ONLINE FIRST ARTICLE
doi.org/10.362653/IJAS.17024

Statistica Applicata - Italian Journal of Applied Statistics

Received: 01.10.23/ **Accepted:** 10.07.25
Published online: 30.12.25

INVESTIGATING UNDERGRADUATE AND HIGH SCHOOL STUDENTS' IDENTIFICATION WITH PHYSICS THROUGH STRUCTURAL EQUATION MODELING

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Abstract. *The disciplinary identity framework has been increasingly used to investigate students' intentions to pursue Science, Technology, Engineering and Mathematics (STEM) related careers. However, much less is known about whether groups of students with different career orientations towards a particular discipline differ in their disciplinary identity. Using physics as a relevant context, the aim of this study was to investigate the validity of an identity framework that includes the following dimensions: identity, interest, recognition and self-efficacy. The analysis was based on a Likert-scale survey conducted online among N = 1135 (female students = 479) Italian high school and undergraduate students, divided into four groups: high school students participating in generic extracurricular vocational activities; high school students participating in specific extracurricular vocational activities focused on physics contents; first-year computer science and biomedical engineering students; first-year undergraduate physics students. We used structural equation modelling to validate the physics identity framework. Differences across groups and between genders were examined by means of multigroup analysis. Results show that for high school students, the effect of self-efficacy on physics identity is fully mediated by interest and recognition. The direct effect of self-efficacy on physics identity is significant only for undergraduate students. Our results show that gender differences in the constructs of the identity model are stronger for students who chose physics as an extracurricular activity or as an undergraduate course. Thus, our results have implications for understanding the mechanism underlying the promotion of students' identity development in physics.*

Keywords: *physics identity, structural equation modeling, gender gap*

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1. INTRODUCTION

Despite higher education plays an increasingly fundamental role in Europe in the construction of social resources for the growth of the individuals, the number of tertiary education graduates is still unsatisfactory (Eurostat, 2022). Italy, in particular, has the lowest percentage of young people holding a university degree (e.g., in 2015, 25.2% of the population aged 25–34 years had a university) and is still currently facing a significant shortage of university graduates, which poses a significant challenge for Italy's future economic growth and development (ANVUR, 2023). This trend can be identified also in the Science – Technology – Engineering – Mathematics (STEM) field[2], despite being a field with a shorter transition into the labor market with respect to all other fields of studies (Rocca & Quintano, 2024).

Research has thoroughly demonstrated that the intention to pursue a STEM-related career is influenced by the extent to which students perceive themselves as a STEM person, namely their perceived STEM *identity*, (Calabrese Barton et al., 2013; Carlone & Johnson, 2007; Grimalt-Alvaro et al., 2022). One of the most common models used in science education research posits that identity in a given discipline is predicted mainly by self-efficacy and interest in the discipline, as well as the sense of perceived recognition by others (Hazari et al., 2010; 2020). This identity model has been applied to different disciplines such as biology and chemistry (Potvin & Hazari, 2013), mathematics (Cribbs et al., 2015), computer science (Mahadeo et al., 2020), engineering (Godwin et al., 2016), and STEM (Dou & Cian, 2022).

However, there is still a lack of studies that address how students aged 14-19 develop their STEM identity and whether students with little or no specific experience in a particular discipline differ in their disciplinary identity from those who have already chosen to study that discipline. The main reason for focusing on these questions is that it is at the high school level that students begin to develop a clear idea of their own identity in relation to the discipline by gaining

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[2] In this work, we refer to the discipline categorization reported in *Gazzetta Ufficiale della Repubblica Italiana*, available here: https://www.gazzettaufficiale.it/do/atto/serie_generale/caricaPdf?cdimg=22A0076300100010110001&dgu=2022-02-07&art.dataPubblicazioneGazzetta=2022-02-07&art.codiceRedazionale=22A00763&art.num=1&art.tiposerie=SG

a deeper understanding of the subject matter related to that discipline and of the job opportunities offered by a particular university course focused on that discipline (Liu et al., 2023; Lockart et al., 2022; Oon & Subramaniam, 2013). Furthermore, exploring how high school students develop their own disciplinary identities may also shed light on the reasons for gender gaps in certain professional areas of STEM, such as physics, where a widespread and generalised underrepresentation of women has been observed in comparison to other sciences – both in university courses and in professional careers – as it has also been highlighted in recent international reports at the European level (EU, 2021; 2022).

To address these issues, we applied the general STEM identity model developed by Dou & Cian (2022) to the discipline of Physics, using the same measurement tool to analyse differences in identity development between university and high school students, and to explore whether gender affects identity constructs differently depending on whether students are STEM undergraduates or high school students.

