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Knowledge on the structure of the solar system in teacher education students: the role of national context and gender

Conoscenza della struttura del sistema solare da parte degli studenti di scienze della formazione: il ruolo del contesto nazionale e del genere

Claudia Melis
Department of Nature, Environment and Health, Queen Maud University College for Early Childhood Education, cme@dmmh.no
Gabriella Falcicchio
Department of Educational Science, Psychology and Communication, University of Bari Aldo Moro, gabriella.falcicchio@uniba.it
Per-Arvid Wold
Department of Nature, Environment and Health, Queen Maud University College for Early Childhood Education, Norway; paw@dmmh.no
Anna Maria Billing
Department of Nature, Environment and Health, Queen Maud University College for Early Childhood Education, Norway; amb@dmmh.no

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Corresponding Author: Claudia Melis
Email: cme@dmmh.no

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Abstract
For many centuries, humanity believed the Earth to be the center of the Universe with the Sun and the planets orbiting around it (geocentric model). The Copernican revolution proved all planets in the solar system are instead orbiting around the Sun (heliocentric model). Since Copernicus time, our knowledge has improved exponentially, also thanks to the possibility to observe the solar system from space. The solar system is an essential topic in science literacy, necessary to understand how we measure time and what makes the Earth suitable for life. However, we did not know whether our students retained a basic astronomical knowledge from previous education. Before teaching had started, we asked students in Early Childhood Education in Norway (n = 102) and Educational Science in Italy (n = 104) to draw the solar system and classified each student's drawing according to a 10 points scale. According to the drawing-writing method of assessing students, we assumed that the drawings would reflect their level of knowledge. Based on this classification, we could assign to each student a score ranging from zero to nine. We then fitted a generalized linear model to the model explaining score variation with nationality and gender. The best model explaining knowledge included as explanatory variables nationality, gender, and their interaction. Being male and Norwegian was associated with higher knowledge score. The gender effect was significant only for the Italian students. These results might be consequence of both differences in gender equality and teaching programs between the two countries.

Keywords: Astronomy Education; Comparative Study; Pre-Service Teachers; Solar System.

Riassunto
Per molti secoli l'umanità ha creduto che la Terra fosse il centro dell'Universo con il Sole e i pianeti in orbita attorno ad essa (modello geocentrico). La rivoluzione copernicana ha dimostrato che tutti i pianeti del sistema solare orbitano invece attorno al Sole (modello eliocentrico). Dai tempi di Copernico, le nostre conoscenze sono migliorate in modo esponenziale, anche grazie alla possibilità di osservare il sistema solare dallo spazio. Il sistema solare è un argomento essenziale nell'alfabetizzazione scientifica, necessario per capire come misuriamo il tempo e cosa renda la Terra adatta alla vita. Per questo motivo ci siamo chiesti se i nostri studenti conservassero una conoscenza astronomica di base derivante dall'istruzione precedente. Prima dell'inizio dell'insegnamento, abbiamo chiesto agli studenti dei corsi di educazione della prima infanzia in Norvegia (n = 102) e scienze dell'educazione in Italia (n = 104) di disegnare il sistema solare, partendo dalla premessa che i disegni riflettessero il loro livello di conoscenza. Su questa base abbiamo assegnato ad ogni studente un punteggio da zero a nove. Abbiamo quindi usato un modello statistico per spiegare la variazione del punteggio in base alla nazionalità e al genere. Il miglior modello includeva come variabili esplicative la nazionalità, il genere e la loro interazione. L'effetto di genere è risultato significativo solo per gli studenti italiani. Questi risultati potrebbero essere la conseguenza sia delle differenze nell'uguaglianza di genere che nei programmi di insegnamento tra i due paesi.

Parole chiave: Educazione Astronomica; Insegnanti In Pre-Servizio; Sistema Solare; Studio Comparativo.

Credit author statement
Conceptualization, C.M., P.-A.W.; methodology, C.M., P.-A.W.; formal analysis, C.M.; investigation, C.M., G.F., and P.-A.W.; writing—original draft preparation, C.M.; writing—review and editing, A.M.B., C.M., G.F., and P.-A.W.

