As mentioned before, we consider this question a proxy for the student-physics relationship, measuring whether participants can imagine themselves as a "physics person." Responses from female participants allowed us to infer that the workshop had a positive effect on this relationship among girls, redrawing the "me doing physics" scenario into possible and imaginable for many girls. For boys, on the other hand, these possibilities were fixed and the workshop did not change them.

V. CONCLUSIONS

In this paper, we demonstrated the process of creating an evidence-informed school workshop intervention and integrating a pre-post evaluation of the impact on female and male participants. Presenting the results of that evaluation, we found that all six survey questions returned a positive change for girls. Effects on boys of five of the six questions were positive although to a lesser extent. In general boys' attitudes were less negative at the start but also remained more fixed postintervention. The intervention program was successful in positively changing more than 1 in 4 female students' declared intentions to study physics for the purposes of matriculation, with 19% of the sample stating their firm intention after the intervention to study physics for the purposes of matriculation, which is comparable to the percentage of boys nationally taking the subject (19.7%). It was particularly successful in enhancing students' perceptions of their own knowledge of what physics is and the accessibility of female role models in the discipline. These outcomes are particularly significant in the Irish context, where the design of the Irish science and physics curricula means that students may graduate from a secondary school without studying a stand-alone subject of "physics" and without a genuine appreciation of the subject. The positive results of the intervention suggest its potential applicability in other regions facing similar challenges in achieving gender parity in participation in physics education. Finally, the authors recommend that, in the context of sparse resources for extracurricular intervention, there is merit in focusing on delivering such workshops during years before students' views are solidified and their matriculation choices are set. On the other hand, when the audience is composed of female students expected to be making their subject choice soon, more focus on the utility of physics in various careers is recommended. We believe that the practical focus of the study will benefit the science education community as it provides a clear presentation of the possibilities of a single-session intervention for the gradual dismantling of stereotypical thinking about physics among female students.

To reiterate and summarize, the intervention outlined in this paper aims to confront misinformation and stereotypes among students, offering significant promise for success in this regard and laying foundations for more informed decisions regarding the pursuit of physics in the Senior Cycle (upper middle school). Drawing upon the social cognitive expectancy-value theory (SEVT) and acknowledging that task values are shaped by various actors and environments, we believe that if delivered as part of a concerted effort operating on the multiple levels necessary to effectively reshape the gender landscape of physics, it has the potential to instigate meaningful change. As shown by Starr and Simpkins, adolescents, regardless of their gender, increasingly endorse gender stereotypes about boys being better at science and math as they progress through High School (from grade 9 to 11) [106]. Given the transnational prevalence of such stereotypes, we recommend interventions like the discussed school visit.

As explained above, the SOPHia Project includes boys in coeducational schools.[13] This way, these schools are encouraged to describe the event as a general physics workshop (rather than an event for "girls in physics") to avoid perpetuating notions of girls needing special attention and being less capable in the field [28] (pp. 108–109). We advocate for the inclusion of boys in "Women in STEM" intervention programs within coeducational settings. Our findings indicate that boys also derive certain advantages from their involvement. Furthermore, we avoid the further mystification (if not otherisation) of "women in STEM". On a practical level, this approach yields data from participants of different genders, enabling the analysis of any gender effects of such interventions. This, in turn, may uncover additional insights into the dynamics that govern the selection of subjects and career paths.

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APPENDIX: ADDITIONAL TABLES WITH SUPPORTING DATA FOR FEMALES AND MALES

Table XIII shows the cross tabulation of responses to questions about the six measured items provided by participants who identified as female and male in

[13]Contrary to school gatekeepers' initial assumptions that these would be girls-only sessions.

each school year before and after the SOPHia workshop.

Tables XIV–XVII show the cross tabulation of responses to questions about the six measured items provided by male students in each school year before and after the SOPHia workshop.

Table XVIII shows magnitude and direction of changes in responses pre- and postintervention by school years for female and male pupils in school years 2–4. Note: Although the data collected included females from year 1, there was no data collected from year 1 males and therefore year 1 data is not included in this table to allow a fairer comparison.

TABLE XIII. Frequency of responses pre- and postintervention by school years for female and male pupils. Responses from participants who did not declare their year of study are not shown. There was no data collected for 1st year male student; ⋯ is not available; L. Cert. = leaving certificate.

