Education Capability: A Focus on Gender and Science

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Abstract The focus of the paper is on the measurement of science education capability with a gender perspective and in the capability approach framework. Measuring science education capability implies going beyond the measurement of children test scores. In the capability approach, we aim at the real opportunities that children can develop later in life and therefore it is important to include some measures of non-cognitive skills. We utilize, therefore, different indicators in addition to test scores in science: enjoyment in science, interest in science, general and personal values of science, self-confidence in performing science related tasks, awareness and perception of environmental issues, and responsibility for sustainable development. We utilize the 2006 PISA survey for Italian 15 years old children because it contains a particular focus on science and we estimate a Structural Equation Model to take into account that capabilities are latent constructs of which we only observe some indicators. We also investigate the determinants of children’s science education capability in Italy taking into account household, individual and school factors. Results confirm that boys outperform girls in science education capability. Our theoretical construct for the science education capability confirms that all the indicators are relevant to measure this capability. School activities to promote sciences improve girls’ capability and...
interactive methods of teaching improve both girls and boys capability. The household educational resources and the household educational possession are also positively correlated with girls’ and boys’ science education capability.

**Keywords**  Capabilities · Education · Gender · Structural Equation Models · Children

**JEL Classification**  I20 · C35 · B54

1 Introduction

The capability approach (Sen 1985, 1999, 2009; Nussbaum 2003) represents an alternative framework for the evaluation of human well-being. The capability approach offers many advantages over traditional approaches. First, it does not primarily focuses on means (income and wealth) as they matter only to the extent to which they can influence the life of the individuals (Sen 2009). Well-being is evaluated in terms of real life achievements (the so-called *functionings*), i.e. what people are and what they do, and, even more, in terms of human *capabilities*, i.e. what people are able to be and do, given their means, their personal characteristics and the characteristics of the environment they live in. As a consequence, the capability approach stresses the importance of taking into account the multidimensionality of well-being and human lives.

The capability approach has more and more spread over the last decades (see amongst others Alkire and Santos 2013; Madonia et al. 2013; Robeyns 2006; Van Ootegem and Verhofstadt 2012) and an interesting literature has risen on the application of the capability approach to children (Addabbo et al. 2014; Addabbo and Di Tommaso 2011; Biggeri et al. 2010; Wüst and Volkert 2012, Trani et al. 2013).

Child well-being includes many dimensions (Biggeri et al. 2006; Di Tommaso 2007; Fernandes et al. 2012, 2013). In this paper, we focus on a crucial dimension of child well-being: the education capability. Many scholars within the capability approach have underlined its importance. It is an essential capability in its own and as a basis for other capabilities (Hart 2014; Terzi 2007).

Nussbaum (2003) provides a broad definition of this capability: “Capability of Senses Imagination and Thought: Being able to use the senses, to imagine, think, and reason and do these things in a “truly human” way informed and cultivated by an adequate education, including by no means limited to, literacy and basic material skills” (Nussbaum 2003, 41).

Biggeri and Libanora (2011) ask directly to children to define a list of capabilities and to give a value to the education capability: 92% of the children consider education a “very important” capability. Other researchers underline the importance of the capability approach to define a broader concept of education outcomes (Kelly 2012; Walker 2005). In particular, schooling and tests’ outcomes can be seen as a mean to enhance children opportunities in the capability approach. Other authors in the capabilities literature propose definitions of the education capability (Terzi 2007; Nussbaum 1997; Hart 2014) and analyse the role of educational institutions in fostering human well-being (Hart 2014; Biggeri 2014; Vaughan and Walker 2012; Walker and Unterhalter 2007).

Science and technology are considered a basic capability for educational functionings by Terzi (2007, 37) together with literacy, numeracy, sociality and participation, learning dispositions, physical activities and practical reason.
In this paper, we focus on the science education capability for Italian children in a gender perspective. Following the capability literature on education and the educational literature on cognitive and non-cognitive skills (Heckman 2008; Cunha et al. 2010; Sikora and Pokropek 2012; Cornwell et al. 2013; Gutman and Schoon 2013; Heckman and Mosso 2014), we believe that the use of test scores is limited. In the spirit of the capability approach, we would like to focus on the real opportunities that children have to become knowledgeable (educated) adults and therefore include some measures of non-cognitive skills. We utilize, therefore, different indicators in addition to test scores in science: enjoyment in science, interest in science, general and personal values of science, self-efficacy (confidence in performing science related tasks), awareness and perception of environmental issues, and responsibility for sustainable development.

We apply the simplest Structural Equation Model, a Multiple Indicators Multiple Causes model (MIMIC), to OECD PISA 2006 micro-data for Italy. The MIMIC model has two important features: first, it allows the estimation of the science capability as a latent construct of which it is possible to observe only some functionings i.e. the indicators listed above (Krishnakumar and Nagar 2008). Second, it allows the presence of exogeneous cause variables that determine the latent capability.

The Italian PISA data provide a relevant example of a country with low achievements on science test scores and high level of gender inequality in the society. OECD (2007) shows that the Italian average test score in science is equal to 475 (477 for males and 474 for females), against an OECD average equal to 500. Further, according to EIGE (2013), the gender equality index in Italy is 40.9 against an EU-28 average by 54.

