“I DON’T KNOW”: DEALING WITH UNCERTAINTY IN STUDENTS’ PERCEIVED COMPETENCE IN STEM

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Introduction

The ongoing digital transformation posits the importance of STEM (science, technology, engineering, and mathematics) subjects in different economic sectors and society as a whole (Murphy et al., 2019).

Worldwide, nations are looking to STEM to manage a rapidly changing environment; to supply food, water, and resources; to preserve health and well-being; to innovate new technologies; and to ensure security.

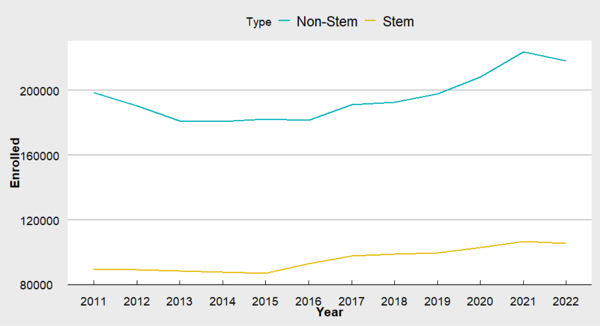
People's ability to enter the STEM-related workforce is contingent on their **mathematics** and **science literacy**, underling the importance of the educational practices in facing these challenges.

INTRODUCTION

There are significant concerns in STEM education (Höhne et al., 2019; Priulla et. al., 2021):

- difficulties in achieving successful academic performances
- high dropout rates
- consistent gender discrepancy

The Italian context



Data retrived from *Anagrafe Miur*

- Italian university students, as in most western countries (Mostafa 2019), are not particularly likely to enrol in STEM courses.
- In Italy, since 1989, more females are enrolling than males, but females are still underrepresented in almost all the STEM fields, while over-represented in nursing, humanities, and law schools.
- In the last 10 years in Italy, the share of students enrolled in STEM disciplines has always ranged between 31% and 34%; last year, 32.6%.

INTRODUCTION

Science-related career expectation and motivation to engage in STEM education is likely to be more related to **perceived competence** in science rather than **actual competence** or high marks (Kang et al., 2021).

The following factors seem to significantly impact students' motivation in STEM education (Franks et al., 2019):

- Self-concept
- Self-efficacy
- Belonging uncertainty (or Ability uncertainty)

MOTIVATION

Some students are cautious about or unsure of their abilities to succeed in mathematics and science, leading to “don’t know” responses when questioned about their competencies.

Aim of the work

Explore uncertainty in students’ perceived competence to i) define if and how it is possible to detect **students’ profiles** according to their self-concept and uncertainty, and ii) understand the main **determinants** affecting the membership to such groups.

- Investigate self-concept with respect to math and science abilities.
- Take into account students’ uncertainty through the "don’t know" option.

THE PRESENT STUDY

Aim: Investigate students' self-concept of math and science ability in higher education.

Self-concept measure

Participants were asked to indicate if they agreed with **13 statements** regarding what they think about their competence and expectancies of success in mathematics and science.

Statements examples:
Math Self-Concept: "I am sure I could do advanced work in math"
Science Self-Concept: "I am sure of myself when I do science"

Each question had three response alternatives: Yes, No, Don't know.

- Note that the "Don't know" category aimed to evaluate the **ability uncertainty** dimension.

Individual covariates

We accounted for some experiences and factors that may have influenced the development of people's self-concepts related to STEM.

Gender differences:
Despite international testing showing females achieving at similar levels to males in STEM education, females tend to have lower aspirations and confidence in STEM subjects.

METHOD

Multidimensional latent class IRT model
The Model

We adopt the **multidimensional latent class IRT model** (Bacci et al., 2017), based on *within-item* multidimensionality, for analysis of item responses affected by **Don't Know** option.