2. BACKGROUND

2.1 THE IDENTITY FRAMEWORK IN THE STEM FIELD

In STEM education, the identity framework has often been used to investigate the extent to which students engage in STEM-related activities and, in particular, to better understand their career choices. In particular, STEM identity has been identified as a significant construct that positively influences students' learning engagement and career aspirations in STEM (Liu et al., 2023), as well as their learning approaches (Hazari et al., 2010). Furthermore, STEM identity has been found to be the most accurate predictor of high school students pursuing a STEM undergraduate major (Cha, 2013). In addition, the literature indicates that at the university level, there is a bidirectional relationship between identity and academic achievement. For example, students who reported higher levels of physics identity tended to get better grades, and students who perform better in their exams generally report higher levels of physics identity at the end of the academic year (Seyranian et al., 2018).

According to this framework, self-identification can be defined as the process by which "people, using the reflexive aspect of the self, name themselves in terms of positional designations or labels" (Burke & Stets, 2009). In other words, an individual’s identity is the result of a dynamic process based on personal and social negotiations with members of the same STEM-related community (Gee, 2000). In this framework, self-identification is considered as a way to characterise a specific aspect of a more general social identity. As such, the process of identity development in a particular discipline is also influenced by the student’s other personal identities (e.g., gender) and personal experiences related to the discipline (Kim et al., 2018). For example, identification with physics is a part of the student’s identity that only partially overlaps with personal and social identities (Hazari et al., 2010). Therefore, the trajectory through which a student’s STEM identity develops can change dynamically over time, as the creation of a personal identity in STEM is a process of recursive social construction (Gee, 2000). This process unfolds in two ways: students shape the identity of the kind of STEM person they want to be through interaction with scientific phenomena and social negotiation of the meaning of STEM concepts (Li, 2012), but also their life experiences with school, perceived sense of belonging and social interactions with relevant others in their family may directly influence their STEM identity (Liu et al., 2023; Verdín, 2021). Previous findings in the STEM field have also shown that when students have a strong sense of identity, they invest more in learning content since they highly value the consequence of such a behavior, thus maintaining the sustainability of the learning process (Liu et al., 2023).

Based on the above theoretical considerations, to explore the mechanism underlying identity development, most existing models (Dou et al., 2019; Dou & Cian, 2022) adopt a four-factor structure (Fig. 1), in which disciplinary identity, considered as an independently measured construct (Grimalt-Alvaro et al., 2022), is predicted by the dimensions of interest in the discipline, perceived recognition – namely, how others view the student in relation to the discipline – and performance/competence – namely, the *belief* in the ability to perform specific tasks and the ability to understand the content knowledge related to the discipline (Carlone & Johnson, 2007).

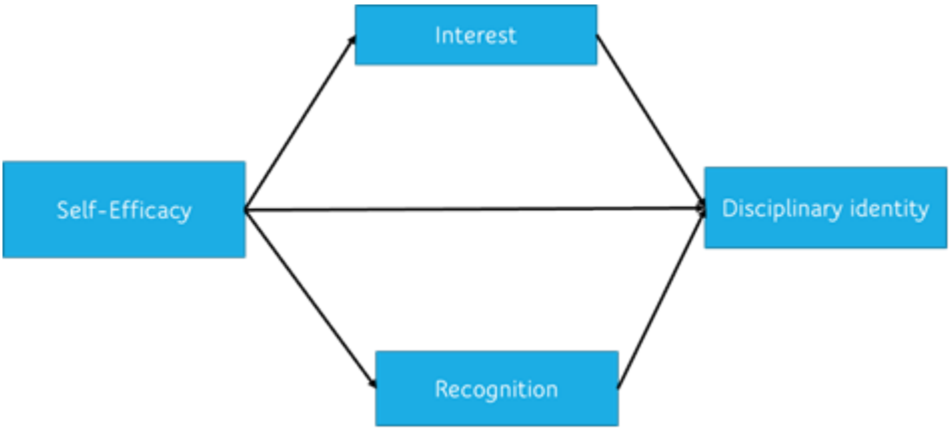

Figure 1: Adopted model of disciplinary identity

The combination of performance and perceived competence into a single category is suggested by previous findings, making this construct closely related to *self-efficacy*. Self-efficacy can be defined as an individual's belief in his or her ability to achieve a certain level of performance or to influence events that affect his or her life (Bandura, 1991). Among those proposed by Bandura, the component of mastery experience, namely the belief in one's ability to handle specific tasks that are similar to previously encountered ones, is particularly relevant for STEM education (Wieselmann et al., 2022).