The major contribution of the paper is to provide a new concept of science education capability that is defined not only on test scores but on a broader set of indicators. This definition of the education capability is particularly relevant, as our results show, for analysing gender differences. Moreover, we utilize a MIMIC model which allows both to consider capabilities as latent variables of which we observe some indicators and to estimate the effect of individual, family, and institutional variables on the latent capability.

The paper is organized as follows: Sect. 2 presents the existing literature focusing on the gender gap in science, and on the family and institutional conversion factors referred to this capability. Data and descriptive statistics are provided in Sect. 3. The MIMIC model is described in Sect. 4 and the results of the estimated model are shown in Sect. 5. The last Section draws conclusions.

2 Gender Differences in Science

Gender differences in science test scores (and more in general in the so-called STEM: Science Technology Engineering and Math disciplines) are widespread in most countries in the world. These differences justify the gender perspective that we take in this analysis. Among others, de San Roman and de La Rica Goiricelaya (2012) find math gender gaps among OECD countries. They find that the average gap in maths is equal to $-8.64$ in PISA 2009; this gap is lower for the lower percentiles ($-7.01$ for the 5th percentile and $-20.33$ for the 95th percentile). Moreover, they find that differences in cultural and social norms across countries and across regions within the same country are crucial determinants in understanding gender differences in PISA 2009 test scores: girls perform relatively better in both math and reading in societies with high gender equality. In addition, they find substantial evidence for the intergenerational transmission of gender role attitudes,
especially from mothers to daughters, as the performance of girls—not that of boys—is better in families where the mother works outside home. The gender gap in math decreases in more gender equal societies (Guiso et al. 2008). Also OECD (2015) confirms a positive correlation between women’s participation rates and girls’ performance in math.

The literature shows that the gender gap in sciences does not emerge until high school. This result suggests that gender differences are due to socialization and to the educational process rather than connected to biological factors (Good et al. 2010; Bleeker and Jacobs 2004; Brownlow and Durham 1997). Sikora and Pokropek (2012) using data from PISA 2006 surveys for 50 countries analyse gender differences in science and they find that the male–female gap in science self-concept (similar to our self-efficacy in Table 1) is larger in advanced industrial countries.

2.1 Family Involvement

The role of early parenting and older siblings on children’s cognitive and non-cognitive abilities at different stages of children’s life has been brought into attention by the literature (amongst others Heckman 2008; Cunha et al. 2010; Dai and Heckman 2013; Heckman and Mosso 2014; Del Boca et al. 2014).

Haveman and Wolfe (1995), Peraita and Sánchez (1998) and Yeung et al. (2002), stress the impact on children’s attainment of family background variables. Duncan et al. (1994) by using the Infant Health and Development Program longitudinal data detect a negative effect of poverty on child cognitive and behavioural functionings at age 5 and a positive effect of mother’s education. By disentangling Bourdieu’s cultural capital and habitus concepts, through a critical survey of the literature on their effects and by considering the joint impact of both in the reproduction of educational inequality, Edgerton and Roberts (2014) stress their relevant joint explanatory potential. Sullivan (2001) operationalizes the concept of cultural capital and provides measures of both parents’ and children’s cultural capital finding a positive effect of cultural capital on children’s performance in the results of the general certificate of secondary education though the inclusion of cultural capital effects does not cancel out the significance of the effect of social class on children’s educational attainment.

With specific reference to sciences, parents’ perception of child ability, parental involvement in homework, sex-stereotypes in parent’s evaluation of children abilities have been found to affect achievements in science and children’s self-perception (amongst others: Jacobs 1991; Jacobs and Bleeker 2004; Jacobs and Eccles 1992; Bhanot and Jovanovic 2009; Twenge and Campbell 2001). Though gender gaps are decreasing over time, boys have better access to science-related resources than girls (Jacobs and Bleeker 2004).

Mothers’ encouragement in science homework has a positive effect on girls’ self-assessment of science ability, and a negative effect on boys’ self-assessment. Mothers’ science discussions have a similar effect on boys and girls beliefs about science (Bhanot and Jovanovic 2009). Moreover, the effect of parental involvement on children’s out-of-school activities related to sciences and math are related to children’s interest in science also later on in their life (Jacobs and Bleeker 2004).

2.2 Teaching Science, Pre-schooling and Schooling

There is an extensive literature showing the impact of schooling and preschool education programs on the development of cognitive and non-cognitive skills. In particular in the last
decade, economic research has been increasingly focusing on non-cognitive skills. Heckman and Kautz (2012, 2014) suggest that not only cognitive skills matter and that non-cognitive skills, such as “personality traits”, “motivation”, “sociability”, “self-esteem”, are important predictors of success in life and in the labour market. The authors call for a better understanding of non-cognitive skills and the promotion of policies enhancing their development. Moreover, Heckman and Mosso (2014) show that also test results depend not only on cognitive skills, but also on non-cognitive skills, such as effort and motivation. This stresses the importance of formative experiences in preschool education programs and in family upbringing focusing not merely on cognitive aspects.