- $Y_{ij} = y_{ij}$: response proved by subject i to dichotomous items j, $j = 1, 2, \ldots, m$.

$$\mathrm{y}_{ij} = \begin{cases} 0 \text{ if} & \text{item j is observed as No} \\ 1 \text{ if} & \text{item j is observed as Yes} \\ \text{NA} & \text{if item j is not observed ("Don't Know" option)} \end{cases}$$

- $R_{ij} = r_{ij}$: item binary indicator of response.

$$\mathrm{r}_{ij} = \begin{cases} 0 & \text{if item j is not observed ("Don't Know" option)} \\ 1 & \text{if item j is observed} \end{cases}$$

- $X_1, \ldots, X_C$: exogenous individual covariates

Multidimensional latent class IRT model

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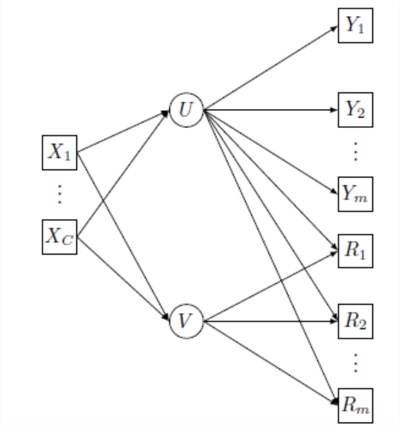

U: latent variable denoting the latent trait (rispondents' Self-concept in STEM disciplines) measured by the test items.

V: latent variable denoting the individual ability uncertainty in STEM disciplines (determining if an item is observed or not observed).

MULTIDIMENSIONAL LATENT CLASS IRT MODEL
LATENT VARIABLES

We assume that the latent variables U and V have **discrete distributions**:

- U has support points (latent classes) u_{hU}.
- V has support points (latent classes) v_{hV}.

The corresponding **weights** are denoted by:

$$\lambda_{h_U}(\mathbf{x}) = Pr(\mathbf{U} = \mathbf{u}_{h_U} \mid \mathbf{X} = \mathbf{x}), \quad h_U = 1, 2, ..., k_U$$

$$\pi_{h_V}(\mathbf{x}) = Pr(\mathbf{V} = \mathbf{v}_{h_V} \mid \mathbf{X} = \mathbf{x}), \quad h_V = 1, 2, ..., k_V$$

given the observed individual covariates.

Multidimensional latent class IRT model
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given the observed individual covariates.

- In the spirit of concomitant variable LC models (Dayton and Macready, 1988), we allow the **membership probabilities** of the latent classes to depend on observed covariates through a **multinomial logit model** (Bartolucci et al., 2015):

$$\log \frac{\lambda_{h_U}(\mathbf{x})}{\lambda_1(\mathbf{x})} = \phi_{0h_U} + \mathbf{x}'\phi_{h_U}, \qquad h_U = 2, ..., k_U$$

$$\log \frac{\pi_{h_V}(\mathbf{x})}{\pi_1(\mathbf{x})} = \psi_{0h_V} + \mathbf{x}'\psi_{h_V}, \qquad h_V = 2, ..., k_V$$

Multidimensional latent class IRT model
Measurement Model

The relationships between the latent variables U and V and the manifest variables (i.e. item responses $Y_1, \dots, Y_m$ and the response indicators $R_1, \dots, R_m$) are described by the measurement part of the model.

Let $q_{h_U h_V, j} = Pr(R_j = 1 \mid \mathbf{U} = \mathbf{u}_{h_U}, \mathbf{V} = \mathbf{v}_{h_V})$, denote the probability of answering item j conditionally on U and V and let $p_{h_U, j} = Pr(Y_j = 1 \mid \mathbf{U} = \mathbf{u}_{h_U})$ denote the probability that the answer to item j is "Yes", conditionally on the latent trait U. Then, we specify a multidimensional LC **Two-Parameter Logistic (2PL) model** (Bartolucci, 2007) for both of the above probabilities:

$$\log \frac{q_{h_U h_V, j}}{1 - q_{h_U h_V, j}} = \gamma_{Uj} u_{h_U} + \gamma_{Vj} v_{h_V} - \delta_j, \qquad j = 1, 2..., m$$

$$\log \frac{p_{h_U j}}{1 - p_{h_U j}} = \alpha_j u_{h_U} - \beta_j, \qquad j = 1, 2..., m$$

where γ_{Uj}, γ_{Vj}, and α_j are the *discrimination parameters*, whereas δ_j and β_j are the *difficulty parameters*.

- We fit the proposed multidimensional LC-IRT model by maximizing the marginal likelihood via the EM algorithm (Dempster et al., 1977), using the **R** package **`MLCIRTwithin`** (Bartolucci and Bacci, 2016).