A large body of research has also shown that interest and self-efficacy – particularly at university level – are strong predictors of STEM identity and disciplinary identity in STEM (Dou & Cian, 2022). Furthermore, findings from recent longitudinal studies are consistent with reciprocal and time-dependent correlational relationships between self-efficacy and academic performance, and between perceived recognition and academic performance (Bottomley et al., 2023). This confirms the 'feedback loop' hypothesized by Kalender and colleagues (Kalender et al., 2019) and is consistent with the finding that early performance influences academic self-concept and past self-concept influences future performance (Marsh et al., 2002).

In the case of physics, which is the focus of this study, previous studies have also thoroughly confirmed that individuals' self-identification with physics is predicted by their interest, sense of recognition, and – indirectly – by their self-efficacy, and that the structural relationships in the models are moderated by gender (Hazari et al., 2010; 2020).

2.2 THE ROLE OF GENDER IN STEM AND PHYSICS IDENTITY

While many studies in the Italian context have addressed the gender gap at university level in STEM field (Barone & Assirelli 2020; Priulla & Attanasio, 2023), the role gender in STEM identity, and specifically physics identity, has been studied mainly in the US context. Specifically, previous studies have reported that women report significantly lower STEM and physics identity than men, suggesting that this perception of the self may contribute to the underrepresentation of women in physics (Dou & Chan, Hazari et al., 2010). Such underrepresentation may in turn affect one's identity, as previous studies have shown that students who belong to underrepresented groups experience a lower sense of belonging than their peers, with a consequent negative impact on self-efficacy and performance in disciplinary coursework, which may affect their disciplinary identity construction over time (Liu et al., 2023). Other studies have also shown that the physics identity of undergraduate physics students declines over time, but this decline does not significantly interact with gender (Bottomley et al., 2023). However, there does appear to be a significant interaction between gender and academic semester in perceived recognition, as gender differences in perceived recognition were greater in the second semester than in the first, regardless of undergraduate year.

Finally, recent results have shown that gender stereotypes can influence individuals' disciplinary identity (Galano et al., 2023; Liu et al., 2023), especially in physics (Marchand & Taasoobshirazi, 2013). For example, stereotypical views of physics typically include perceptions of masculinity (Kessels et al., 2006). Thus, it is likely that women do not identify with physics as a discipline to the same extent as men, not only because of their lower levels of self-efficacy and perceived recognition (Bottomley et al., 2023; Kalender et al., 2019), but also because they do not perceive physics as fitting their female identity.

3. RESEARCH QUESTIONS

While literature has thoroughly validated the model of physics identity for undergraduate students, there is a lack of research on whether the model also holds for secondary school students. In particular, there is little evidence on whether the structural relationships of the model are moderated by different types of out-of-school time experiences focused on physics. Furthermore, there is little evidence as to whether the model is also valid for students enrolled in a typical undergraduate STEM course other than physics (e.g. engineering).

Therefore, the specific research questions that guided this part of the study were:

RQ1. Does the model reported in Figure 1 accurately describe the physics identity of secondary and undergraduate students?

RQ2.a Does the physics identity construct differ between secondary school students who attended out-of-school activities in physics and other students?

RQ2.b Does the physics identity construct differ between physics and engineering undergraduates?

Finally, given the role of gender in identity construction, especially in physics where there is a significant under-representation of women in professional careers compared to other STEM fields, we also investigated whether the gender variable moderates the relationships between the constructs of the physics identity model (self-efficacy, interest, perceived recognition and identity) for the sample of secondary school and undergraduate students we included in the study. Therefore, the final research question that guided our study was:

RQ3. Does gender affect the relationships of the physics identity construct? If so, what are the differences between secondary school students who attended extra curriculum activities in physics and other students who did not attend these activities and between physics undergraduates and engineering undergraduates?

Figure 2 summarizes the hypothesized effects of the out-of-school activities, the chosen undergraduate course and gender.

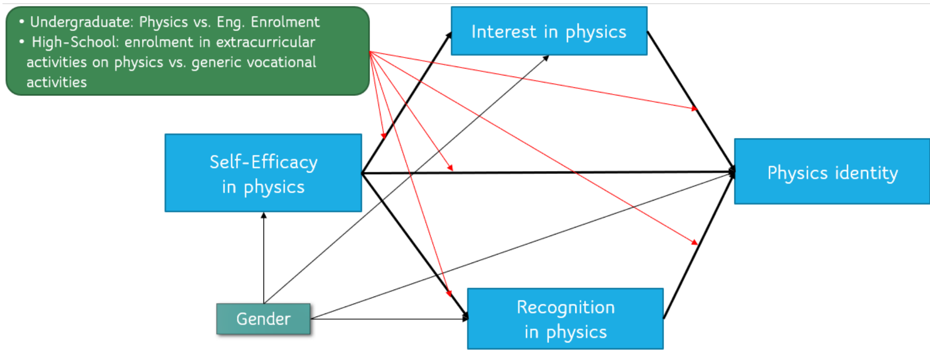

Figure 2: Modified model of disciplinary identity

4. METHODS

4.1 SAMPLE

Overall, 1135 Italian students participated in the study and completed the final survey (see next section). The sample consisted of four groups:

G1) 169 high school students (female students: 48.5%) who participated in general out-of-school vocational activities (duration = 15 hours);

G2) 177 high school students (female students: 59.9%) who participated in specific out-of-school vocational activities (duration = 15 h) focused on physics contents (quantum mechanics, astrophysics, optics);

G3) 427 first-year students of computer science and biomedical engineering (female students: 37.5%);

G4) 362 first-year physics students (female students: 36.2%).

All groups of high school students (G1 and G2) attended school streams where physics is a compulsory subject, with the same curriculum and the same amount of time devoted to physics (4 hours per week). G3 and G4 students had already attended an introductory physics course of 48 and 96 hours, respectively. The percentage of female students in the G3 and G4 groups reflects that of these university courses at national level.

4.2 INSTRUMENT

We used a 12-item instrument with a 5-point Likert scale: not at all, not very, fairly, mostly, completely. The instrument aimed at measuring the constructs of the model in Fig 1, and specifically:

Physics identity: we used a single item: *do you see yourself as a physics person?* from Hazari et al. (2010). This item has been used in several studies, both for physics (Bottomley et al., 2023) and STEM identity (Dou & Cain, 2022), as it was found to be a good proxy for overall physics identity (Potvin & Hazari, 2013).

Perceived recognition in physics: we used a 2-item scale that measured the perceived recognition as a physicist from others, namely teachers and classmates using the same structure for identity measurement: '*do ... see you as a physics person?*'

Interest in physics: we used 3 items to investigate to what extent students were interested in topics and research results in physics, as well as in physics-related hobbies.

Self-efficacy in physics: we used 6 items targeting how students rate themselves in: explaining the topics they studied (1 item); solving 'easy' and 'difficult' problems (2 items); designing an experiment and performing it alone/guided by teachers (3 items).

The data collection took place between 2020 and 2021 in remote teaching modality. Students completed the survey online and were informed that their participation was voluntary. Gender was indicated by the students themselves and was added to the survey prior to anonymizing the data for analysis.

4.3 DATA ANALYSIS

First, we explored how the four involved groups differed in their physics identity by means of an Analysis of Variance (ANOVA). Post-hoc analysis was then carried out to inspect differences between the four groups. Gender differences in each group were first explored through a series of *t-tests* and then investigated through a 2-way ANOVA testing the interaction between the group variable (categorical with 4 values) and the gender variable (binary, 1 = female student, 0 = male student).

Then, to answer our research questions, we performed a Structural Equation Modeling (SEM) based on the relationships hypothesized in Figure 2. SEM is a theory-driven statistical approach aimed at: testing hypotheses; inferring causal relationships; estimating direct and indirect effects. In other words, with SEM it is possible to test if a model in which well-determined relationships between variables are consistent with the empirical data. As in the confirmatory factor analysis, a χ^2 test assesses how consistent the model is with empirical data (acceptable values of χ^2/d.o.f. < 3) and it is also used to calculate the goodness indices of the fit (Schreiber et al., 2006). In this study, we also used two further indices, namely the Comparative Fit Index (CFI), which compares the hypothesized model with the null model, and the Tucker – Lewis index (TLI), which compares a χ^2 calculated on the hypothesized model with a χ^2 calculated on the null model, i.e. without the item-factor correlations. Both CFI and TLI should be above 0.95 (Hooper et al., 2008). To establish goodness of fit, we also used the Root Mean Squared Error of Approximation (RMSEA), which refers to the estimate of the approximation error of the correlation matrix between the items of the instrument. The RMSEA index addresses the problem of the strong dependency of the χ^2 test when the sample size N is high. Typically, acceptable values of RMSEA for a good-model fit are lower than 0.08 (Hooper et al., 2008; Schreiber et al., 2006). Finally, we also assessed convergent validity, which indicates whether the dominant latent factor is extracted from the items, by calculating the Average Variance Extracted (AVE) for each latent factor of the model. AVE values greater than 0.50 indicate that more than half of the variance of the items is explained by the latent factor.