High quality preschool education programs like the Child–Parent Center Program\(^1\) or the High Scope Perry Preschool Program\(^2\) have been shown to positively affect later life outcomes in terms of educational attainment, cognitive and non-cognitive skills, labour market status, earnings, and reduced crime (Temple and Reynolds 2007; Heckman et al. 2010a, b; Heckman et al. 2013).

The effect of schooling in affecting test scores has been widely analysed in the literature. Hansen et al. (2004) have modelled the interaction of schooling and test scores as generated by a common unobserved latent ability detecting different effects of schooling at different ability levels. Martins and Veiga (2010) detect a significant role of socioeconomic inequalities in explaining children’s mathematical achievement in EU-15 countries by using the OECD Programme for International Student Assessment (PISA) 2003 data; according to their results Italy belongs to those countries (amongst them also The Netherlands, Germany, Belgium and Austria) where school seems to play an important role in the observed difference in children’s achievements in mathematics.

Focussing on the gender differences in STEM and on different teaching activities, evidence shows how different approaches to math and physics can increase gender inequality in achievements. Problem-solving and cognitive activation strategies teaching methods yield positive results on STEM test scores (Aka et al. 2010; OECD 2015). Problem-solving, class-discussions and investigative work and cognitive activation strategies have been found to improve girls’ performances (Boaler 2002; Zohar and Sela 2003; OECD 2015). Boaler et al. (2011) analyse other factors affecting lower achievement in math and science, e.g. images shown in textbooks. Good et al. (2010) show that, by using counter-stereotypic images with female scientists, girls’ comprehension increases.

Moreover, children’s overall self-perception of abilities is more affected by negative evaluation by others during teenage-hood (Bhanot and Jovanovic 2009; Twenge and Campbell 2001).

3 Data and Descriptive Statistics

We utilize the 2006 survey of the Programme for International Student Assessment (PISA) conducted by the OECD. Our sample consists of 8582 boys and 8369 girls. PISA tests are collected on 15 years old children.

The 2006 PISA survey contains a particular focus on sciences, which is useful to extend the estimation of the education capability in science beyond test results. In particular, in

\(^1\) The program provided 6 years of educational and family-support services to socioeconomic disadvantaged children from age 3 in Chicago Public Schools since 1967.

\(^2\) This program has been experimented in Michigan in the mid-1960s and was devoted to low IQ and socioeconomic status African American aged 3–4 children including also activities with their parents.
Table 1  Items measuring each index

**Interest in science**
*Student’s interest in learning the following topics*
- Physics
- Chemistry
- Biology of plants
- Human biology
- Astronomy
- Geology
- Experiment design
- What is required for scientific explanations

**Enjoyment in sciences**
*Student’s replies on the degree of agreement to the following statements*
- Generally I have fun in learning science
- I like reading about science
- I’m happy doing science problems
- I enjoy acquiring new knowledge in science
- I am interested in learning about science

**Self-efficacy**
*Student’s replies on the degree of agreement to the following statements*
- Learning advanced scientific topics is easy for me
- I can usually give good answers in scientific tests
- I learn science topics quickly
- Science topics are easy for me
- I can understand scientific topics very well
- I can easily understand new ideas in science

**General value of science**
*Student’s replies on the degree of agreement to the following statements*
- Advances in broad science and technology usually improve people’s living conditions
- Broad science is important for helping us to understand the natural word
- Broad science is valuable to society
- Advances in broad science and technology usually bring social benefits

**Personal value of science**
*Student’s replies on the perception of the value attached to science on personal grounds in terms of*
- Helping in relating to other people
- Use when adult
- Understanding things around oneself
- High relevance

**Science activities**
*Frequency of the following activities*
- Watch TV programmes about broad science
- Borrow or buy books on broad science topics
- Visit web sites about broad science topics
- Listen to radio programmes about advances in broad science
- Read broad science magazines or science articles in newspapers
addition to the test scores, we use data on interest in science, enjoyment in science, science self-efficacy (confidence in performing science related tasks), general and personal values of science, science activities, perception of environmental issues, responsibility for sustainable development and awareness of environmental issues as indicators of the cognitive capability in science. Each of these additional dimensions is a synthetic index of a set of items and is provided by OECD.3

Table 1 shows the lists of indicator for each index.

PISA provides normalized indicators: test scores’ mean is equal to 500 and their standard deviation equal to 100 at the whole OECD level, while Table 1 indices have zero mean and standard deviation equal to one. As our primary purpose is not to carry out an international comparison, but to compare Italian children by gender, in presenting these statistics, we re-normalize all these indices within our sample (i.e. the variables have been