Multidimensional latent class IRT model
Conditional Response Probabilities

Discrete latent variables $\Longrightarrow$ Clustering the individuals into latent classes that are homogeneous with respect to the latent traits.

The multidimensional within-item LC-IRT model allows identifying a finite number of latent classes for each latent construct U, V

- Estimate the conditional probability for the item Y_j given the membership to the h-th class of U:

$$p_{h_U,j} = Pr(Y_j = 1 \mid \mathbf{U} = \mathbf{u}_{h_U}), \qquad h_U = 1, \dots, k_U$$

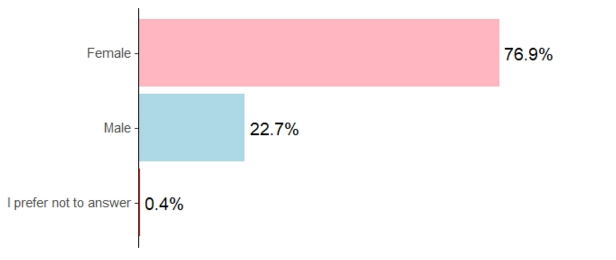
- Estimate the conditional probability for the item R_j given the membership to the h_U-th class of U and the h_V-th of V:

$$q_{h_U h_V,j} = Pr(R_j = 1 \mid \mathbf{U} = \mathbf{u}_{h_U}, \mathbf{V} = \mathbf{v}_{h_V}), \qquad h_U = 1, \dots, k_U, \quad h_V = 1, \dots, k_V$$

DATA AND RESULTS

Participants

The data set used in our analysis contains the responses provided by $n = 1007$ subjects to a questionnaire on the Self-Concept in STEM disciplines.



- Most of the respondents are females, about 23% are males, while only 0.4% of the subjects preferred not to answer. The latter individuals were removed from the analysis.
- Respondents' median age is approximately 25 years, while the first and third quartiles of the sample are 23 and 27, respectively.

Measures

Individual covariates:

- Socio-demographic information (gender, age, region of residence, type of high school graduation, type of degree);
- Socio-family background (such as, parents' education level);
- Attitude towards STEM disciplines (assessed through 5 items on a 7−point Likert scale (e.g., 'For me, a STEM-related career is *exciting*);
- Teacher support: "Do you think teachers have encouraged you in STEM disciplines during your studies?" Yes/No;
- STEM role: "Do you hold a role in STEM disciplines or would you like to take it in the future?" Yes/No;
- STEM time: "If you had gone back in time, would you have taken more time and/or commitment to STEM disciplines?" Yes/No.

Item related to Self−Concept in STEM disciplines.

Math Self-Concept
1. Math has been my worst subject(*)
2. Math is hard for me(*)
3. I am the type of student to do well in math
4. I can handle most subjects well, but I cannot do a good job with math(*)
5. I can get good grades in math
6. I am good at math
Science Self-Concept
7. I am sure of myself when I do science
8. I expect to use science when I get out of school
9. Knowing science will help me earn a living
10. I will need science for my future work
11. I know I can do well in science
12. Science will be important to me in my life's work
13. I am sure I could do advanced work in science

Note. (*) Reversed coded in analysis

ESTIMATED LATENT STRUCTURE OF THE MODEL

We initially fitted a series of models without covariates to select the optimal number of latent classes for the latent variables U (**Self-Concept**) and V (**Uncertainty**), according to the BIC index.

The BIC indicated the model with $k_U = 2$ latent classes for U and $k_V = 2$ latent classes for V as the best one:

	Self-Concept U class h_U		Uncertainty V class h_V	
	1	2	1	2
Standardized support points ($\hat{u}^*_{h_U}$, $\hat{v}^*_{h_V}$)	-1.285	0.778	-1.275	0.784
Average probabilities ($\bar{\lambda}_{h_U}, \bar{\pi}_{h_V}$)	0.377	0.623	0.381	0.619