To explore the role of extracurricular activities and of the chosen undergraduate course as moderating variables (see Figure 2), we conducted two separate multigroup analyses, comparing the G1 and G2 groups and the G3 and G4 groups, respectively. For both multigroup analyses, we hypothesized that the role of gender would influence the four variables in the models (self-efficacy, interest, recognition, identity). The significance of indirect effects was assessed using the bootstrap bias-corrected percentile method, which provides confidence intervals for the effect estimate. The magnitude of indirect effects was assessed by the ratio of the indirect effect to the direct effect (Sobel, 1982). To estimate the parameters of the hypothesised model and the goodness of fit indices, we followed the covariance-based approach using the maximum likelihood method in IBM SPSS Amos 28.

5. RESULTS

5.1 DIFFERENCES IN PHYSICS IDENTITY ACROSS GROUPS

Table 1 reports the descriptive statistics and correlations for all measured variables. For the self-efficacy, interest and recognition scales we report the average scores. Cronbach’s alpha of each scale is also reported on the table’s diagonal.

Table 1. Complete descriptive statistics for the measured variables (N = 1135)

Variable	1	2	3	4
1. Physics identity	-	-	-	-
2. Self-Efficacy	.371**	0.86[a]	-	-
3. Interest	.573**	.441**	0.84 [a]	-
4. Recognition	.492**	.490**	.464**	0.88 [a]
Mean	2.87	3.45	3.65	3.32
SD	1.08	0.69	0.82	0.83
Kurtosis	-0.567	-0.137	-0.099	0.155
Asymmetry	0.143	0.036	-0.342	-0.114

[a] Cronbach's alpha; ** $p < .01$

Note that the physics identity scale has no Cronbach's alpha associated since it is a single item scale. Table 2 reports the mean scores for female and male students for the four groups involved.

The results of the ANOVA show that the four groups significantly differed for their level of physics identity, Welch's F (3, 482.855) = 60.596, $p < .001$, $\eta^2 = .13$. Post-hoc analysis shows that differences between the groups are all statistically significant, with physics students (G4) scoring highest (mean = 3.33, SD =1.07), followed by the high school students who followed also out-of-school activities focused on physics (G2, mean = 3.15, SD = 1.08), the engineering students (G3, mean = 2.60, SD = 0.99) and the high school students who followed generic out-of-school activities (G1, mean = 2.30, SD = 0.84).

Table 2. Mean scores of the measured variables for the four groups of the sample

Variable	G1 (N = 169)	G2 (N = 177)	G3 (N= 427)	G4 (N=362)
1. Physics identity	2.30	3.15	2.60	3.33
Female students	2.23	3.00	2.60	3.04
Male students	2.37	3.38	2.60	3.49
t	-1.408	-2.265*	-0.030	-3.929***
Cohen's *d*	-0.16[a]	-0.36[b]	-0.00[a]	-0.43[b]
2. Self-Efficacy	3.05	3.72	3.67	3.22
Female students	2.94	3.58	3.63	3.11
Male students	3.16	3.94	3.70	3.29
t	-2.352*	-3.70***	-1.124	-2.629**
Cohen's *d*	-0.36[b]	-0.57[c]	-0.11[a]	-0.29[b]
3. Interest	3.01	3.77	3.68	3.87
Female students	2.86	3.63	3.81	3.72
Male students	3.15	3.97	3.60	3.95
t	-2.610*	-2.407*	2.878**	-2.915**
Cohen's *d*	-0.40[b]	-0.37[b]	0.29[b]	-0.32[b]
4. Recognition	2.94	3.80	3.37	3.19
Female students	2.90	3.71	3.56	3.02
Male students	2.96	3.95	3.27	3.29
t	-0.311	-2.181*	3.378***	-3.54
Cohen's *d*	-0.05[a]	-0.33[b]	0.34[b]	-0.39[b]

* $p < .05$; ** $p < .01$; *** $p < .001$; Cohen's *d* magnitude: a → negligible (0.0-0.2); b → small (0.2-0.5); c → moderate (0.5-0.8).

5.2 GENDER DIFFERENCES IN PHYSICS IDENTITY AND GENDER - GROUP INTERACTION

The *t-test* statistics show that, independently on the group, female students have lower physics identity and lower self-efficacy than their male counterpart. The magnitude of such differences is moderate for the G2 and G4 groups, namely high school students involved in out-of-school activities focused on physics and physics undergraduates, respectively. Girls of G1, G2 and G4 groups also scored significantly lower than boys in the interest and recognition scales, while for the G3 group girls report higher interest and perceive higher recognition.