Table 1 continued

| Perception of environmental issues |
|-----------------------------------|
| *Student’s perception about the serious concern for him/her or others of the following problems* |
| Air pollution |
| Energy shortages |
| Extinction of plants and animals |
| Clearing of forests for other land use |
| Water shortages |
| Nuclear waste |

| Responsibility for sustainable development |
|--------------------------------------------|
| *Student’s agreement on the following statements* |
| It is important to carry out regular checks on the emissions from car as a condition of their use |
| It disturbs me when energy is wasted through the unnecessary use of electrical appliances |
| I am in favour of having laws that regulate factory emission even if this would increase the price of products |
| To reduce waste the use of plastic packaging should be kept to a minimum |
| Industries should be required to prove that they safely dispose of dangerous waste materials |
| I am in favour of having laws that protect the habitats of endangered species |
| Electricity should be produced from renewable sources as much as possible, even if this increases the cost |

| Awareness of environmental issues |
|-----------------------------------|
| *Student’s replies on the awareness to the following environmental issues* |
| Greenhouse gases |
| Genetically modified organisms |
| Acid rain |
| Nuclear waste |
| Consequences of clearing forests |

3 OECD inverts the items if appropriate, such that the higher the index, the better the performance of the child in a particular dimension. Each index is computed by OECD by running a Confirmatory Factor Analysis using Weighted Likelihood Estimator on the corresponding set of items. The (latent) index scale is then set with mean equal to zero and standard deviation equal to 1 at the OECD level. A positive or a negative index score of a child or of a group of children has therefore no meaning per se; it is interpretable only in comparison with the scores of another peer or of a group of peers (see OECD 2009 for details).
Table 2 shows boys’ and girls’ achievements in terms of the indicators of the latent science education capability. Table 2 also shows the gender gap (male–female mean) and the result of the mean-comparison test. As expected, we find a significant gender gap in the test scores in favour of boys equal to 0.13 standard deviations: boys’ scores are 0.06 standard deviations above the overall mean and girls’ scores are 0.06 below the overall mean. The gender gaps are statistically significant for all indicators, but for interest in science. Gender gaps are higher for performing science activities (+0.22) and for the general and personal value of science (+0.22 and +0.17 respectively). Boys’ higher perception of personal value of science can also be correlated to different expectations in terms of future career. The percentage of male students in STEM’s subjects in tertiary education is higher than that of girls (OECD 2012). In addition, STEM’s related jobs are mainly males (OECD 2006).

Boys show also higher level of enjoyment in science (+0.10). Boys are better off than girls also in self-efficacy in science (+0.17), suggesting that boys are more confident (see Bhanot and Jovanovic 2009 for a survey). Boys show better achievements also in term of awareness of environmental problems (+0.17).

On the other hand, girls outperform boys in the perception of the gravity of environmental issues (by 0.17) and in the responsibility for carrying out activities towards sustainable development (by 0.08).

Table 3 shows the description of the above-mentioned indicators and of exogenous individual, household and school variables.

At individual level, we consider gender and immigration status, also interacted.

At the household level, we consider the following variables: an index on the household’s possession of cultural goods; an index of educational resources in the household; mother and father education; mother and father occupational status, also in terms of socio-economic occupational status (see Ganzeboom et al. 1992).

School’s variables include hours of science at school, a variable for participative teaching methods, a factor describing the development of activities for the promotion of science at school, the shortage of science teachers.

Table 4 shows descriptive statistics on the conversion factors described above. We have two types of variables: binary variables and continuous variables provided and scaled by PISA in a way similar to the one explained for the functioning indicators. Also in this table, we re-normalize continuous variables within our sample (i.e. the variables have been standardized to have zero mean and variance equal to one in the whole sample of boys and girls).

Table 4 shows that about 3.5 % of children in our sample are immigrant. Mothers and fathers show a very similar educational level but they are very different in terms of occupation: one-third of the mothers do not work in the labour market, this is against about 2 % of the fathers; fathers are also better off in terms of socio-economic occupational status. As for the school factors, boys are more likely than girls to enjoy interactive teaching methods, science promotion activities, more hours of science at school (about 30 % of boys have more than 4 h weekly, against 26 % of girls).4

4 These differences are highly statistically significant: t test = 21.53 for interactive teaching methods and t test = 4.37 for promotion of science.
The Multiple Indicators Multiple Causes Model

We estimate the education capability utilising a Multiple Indicators Multiple Causes model (MIMIC). Multiple indicators models (Muthén 1979) link several observed outcomes to a reduced number of underlying latent variables (in this case, a single “science education capability”). Moreover, MIMIC models also estimate the coefficients of the exogenous variables that are considered to be determinants of the latent variable.

Our justification for choosing the MIMIC specification is that the latent variable estimators delivered by this model represent the fundamental objects of interest (see Krishnakumar and Nagar 2008).

We construct a system of equations which specify the relationship between an unobservable latent variable \( Y^* \), a set of observable endogenous ordinal indicators \( Y \), and a set of observable exogenous variables \( X \) (causes e.g. individual, school and household variables).

The structure of the model is as follows:

\[
Y = \Lambda^Y Y^* + \varepsilon
\]  

(1)

where \( Y = (Y_1, Y_2, Y_3, \ldots, Y_m)' \) is a \( m \times 1 \) vector with each element representing an indicator of the latent variable, denoted \( Y^* \). \( \Lambda^Y = (\lambda^Y_1, \lambda^Y_2, \lambda^Y_3, \ldots, \lambda^Y_m)' \) denotes a \( m \times 1 \) parameter vector of factor loadings, with each element representing the expected change in the respective indicators following a one unit change in the latent variable. \( \varepsilon \) is a \( m \times 1 \) vector of measurement errors, with \( \Theta_\varepsilon \) denote the covariance matrix.