	Female								Male							
	Preworkshop				Postworkshop				Preworkshop				Postworkshop			
School year ⇒	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Knowledge of what physics is																
A lot	0	0	2	2	9	14	17	20	⋯	0	0	0	⋯	2	0	5
Above average	3	7	13	24	26	41	58	99	⋯	1	2	5	⋯	6	6	12
Average	38	30	73	110	19	38	55	89	⋯	6	11	17	⋯	1	10	11
Below average	18	39	48	82	7	5	16	25	⋯	2	8	8	⋯	2	7	4
Not much	5	25	16	24	0	1	4	4	⋯	4	6	5	⋯	1	4	3
No answer	0	0	0	0	3	2	2	5	⋯	0	0	0	⋯	1	0	0
Physics role models																
A lot	0	1	1	6	10	11	11	21	⋯	1	1	2	⋯	1	0	4
Above average	6	3	3	1	17	25	22	51	⋯	0	0	4	⋯	2	1	8
Average	11	9	9	18	19	22	31	68	⋯	2	3	8	⋯	2	6	8
Below average	22	23	36	64	15	35	57	59	⋯	4	10	4	⋯	5	13	7
Not much	25	62	102	152	0	6	28	36	⋯	6	13	16	⋯	2	7	8
No answer	0	3	0	1	3	2	2	7	⋯	0	0	1	⋯	1	0	0
Confidence in doing physics																
Very (much) confident	5	8	5	12	9	12	8	16	⋯	1	4	2	⋯	1	5	4
Confident	13	14	27	32	20	31	42	70	⋯	3	3	7	⋯	5	3	9
Average	31	43	67	86	20	46	60	82	⋯	2	10	13	⋯	2	11	11
Not confident	12	21	33	65	10	8	29	48	⋯	4	6	8	⋯	3	5	8
Not confident at all	3	15	20	47	1	2	10	20	⋯	3	4	5	⋯	0	3	3
No answer	0	0	0	0	4	2	3	6	⋯	0	0	0	⋯	2	0	0
Enjoyment of physics																
A lot	2	7	9	18	14	21	24	36	⋯	4	3	2	⋯	3	5	4
Above average	17	13	39	43	20	39	44	74	⋯	2	4	7	⋯	4	6	8
Average	28	41	41	74	18	25	42	76	⋯	5	12	15	⋯	3	8	16
Below average	12	28	46	66	6	13	30	38	⋯	1	5	9	⋯	2	4	7
Not much	5	12	15	41	3	1	9	12	⋯	1	3	2	⋯	0	4	0
No answer	0	0	1	0	3	2	2	6	⋯	0	0	0	⋯	1	0	0
Appreciation of relevance of physics																
A lot	14	14	13	30	18	32	32	66	⋯	4	5	5	⋯	5	5	8
Above average	24	23	35	41	25	34	48	76	⋯	3	1	10	⋯	2	3	13
Average	14	33	54	94	11	25	38	62	⋯	3	11	11	⋯	1	13	10
Below average	9	23	36	55	6	7	29	27	⋯	3	6	5	⋯	4	3	3
Not much	3	7	11	22	1	1	3	4	⋯	0	4	3	⋯	0	3	1
No answer	0	1	3	0	3	2	2	7	⋯	0	0	1	⋯	1	0	0
Intention to study physics for L. Cert.:																
Yes	6	11	14	34	17	22	21	43	⋯	2	7	10	⋯	2	7	11
Maybe	41	56	71	63	38	67	96	101	⋯	9	12	15	⋯	9	12	17
No	15	33	66	144	5	10	32	91	⋯	2	8	9	⋯	1	8	7
No answer	2	1	1	1	4	2	3	7	⋯	0	0	1	⋯	1	0	0

TABLE XIV. Cross tabulation of answers from male students to question B/C1 (Do you think you know what physics is about?) pre/postintervention.

Pre ⇓	Post ⇒	(5)	(4)	(3)	(2)	(1)	(0)
A lot (5)		0	0	0	0	0	0
Above average (4)		4	4	0	0	0	0
Average (3)		2	15	13	4	0	0
Below average (2)		1	4	6	6	1	0
Not much (1)		0	1	3	4	7	1
No answer (0)		0	0	0	0	0	0

TABLE XV. Crosstabulation of answers from male students to question B/C4 (Do you feel like there are good physics role models for someone like you?) pre/post intervention.