Self-Concept U

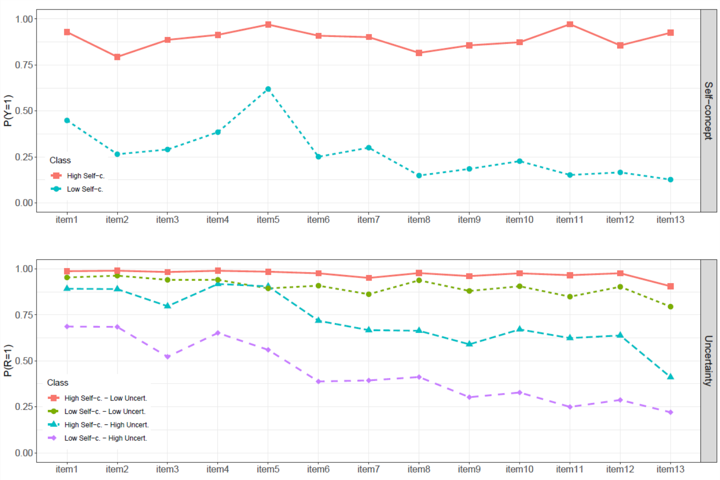
- Class 1: subjects with a more negative Self-concept in STEM disciplines.
- Class 2: collects the main part of interviewees, subjects with a more positive Self-concept.

Uncertainty V

- Class 1: subjects with a lower level of uncertainty.

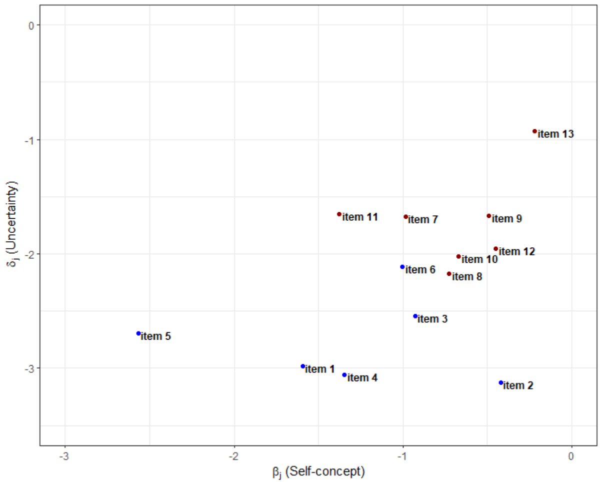
- Class 2 collects the main part of interviewees, subjects with a higher level of ability uncertainty.

Conditional Response Probabilities



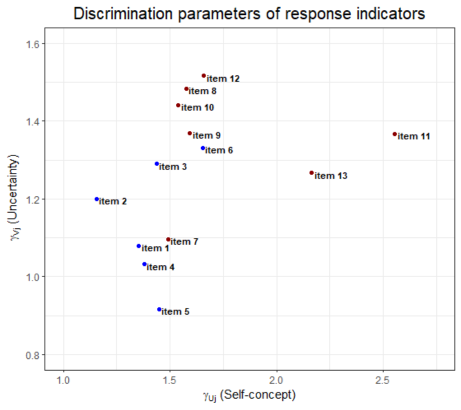
- **Item 5** ("I can get good grades in math") had the largest proportion of "Yes" responses, followed by **Item 4** ("I can handle most subjects well, but I cannot do a good job with math"[reversed]).
- For **Item 13** ("I am sure I could do advanced work in science") the probability of "Don't know" response is higher with respect to the other items in all latent classes.

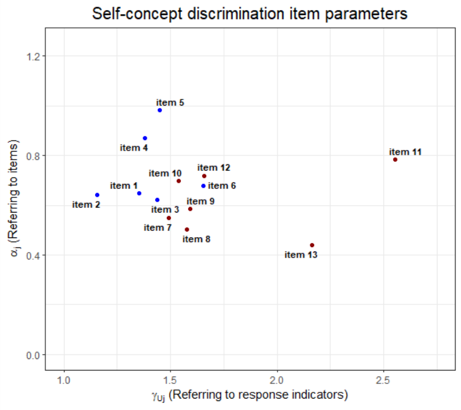
DIFFICULTY ITEM PARAMETERS



- Item 5 is the easiest one for the Self-concept variable, whereas item 13 is the most difficult one for the uncertainty dimension.
- There is greater **uncertainty** in responses about science self-concept (red points in the graph) than in those about math self-concept (blue points in the graph);
- Overall, respondents showed a more positive **self-concept** about math than about science.