In addition, we posit that the latent variable \( Y^* \) is linearly determined by a vector of observable exogenous variables \( x = (x_1, x_2, \ldots, x_s)' \) and a stochastic error \( \zeta \) giving,

\[
Y^* = x^\prime \gamma + \zeta
\]  

(2)

where \( \gamma \) is a \( s \times 1 \) vector of parameters.

### Table 2 Descriptive statistics by gender on the scientific education capability indicators

| M | F | Gender gap | \( t \) test |
|---|---|------------|-------------|
| Mean | SD | Mean | SD | M–F |
| Test scores | 0.06 | 1.02 | -0.06 | 0.97 | 0.13 | 8.26*** |
| Interest in science | 0.01 | 1.07 | -0.01 | 0.92 | 0.02 | 1.29 |
| Enjoyment of science | 0.05 | 1.03 | -0.05 | 0.97 | 0.10 | 6.66*** |
| Science self-efficacy | 0.08 | 1.04 | -0.08 | 0.96 | 0.17 | 10.95*** |
| General value of science | 0.11 | 1.06 | -0.11 | 0.93 | 0.22 | 14.44*** |
| Personal value of science | 0.09 | 1.03 | -0.09 | 0.96 | 0.17 | 11.36*** |
| Science activities | 0.11 | 1.01 | -0.11 | 0.97 | 0.22 | 14.19*** |
| Perception of environmental issues | -0.08 | 1.00 | 0.09 | 0.99 | -0.17 | -11.15*** |
| Responsibility for sustainable development | -0.04 | 1.04 | 0.04 | 0.96 | -0.08 | -5.52**** |
| Awareness of environmental issues | 0.08 | 1.04 | -0.09 | 0.95 | 0.17 | 11.16*** |
| Obs. | 8582 | 8369 |

Source: OECD PISA 2006

*** \( p < 0.01 \); ** \( p < 0.05 \); * \( p < 0.10 \)
| Variable                                           | Type       | Description                                                                                                                                 |
|---------------------------------------------------|------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| **Household factors**                             |            |                                                                                                                                            |
| Cultural possessions                              | Continuous | A index measuring possession of: classic literature, books of poetry, works of art                                                          |
| Educational resources                             | Continuous | A index measuring possession of: a desk to study at, a quiet place to study, a computer the child can use for school work, educational software, child own calculator, books to help with school work, a dictionary |
| **Mother and father educational level**           | Binary     |                                                                                                                                            |
| Mother/father degree                              | 1 if mother/father has a university degree; 0 otherwise                                                                                     |
| Mother/father high school                          | 1 if mother/father has a high school degree; 0 otherwise                                                                                   |
| Mother/father less than high school degree         | 1 if mother/father with educational level lower than high school; 0 otherwise                                                                |
| **Mother and father occupational status**         | Binary     |                                                                                                                                            |
| Mother/father not working                          | 1 if mother/father not working; 0 otherwise                                                                                               |
| Mother/father working and Sei below the mean      | 1 if mother/father is working with a socio-economic occupational status (Sei code) between 16 and 53; 0 otherwise                           |
| Mother/Father working and Sei above the mean       | 1 if mother/father is working with a socio-economic occupational status (Sei code) between 54 and 90; 0 otherwise                           |
| **Personal factor**                               |            |                                                                                                                                            |
| Female                                            | 1 if female; 0 if male                                                                                                                     |
| Immigrant                                         | 1 if immigrant; 0 otherwise                                                                                                                 |
| Female x Immigrant                                | 1 if female and immigrant; 0 otherwise                                                                                                     |
| **School factor**                                 |            |                                                                                                                                            |
| Weekly hours of science at school                  | Binary     |                                                                                                                                            |
| 0 h                                               | 1 if 0 h; 0 otherwise                                                                                                                     |
| More than 0, less than 2                          | 1 if more than 0 less than 2 h; 0 otherwise                                                                                               |
| More than 2, less than 4                          | 1 if more than 2 less than 4 h; 0 otherwise                                                                                               |
| More than 4, less than 6                          | 1 if more than 4 less than 6 h; 0 otherwise                                                                                               |
| More than 6                                       | 1 if more than 6 h; 0 otherwise                                                                                                             |
| Interactive teaching methods                      | Continuous | A index summing up the frequency of: interactive teaching in science lessons, hands-on-activities, student investigations, lessons with a focus on applications |
| Promotion of science (principal)                  | Continuous | A index measuring school involvement in activities promoting students’ engagement with science: science clubs, science fairs, science competitions, extracurricular science projects, excursions and field trips |
| Shortage of science teachers (principal)          | Binary     | 1 if the school is lacking “to some extent” or “a lot” in qualified science teachers; 0 if “not at all” or “very little”                     |