Pre ⇓	Post ⇒	(5)	(4)	(3)	(2)	(1)	(0)
A lot (5)		2	2	0	0	0	0
Above average (4)		0	3	1	0	0	0
Average (3)		2	4	5	2	0	0
Below average (2)		0	0	5	12	1	0
Not much (1)		1	1	5	11	17	1
No answer (0)		0	1	0	0	0	0

TABLE XVI. Cross tabulation of answers from male students to question (a) B/C2 (Do you enjoy learning about physics (…)?) (b) B/C3 (Do you feel confident about doing and learning about physics at school?) and (c) B/C5 (Do you think physics is interesting and important in your life?) pre/postintervention.

Pre ⇓	Post ⇒	(5)	(4)	(3)	(2)	(1)	(0)
(a) Enjoyment of physics							
A lot (5)		7	1	1	0	0	0
Above average (4)		4	7	2	0	0	0
Average (3)		1	7	19	5	0	0
Below average (2)		0	3	5	6	1	0
Not much (1)		0	0	0	2	4	1
No answer (0)		0	0	0	0	0	0
(b) Confidence in doing physics							
Very (much) confident (5)		7	0	0	0	0	0
Confident (4)		2	9	1	1	0	0
Average (3)		1	6	16	2	0	0
Not confident (2)		0	1	6	9	1	1
Not confident at all (1)		0	1	1	4	6	1
No answer (0)		0	0	0	0	0	0
(c) Appreciation of relevance of physics							
A lot (5)		11	2	0	0	1	0
Above average (4)		6	6	2	0	0	0
Average (3)		0	7	16	1	0	1
Below average (2)		0	2	5	7	0	0
Not much (1)		0	1	1	2	4	0
No answer (0)		1	0	0	0	0	0

TABLE XVII. Cross tabulation of answers from male students to question B/C6 (Do you think you are likely to take physics as a subject for your leaving certificate?) pre/postintervention.

Pre ⇓	Post ⇒	(3)	(2)	(1)	(0)
Yes (3)		18	1	0	0
Maybe (2)		2	30	4	0
No (1)		0	6	13	1
No answer (0)		0	1	0	0

TABLE XVIII. Magnitude and direction of changes in responses pre- and postintervention by school years for female ($N = 562$) and male pupils ($N = 76$) in school years 2–4. Values calculated for participants who did not declare their year of study are not shown. Frequencies of responses are included in Appendix Table XIII.

School year ⇒	2nd		3rd		4th (TY)		Average 2nd to 4th	
Gender ⇒	Female	Male	Female	Male	Female	Male	Female	Male
Knowledge of what physics is								
Negative change	0%	8%	2%	7%	2%	6%	1%	7%
No change	15%	8%	30%	56%	31%	40%	25%	35%
Positive change	85%	83%	68%	37%	67%	54%	73%	58%
Physics role models								
Negative change	1%	17%	3%	7%	3%	6%	2%	10%
No change	18%	33%	30%	59%	24%	53%	24%	49%
Positive change	81%	50%	68%	33%	73%	41%	74%	42%
Confidence in doing physics								
Negative change	7%	0%	14%	7%	3%	9%	8%	5%
No change	44%	64%	46%	70%	53%	57%	48%	64%
Positive change	48%	36%	40%	22%	43%	34%	44%	31%
Enjoyment of physics								
Negative change	7%	17%	7%	15%	2%	11%	5%	14%
No change	24%	67%	49%	56%	49%	54%	41%	59%
Positive change	69%	17%	43%	30%	50%	34%	54%	27%
Appreciation of relevance of physics								
Negative change	5%	17%	7%	4%	6%	9%	6%	10%
No change	40%	67%	48%	63%	34%	53%	41%	61%
Positive change	55%	17%	45%	33%	60%	38%	53%	29%
Intention to study physics for leaving certificate								
Negative change	2%	8%	3%	7%	0%	6%	2%	7%
No change	63%	83%	67%	85%	74%	79%	68%	83%
Positive change	35%	8%	30%	7%	25%	15%	30%	10%

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