Results of the 2-way ANOVA on physics identity show a significant effect of the group variable, F (3; 1127) = 50.843; $p < .001$; $\eta^2 = .12$, as well as of gender, F (1; 1127) = 13.598, $p < .001$, $\eta^2 = .01$. The interaction between gender and groups is also statistically significant, F (3; 1127) = 3.515; $p = .015$; $\eta^2 = .01$. Simple effects analysis shows that differences between groups are significant for both male students, F (3; 1127) = 47.242; $p < .001$, and female students, F(3; 1127) = 14.355, $p < .001$, although the effect is greater for male students (η^2 = .11) than for female student ($\eta^2 = .04$). Simple effect analysis within each group show that gender differences are stronger for the G4 group, F(1; 1127) = 16.983, $p < .001$, $\eta^2 = .015$ and the G2 group, F(1; 1127) = 6.141, $p = .013$, $\eta^2 = .005$, while there are no significant gender differences for the G1 and G3 groups.

5.3 ASSESSMENT OF THE DISCIPLINARY IDENTITY MODEL THROUGH STRUCTURAL EQUATION MODELING

The results of the SEM analysis carried out for the first-year students (G3 and G4) and the high school students (G1 and G2) are shown in Figures 3 and 4 respectively. The AVE values for the three predictors of disciplinary identity, namely self-efficacy, interest and recognition by others are: 0.53, 0.65 and 0.79, thus convergent validity is confirmed for both models. The variables reported in rectangles represent the items of the instrument, except for those related to self-efficacy scale, for which we performed item parcelling for a more efficient parameter estimation (Bandalos, 2002). Specifically, we averaged the two items about students' perceived self-efficacy in solving 'easy' and 'difficult' problems, and the three items about students' perceived self-efficacy in designing an experiment and performing it alone/guided by teachers.

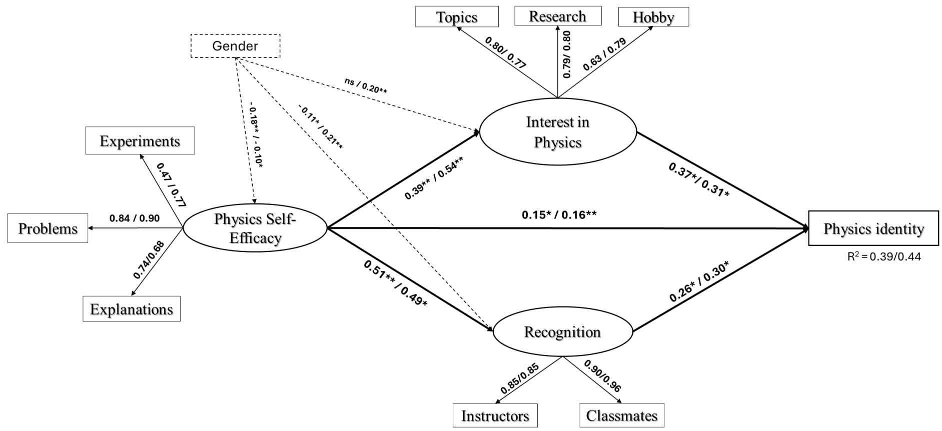

Figure 3. Standardized parameters estimate of relations of the physics identity model for undergraduate students. Results are reported in format *Physics/Engineering*. Note: * 0.01 < p ≤ 0.05; ** 0.001 < p ≤ 0.01

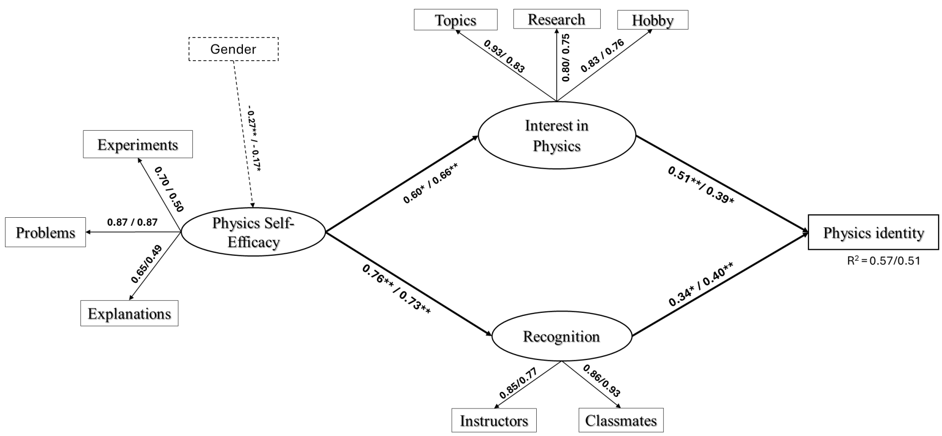

Figure 4. Standardized parameters estimates of relations of the physics identity model for high school students. Results are reported in format *Physics out-of-school/Generic vocational activities*. Note: * 0.01 < p ≤ 0.05; ** 0.001 < p ≤ 0.01