If “principal” is specified, the school’s principal reports the information
Examining (1) and (2) we may think of our model as comprised of two parts: (2) is the structural (or state) equation and (1) is the measurement equation reflecting that the observed measurements are partial indicators. The structural equation specifies the casual relationship between the observed exogenous causes and the latent variable. Since \( Y^* \) is unobserved, it is not possible to recover direct estimates of the structural parameters \( \gamma \). Combining (1) and (2) the reduced form representation is written as

\[
\text{Table 4} \quad \text{Descriptive statistics by gender on the conversion factors}
\]

| Continuous variables | M     | SD  | F     | SD  |
|----------------------|-------|-----|-------|-----|
| Cultural possessions | -0.08 | 1.03| 0.08  | 0.96|
| Educational resources| 0.03  | 0.99| -0.03 | 1.00|
| Interactive teaching methods| 0.16  | 1.03| -0.16 | 0.94|
| Promotion of science | 0.03  | 0.97| -0.03 | 1.03|

| Binary variables     | Percentage | Percentage |
|----------------------|------------|------------|
| Mother educational level |           |            |
| Mother degree        | 21.0       | 14.5       |
| Mother high school   | 33.6       | 33.4       |
| Mother less than high school | 45.4 | 52.1 |
| Father educational level |       |            |
| Father degree        | 20.4       | 15.6       |
| Father high school   | 35.1       | 35.5       |
| Father less than high school | 44.5 | 48.9 |
| Mother occupational status |      |            |
| Mother not working   | 33.4       | 32.9       |
| Mother working and Sei below the mean | 53.4 | 55.7 |
| Mother working and Sei above the mean | 13.2 | 11.4 |
| Father occupational status |       |            |
| Father not working   | 1.7        | 2.0        |
| Father working and Sei below the mean | 79.1 | 81.2 |
| Father working and Sei above the mean | 19.2 | 16.9 |
| Immigrant            | 3.4        | 3.5        |
| Hours of science     |            |            |
| 0 h                  | 6.6        | 4.4        |
| More than 0 less than 2 | 25.0 | 21.3 |
| More than 2 less than 4 | 38.5 | 48.3 |
| More than 4 less than 6 | 15.7 | 15.6 |
| More than 6          | 14.2       | 10.4       |
| Shortage of science teachers | 12.6 | 12.8 |
| Obs.                 | 8582       | 8369       |

Source: OECD PISA 2006
\[ y = \pi x + v \] (3)

where \( \pi = \Lambda^Y \gamma' \) is the \( m \times s \) reduced form coefficient matrix and \( v = \Lambda^Y \zeta + \varepsilon \) is the reduced form disturbance.

SEM have been widely used in the capability literature (see, among others, the work by Kuklys 2005; Di Tommaso 2007; Krishnakumar 2007; Krishnakumar and Ballon 2008; Anand et al. 2011).

In this paper, the latent variable is the “science education capability”, the indicators are the observable functionings of Table 2 above while the exogenous variables are the set of conversion factors listed in Tables 3 and 4.

The model can be schematized as in Fig. 1.

### 5 Estimation Results

In this Section, we report the results of the estimation of the MIMIC model presented above. In the estimation results, we show both the standardized and unstandardized solutions. Both are meaningful. The unstandardized solution is achieved by setting a lambda parameter equal to 1 and it also reports the standard errors and significance level of the variable coefficient. The disadvantage of unstandardized solutions is that they are not easily interpretable, as they refer to changes in variables that have no clear and homogeneous measurement unit. The standardized solution overcomes this problem. Standardization is achieved by setting the variance of the latent variable equal to 1, therefore

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**Fig. 1** Path diagram of the MIMIC model

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standardized coefficients can be read as the standard deviation change in the dependent variable that follows one standard deviation change in the independent variable. Table 5 reports the results of the measurement equation. All the included functionings are relevant and positively related to the development of the science capability. This is true both for the overall model (first column) and for the model estimated separately by gender (second and third column). Moreover, with very little differences by gender, the standardized coefficients are the highest for enjoyment of science, personal value of science and interest in science, suggesting that these variables are the most sensitive to changes in the science capability. Test scores, on the contrary, show the second lowest standardized coefficient. This result supports our choice of introducing other indicators of the latent science education capability and is consistent with the literature that highlights the limits related to the use of test scores (Cunha et al. 2010; Sikora and Pokropek 2012; Cornwell et al. 2013; Gutman and Schoon 2013).

Looking at the structural model, the results (Table 6) show that the science capability is more developed for boys: looking at column one, the coefficient for the female dummy is