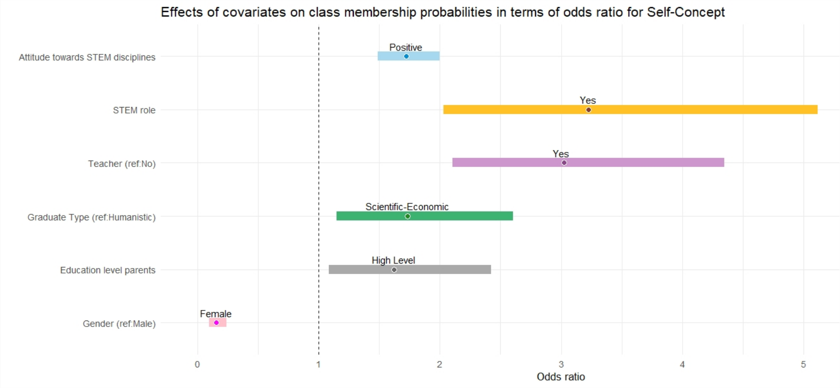
DISCRIMINATION ITEM PARAMETERS





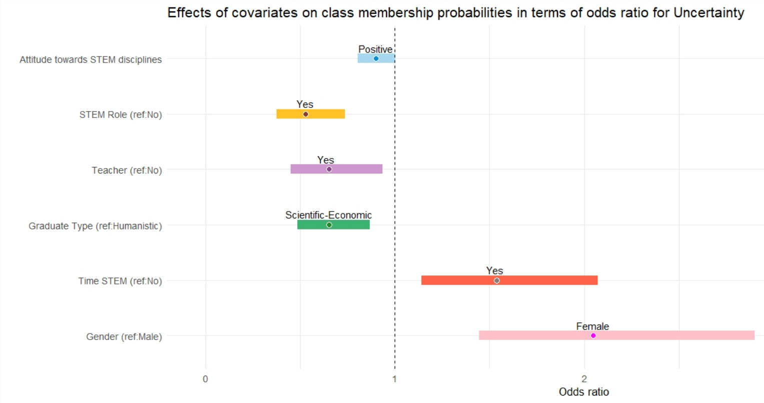
- The response indicators 11 ("I know I can do well in science") and 13 ("I am sure I could do advanced work in science") are the most discriminating ones for the self-concept latent variable;
- The response indicators about science (red points in the graph) are the most discriminating ones for ability uncertainty in STEM;
- Items 4 and 5, and in general items about math, are the most discriminating ones for the self-concept latent variable.

Effects of covariates on class membership probabilities
Odds ratio for Self-Concept



- Girls tend to have a more negative Self-concept in STEM disciplines than boys;
- A high level of parents' education was associated with a more positive Self-concept in STEM disciplines;
- Perceived teacher support correlated with the development of a more positive Self-concept in STEM disciplines;
- Who attends a Scientific-Economic degree program or attained a degree in this field, who holds a role in STEM disciplines, and, in general, who has a more positive attitude towards STEM disciplines presented a more positive Self-concept in STEM disciplines.

Effects of covariates on class membership probabilities
Odds ratio for Uncertainty



- Girls showed a higher ability uncertainty in STEM disciplines than boys;
- Who attends a Scientific-Economic degree program or attained a degree in this field, who holds a role in STEM disciplines, and, in general, who has a more positive attitude towards STEM disciplines presented lower ability uncertainty;
- Perceived teacher support was associated with a lower ability uncertainty in STEM disciplines;
- Who stated that if they had gone back in time they would have taken more time to STEM disciplines reported a higher level of ability uncertainty.

Final remarks

The data analyzed showed greater ability uncertainty in science than in mathematics.

How can we interpret this result? Further studies should explore in-depth this issue.

Our analysis pointed to a persistent gender difference in self-concept in STEM disciplines and uncertainty.

Belonging uncertainty may constitute a major leak for women in the pipeline to a STEM-related career and explain gender disparities and under representation in sectors that in today's economies provide greater job stability and higher wages in the future.

Unfortunately, there is still an ingrained thought that girls' achievement in STEM disciplines can be attributed to their diligence rather than talent.

Educators have to encourage feelings of excitement or happiness in learning about science in every student in order to promote a positive self-concept in STEM and reduce ability uncertainty in STEM disciplines.

THANK YOU FOR YOUR ATTENTION!

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