Both models have optimal fit indices (Model for G1 and G2 groups: χ^2/df = 1.711, $p < 10^{-3}$, RMSEA = 0.045, CFI = 0.97, TLI = 0.96; Model for G3 and G4 groups: χ^2/df = 2.510, $p < 10^{-3}$, RMSEA = 0.044, CFI = 0.97, TLI = 0.96). The model for G1 and G2 explains 57% and 51% of the variance of the physics identity, respectively, and shows measurement and structural invariance, $\Delta\chi^2(7) = 9.171$, $p = 0.241$, $\Delta\chi^2(10) = 12.005$, $p = 0.285$, respectively. Differently, the model for G3 and G4 groups explains 39% and 44% of the variance of the physics identity, respectively, while measurement and structural invariance are not supported, $\Delta\chi^2(8) = 22.098$, $p = 0.005$, $\Delta\chi^2(14) = 55.746$, $p < 0.001$, respectively.

Unstandardized indirect effects are reported in Table 3.

Table 3. Unstandardized indirect effects for SEM diagrams of Figures 3 and 4.

Path		*B*	CI	R_M
Self-efficacy → Interest → Identity				
	G1	0.55*	[0.278 – 1.008]	7.64
	G2	0.60*	[0.327 – 0.889]	3.33
	G3	0.28*	[0.169 – 0.425]	1.06
	G4	0.37**	[0.231 – 0.577]	0.95
Self-efficacy → Recognition → Identity				
	G1	0.62**	[0.363 – 1.149]	8.61
	G2	0.51*	[0.290 – 0.848]	2.83
	G3	0.25*	[0.160 – 0.335]	0.94
	G4	0.34*	[0.161 – 0.544]	0.88

Note: CI = Confidence Interval; R_M = Ratio of unstandardized indirect to unstandardized direct effect; * $p < 0.05$; ** $p \leq 0.01$. G1 = high school students who participated in generic out-of-school vocational activities; G2 = high school students who participated in specific out-of-school vocational activities focused on physics contents; G3 = freshman computer science and biomedical engineering students; G4 = freshman undergraduate physics students.

Indirect effects of self-efficacy are significant for the path mediated by interest and the path mediated by recognition, for all groups. However, self-efficacy has a significant direct positive effect on physics identity only for undergraduate students. After accounting for such mediating paths, gender has no significant direct effect on physics identity for all groups in the sample, but its effect is fully mediated by self-efficacy (all groups) and recognition (G3 and G4 groups). Specifically, gender has a negative effect on self-efficacy and recognition for the G4 group (physics students), while it has a weak negative effect on self-efficacy and a positive effect on recognition and interest for the G3 group (computer science and biomedical engineering students). This means that, in general, being a female student has a negative impact on perceived self-efficacy in physics, regardless of the chosen undergraduate course. In contrast, being a female engineering student increases both interest and recognition in physics. Similarly, for high school students, gender has a negative effect on self-efficacy of both groups. This means that, in general, being a female student has a negative impact on perceived self-efficacy in physics, regardless of attending extracurricular activities.

6. DISCUSSION

In the following, we briefly describe the results according to the research questions of the study**.**

6.1 RQ1. Does the model reported in Figure 1 accurately describe the physics identity of secondary and undergraduate students?

Our results confirm that the disciplinary identity model in Figure 1, developed from previous research, accurately describes the physics identity of the students in our sample, namely high school students with different career orientations towards physics and university students who had chosen two different STEM subjects, physics and engineering, respectively. In particular, our results support the use of three latent constructs, namely interest, recognition and self-efficacy, to measure physics identity for our population. Consistent with previous models (Dou & Cian, 2022; Hazari et al., 2010), our results support a significant direct effect of interest and recognition on physics identity and a significant indirect effect of self-efficacy mediated by interest and recognition.

However, some differences in the strength of structural relationships emerge when comparing our findings with previous research. First, in our case, the recognition construct makes a smaller contribution to physics identity, contrary to what happens for STEM identity in Dou & Cian (2022). As physics is a specific area of STEM, we can argue that being interested in physics may play a more important role in contributing to identity development than recognition from others, as classmates or other students may be perceived as poorly informed about one's physics knowledge (Kalender et al., 2019). The same argument may apply to recognition from teachers or lecturers, as their judgement may be perceived as less relevant, given that the high school and undergraduate students involved in the study already had an interest in STEM (Starr et al., 2020). The second difference is that self-efficacy has a direct effect on physics identity only for undergraduate students. This finding may be related to our decision to include in the survey items on problem solving, oral presentation, and conducting experiments, which may be more familiar to undergraduate STEM students than to high school students.

6.2 RQ2.a Does the physics identity construct differ between secondary school students who attended out-of-school activities in physics and other students?