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**Table 5** Results of the MIMIC Model: measurement equation results

|                      | M + F Unstd. | M Unstd. | F Unstd. |
|----------------------|-------------|----------|----------|
|                      | Std.        | Std.     | Std.     |
| Test scores          | 1.000       | 0.350    | 1.000    | 0.352    | 1.000    | 0.335    |
| Interest in science  | 0.019***    | 0.717    | 0.020*** | 0.721    | 0.019*** | 0.725    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| Enjoyment of science | 0.020***    | 0.738    | 0.020*** | 0.736    | 0.021*** | 0.742    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| Science self-efficacy| 0.013***    | 0.551    | 0.014*** | 0.579    | 0.013*** | 0.505    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| General value of science | 0.016*** | 0.566    | 0.017*** | 0.572    | 0.016*** | 0.543    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| Personal value of science | 0.019*** | 0.727    | 0.019*** | 0.730    | 0.020*** | 0.719    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| Science activities   | 0.020***    | 0.680    | 0.019*** | 0.669    | 0.021*** | 0.685    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| Perception of environmental issues | 0.005*** | 0.160    | 0.006*** | 0.199    | 0.004*** | 0.142    |
| (0.000)              |             |          | (0.001)  |          | (0.001)  |          |
| Responsibility for sustainable development | 0.011*** | 0.411    | 0.012*** | 0.431    | 0.011*** | 0.405    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| Awareness of environmental issues | 0.015*** | 0.492    | 0.015*** | 0.494    | 0.014*** | 0.477    |
| (0.001)              |             |          | (0.001)  |          | (0.001)  |          |
| Obs.                 | 16,951      | 8582     | 8369     |

Source: OECD PISA 2006

Robust standard errors in parentheses

*** p < 0.01; ** p < 0.05; * p < 0.10

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5 We ran an Exploratory Factor Analysis on the chosen ten indicators that confirms that there is only one single latent variable. Results are available from the Authors upon request.
Table 6  Results of the MIMIC Model: Structural equation results

|                      | M + F |         | M |         | F |         |
|----------------------|-------|---------|---|---------|---|---------|
|                      | Unstd. | Std.    | Unstd. | Std.    | Unstd. | Std.    |
| **Household variables** |       |         |     |         |     |         |
| Cultural possession  | 7.594*** | (0.558) | 0.196 | 8.147*** | (0.801) | 0.210 | 6.701*** | (0.743) | 0.178 |
| Educational resources | 4.493*** | (0.427) | 0.139 | 5.427*** | (0.632) | 0.162 | 3.364*** | (0.554) | 0.113 |
| **Mother educational level—ref. group: lower than high school degree** |       |         |     |         |     |         |
| Mother degree        | 1.644 | (1.219) | 0.021 | -0.463 | (1.684) | -0.006 | 4.583*** | (1.717) | 0.057 |
| Mother high school   | 1.388* | (0.826) | 0.021 | 0.874 | (1.226) | 0.013 | 1.815* | (1.083) | 0.030 |
| **Father educational level—ref. group: lower than high school degree** |       |         |     |         |     |         |
| Father degree        | 3.665*** | (1.252) | 0.046 | 2.831* | (1.703) | 0.036 | 4.631*** | (1.767) | 0.059 |
| Father high school   | 3.171*** | (0.834) | 0.049 | 2.767** | (1.252) | 0.042 | 3.549*** | (1.064) | 0.060 |
| **Mother occupational status—ref. group: working and Sei code above the mean** |       |         |     |         |     |         |
| Mother not working   | -3.120** | (1.337) | -0.048 | -4.139** | (1.849) | -0.062 | -0.996 | (1.838) | -0.016 |
| Mother working and Sei code below the mean | -3.329*** | (1.223) | -0.054 | -4.121** | (1.691) | -0.065 | -1.393 | (1.680) | -0.024 |
| **Father occupational status—ref. group: working and Sei code above the mean** |       |         |     |         |     |         |
| Father not working   | -2.443 | (3.137) | -0.011 | -3.074 | (3.913) | -0.012 | -2.299 | (4.468) | -0.011 |
| Father working and Sei code below the mean | -2.303** | (1.011) | -0.030 | -1.539 | (1.357) | -0.020 | -3.005** | (1.449) | -0.041 |
| **Individual variables** |       |         |     |         |     |         |
| Female               | -4.419*** | (0.759) | -0.072 |         |       |         |
| Immigrant            | 0.893 | (2.585) | 0.005 | 1.385 | (2.566) | 0.008 | -1.983 | (2.144) | -0.013 |
| Female × immigrant   | -1.860 | (3.318) | -0.008 |         |       |         |
| **School variables**  |       |         |     |         |     |         |
| Weekly hours of science at school—ref. group: 0 h |       |         |     |         |     |         |
| Hours of science: more than 0 less than 2 | 14.312*** | (1.850) | 0.197 | 12.896*** | (2.316) | 0.177 | 15.093*** | (2.877) | 0.217 |
| Hours of science: more than 2 less than 4 | 22.705*** | (1.966) | 0.367 | 23.125*** | (2.590) | 0.356 | 21.362*** | (2.957) | 0.375 |
| Hours of science: more than 4 less than 6 | 28.300*** | (2.210) | 0.336 | 27.251*** | (2.863) | 0.314 | 28.255*** | (3.381) | 0.360 |
| Hours of science: more than 6 | 28.693*** | (2.290) | 0.308 | 27.369*** | (2.960) | 0.302 | 28.980*** | (3.501) | 0.311 |
| Interactive teaching methods | 9.322*** | (0.507) | 0.236 | 9.516*** | (0.728) | 0.242 | 8.958*** | (0.661) | 0.230 |
| Promotion of science | 1.370*** | (0.422) | 0.037 | 0.633 | (0.638) | 0.016 | 1.946*** | (0.544) | 0.058 |
negative and statistically significant. This result leads us to estimate the same model on the two subsamples of boys and girls in order to analyse the differences in the effect of the conversion factors (second and third column).

Looking at the standardized coefficients, the most relevant variables are number of hours dedicated to science, interactive methods of teaching, household’s cultural possession and educational resources.

The number of hours dedicated to science and interactive methods of teaching are positively correlated with both girls’ and boys’ science capability. Promotion activities in science have a lower positive parameter and it is significant for girls only. Being in a school characterized by a science teachers shortage negatively affects only boys’ science capability. This can be determined by a higher need of teacher’s supervision shown by boys in their education process.

Cultural possession at home and educational resources have a positive and significant effect on the development of science capability for both girls and boys, and they are both higher for boys. The relevance of family cultural possessions is in line with the literature showing the relevance of cultural capital and habitus (Bourdieu 1973; Edgerton and Roberts 2014) and of a stimulating learning environment at home (De Graaf et al. 2000). Being a migrant does not significantly affect science capability. This is not consistent with other results where racial disparities continue to increase throughout high school (Bacharach et al. 2003). It could be in part related to the inclusion in the model of family background variables—to the extent that immigrant households are characterized by a lower attainment in terms of socioeconomic background—(Azzolini et al. 2012; Fullin and Reyneri 2011; Shapira 2012) but even more to the inclusion of school characteristics as long as immigrant children are not randomly distributed across different types of schools (Azzolini et al. 2012; Shapira 2012).

Parents’ level of education plays a higher positive effect on girls’. In particular, the parameters for mothers’ educational levels are only statistically significant for girls while fathers’ education affects both girls and boys but with a higher effect on girls. These results are consistent with Kleinjans’ (2010) analysis on the effect of parental education and income on the educational expectations of children at age 19 in Denmark. For the USA, Bhanot and Jovanovic (2009) find a positive effect of mothers’ encouragement only on girls’ self-assessments of science ability at the end of the year. The relevance of parents’ education on children’s educational attainment is also in line with other literature results.

**Table 6 continued**

|                      | M + F |          |          |          |          |
|----------------------|-------|----------|----------|----------|----------|
|                      | Unstd.| Std.     | Unstd.   | Std.     | Unstd.   |
| Shortage of science teachers | -2.256** | -0.025   | -3.841** | -0.040   | -0.821   |
|                      | (1.119) |          | (1.726)  |          | (1.371)  |
| SRMR                 | 0.037 | 0.039    | 0.041    |          |          |
| Obs.                 | 16,951| 8582     | 8369     |          |          |

*Source*: OECD PISA 2006

Robust standard errors in parentheses

The reference category for parental education is parents with less than high school degree; for parental occupational status is working parents with Sei code above the mean; for hours of science at school is 0 h

*** p < 0.01; ** p < 0.05; * p < 0.10
Mothers’ employment status below the mean or jobless status negatively affects only boys’ science capability whereas fathers’ employment status below average negatively affects only girls’ achievements in science. This, given the higher father’s household income share, can be related to a positive correlation between household’s income and girls’ achievement in science. Evidence on the positive impact of household’s income on children’s achievement in science have been found amongst others by Beaumont-Walters and Soyibo (2001). Other studies (in particular, for developing countries) have also found that the elasticity of education demand to changes in parents’ income is higher for girls than for boys (Mason and King 2001; Tansel 2002).

Differently from what has been found in other contexts, for instance in UK by Boaler et al. (2011), interactive methods of teaching do not play a positive role only for girls: in our estimates, they affect both boys’ and girls’ achievement in science. This result, though specific to the science education capability, is in line with the literature on the positive effect of participatory methods to the development of education capabilities (Hart 2014; Biggeri 2014).

On the other hand, promotion of science activities positively affects only girls’ achievements in science. To reduce the gender gap in science, these types of activities should be promoted.

Finally, the fit of the model is satisfying as shown by the Standardized Root Mean Square Residual (SRMR) below 0.08.

6 Conclusions

This paper analyses gender differences in science education capability in Italy, a country characterized by a lower than OECD-average achievement of test scores in science (according to PISA 2006 survey) and by a gender gap to the disadvantage of girls. We utilize a Structural Equation Model, a technique increasingly used in the measurement of capabilities. We measure the education capability as a latent variable of which we observe ten indicators. All the chosen indicators significantly contribute to the latent science capability, showing that it is relevant not to limit the analysis to test scores.

The structural part of the estimated model reveals different impact of institutional and family variables by gender. In particular, we find that activities to promote sciences have a greater effect on girls’ capability. Therefore, policies oriented to improve these activities could reduce the gender gap. Among the policies that can reduce the gender disparities in STEM subjects, OECD (2012) suggests addressing gender stereotypes in textbooks and developing teaching strategies and learning materials to encourage girls’ involvement. Interactive methods of schooling and hours of science at school have a positive effect both on girls and on boys and, together with cultural and educational resources at household’s level, have the highest impact on boys and girls science capability. Given Italian children low achievements in science (respect to OECD average), these results call for higher investment in education and cultural family possessions and for the adoption of more interactive and less traditional teaching methods.

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