We found that, from a measurement and structural point of view, our model of identity is invariant with respect to the type of extracurricular activities engaged in, despite significant differences in identity scores between the two groups of students. This means that interest and recognition by others significantly predict physics identity independently of involvement in physics activities. Furthermore, self-efficacy has only an indirect effect on identity, which is fully mediated by both interest and recognition. This is in line with the findings of Dou & Chan (2021), who found that self-efficacy does not directly influence STEM identity. This result can be interpreted by considering that the self-efficacy items were related to specific teaching practices in physics (e.g. designing an experiment), which are hardly implemented at high school level.

6.3 RQ2.b Does the physics identity construct differ between physics and engineering undergraduates?

Our results support the validity of the proposed physics identity model for undergraduate students. In particular, self-efficacy, interest and recognition independently predict career identity, but self-efficacy also has a direct effect on identity for undergraduate physics students. The different role played by self-efficacy is in line with previous studies which have shown that self-efficacy has an impact on the identity of the person in a particular discipline (Stout et al., 2011). The significant differences between physics and engineering students in the measurement and structural model can be explained by taking self-efficacy into account. In particular, we found that self-efficacy significantly affects interest, recognition and identity, as measured by our items that target the perceived ability to solve problems, design and perform an experiment, and orally discuss curriculum content. This perception may be very different, as physics students may be more familiar with these practices than engineering students.

6.4 RQ3 Does gender affect the relationships of the physics identity construct? If so, what are the differences between secondary school students who attended extra curriculum activities in physics and other students who did not attend these activities and between physics undergraduates and engineering undergraduates?

Our results show that gender does not directly affect physics identity, but only indirectly. For all students in the sample, gender negatively affects self-efficacy, i.e. female students are less confident in their knowledge, while for undergraduates, gender also affects recognition, with different directions, positive for engineering students, negative for physics students. Another direct effect, on interest, was only observed for engineering students. Overall, our results are consistent with previous studies in physics education, which have shown that even when learning experiences are similar, stereotypical associations of competence with men can lead women to be underconfident about their performance (Galano et al., 2023; Li & Singh, 2021). Notably, in the physicist group, gender negatively affects self-efficacy and recognition, whereas in the engineering group, gender negatively affects self-efficacy but positively affects recognition and interest. A possible explanation for this result is that, in the engineering courses included in our sample (computer science and biomedical engineering), female students are more interested in physics than boys and are recognised as better students by classmates and teachers due to the different type of school attended, namely technical school or scientific lyceum. However, further studies with a more representative sample are needed to support our interpretation.

7. CONCLUSIONS AND IMPLICATIONS

Our results provide further evidence for the validity of the three-factor structure of identity predictors (Hazari et al., 2010; Hazari et al., 2020; Dou & Cian, 2022), while supporting the use of our instrument to measure physics identity. However, due to the use of a convenience sample, better sampling approaches are needed to confirm the emerging direct and indirect effects. Furthermore, the model should be improved by including other predictors and mediators in the model that take into account the cultural milieu in which the identity develops (e.g., utility value of physics, family background, socio-economic status, school context). Following Gee (2000) and Bottomley (2023), this would also require longitudinal studies, although this construct appears to be quite stable over time (Starr et al., 2020).

These findings also have implications for high school teachers and university instructors, in particular the role they can play in influencing perceived recognition as a physicist as a mediator of physics identity. As suggested by Wang and Hazari (2018), explicit and implicit attempts to increase students' perceptions of being recognised 'as a physicist' can be internalised by students. This can take the form of explicitly telling students that they are capable of setting tasks that make students feel recognised without explicitly telling them so (Bottomley et al., 2023). However, further research is needed to explore whether these findings can be extended to undergraduate students.

Some limitations of the study have to be highlighted. First, the convenience sample was based on a voluntary online participation, and this could have biased the results. Future studies may hance investigate if the relationship found in this study can be extended to a representative sample of the population involved in this study. Second, reproducibility of the results should be investigated, as there is a lack of this kind of quantitative research involving Italian students. Furthermore, the role of confounding variables – such as performance in physics or social indicators – as mediator in the physics identity model should be considered as a further research step. Third, the study was carried out during remote teaching due to the COVID-19 pandemic, and this may have affected the measured variables. Specifically, in one of our previous studies in the Italian university context (Marzoli et al., 2021), we found that the transition to remote teaching led to a significant decrease in interest towards physics as well as in the students' perceived self-efficacy in physics. Hence, further research is needed to find whether the decrease in these dimensions affected also the relationships of physics identity model. Finally, we focused on the classification of gender into two categories (male and female). While we recognize this as a limitation of the present study due to adequately power our analysis, the evolving experience of those students who identify as non-binary is an interesting question for future research.

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