1. Introduction

Since almost 500 years ago, when Copernicus and then Galileo came out with a cosmological model that placed the Sun and not the Earth at the center of the Universe (heliocentric model), our knowledge about space has increased exponentially and our picture of the solar system has been refined accordingly. We have never been able to explore space in such a way as we have in the last century, from stepping for the first time on the Moon in 1969, to sending in 1997 the first of a series of robots to explore Mars in the hope to colonize this planet in a near future. Despite these enormous advances in knowledge and methods to acquire new information, there is a growing skepticism in the society about science (Rutjens et al., 2018), and alternative theories about how our planet is shaped are becoming increasingly diffuse, also due to the spreading of conspiracy theories through social media (Del Vicario et al., 2016; Landrum et al., 2021). For example, 1% of Americans (accounting for 3 million people) firmly believes that the Earth is flat and another 6% (which means ca. 18 million) is unsure about it (Raleigh, 2017). For thousands of years humanity looked at the Sun, Moon, stars, and other celestial bodies to try to forecast the destiny of individuals and entire nations or to explain traits of our personality.

Nowadays, we know that the stars belonging to the same constellation appear on one plane to us only because we see them from our perspective, many light-years far away from them. However, we still measure time based on the movements of the Earth and the Moon and we need a basic knowledge of astronomy to explain the occurrence of seasons, tidal excursions, and climatic patterns. In a democratic society, all citizens need to reach a sufficient level of science literacy to be able to make informed decisions (National Academies of Sciences & Medicine, 2016). This because at some point everybody will be confronted with decisions that involve science (e.g., medical treatments or voting decisions on environmental issues) and require being able to distinguish pseudoscience from valid science and understand science limitations (Duncan & Arthurs, 2012). Among many other aspects of science literacy, such as health and mathematics, basic knowledge of the solar system is necessary to recognise why the Earth is suitable for life (with respect to the other planets) and therefore understand issues related to sustainability, such as, for example, global warming.

Although there is not a consensus among preschool teacher educators, about what astronomy for young children should be (Kallery, 2011), and some may argue that at an early age it is enough to foster curiosity and imagination, it is desirable that young children are presented with correct information (Agan & Sneider, 2004). A study examining conversations about nature engaged by young children with their parents showed that astronomy was a very interesting topic to them, ranking in the top three most frequent topics (Callanan et al., 2019). According to Vygotsky, learning is very important for cognitive development (Vygotsky, 2012) and the best time to start learning science is during early childhood (Eshach & Fried, 2005). A prerequisite for that is that the early childhood teachers themselves do not hold misconceptions about basic astronomy concepts (Bektasli, 2013). Finally, the picture of the solar system, showing the "Blue Marble" of planet Earth, gives us with a unique cosmological perspective that reinforces our common fate as citizens of the Earth (Retrê et al., 2019).

Several studies across the continents have investigated both students and pre-service teachers' conceptions and misconceptions of different aspects of basic astronomy, such as for example knowledge about the universe, Earth's shape, what causes night and day, solar and lunar eclipses, and seasons (Bailey & Slater, 2003; Kanli, 2014; Korur, 2015; Ricardo, 2000). These investigations revealed several issues, for instance, almost one third of science pre-service teachers who participated to a study in Turkey believed the stars to be closer to the Earth than Pluto (Kanli, 2014), likewise almost half of university students in a study conducted in Israel placed Pluto behind the stars (Ricardo, 2000). A study conducted in Norway on science pre-service teachers' knowledge of sizes and distances of astronomical objects showed that their average score in ranking ten astronomical objects by distance was 53% (percentage of items ranked correctly) (Rajpaul et al., 2018). In 2010, a review of astronomy education research conducted in the last 30 years, already advocated for an improved in service training for all teachers to enhance the quality of astronomy education (Lelliott & Rollnick, 2010).

The aim of this study was to assess the level of knowledge acquired at the end of high school by Bachelor students who started mandatory school after the use of interactive digital tools, expected to enhance learning about astronomy, has become increasingly common (Atta et al., 2022; Barab et al., 2000; Haleem et al., 2022). We thus used a simple drawing task to assess student's knowledge about the structure of the solar system, starting from the position of the Sun with respect to the orbiting planets, the order and name of the planets and the presence of additional details such as orbits and planets' rings. We chose to contrast Norway and Italy to assess whether differences in gender equality are mirrored in STEM education (where STEM means Science, Technology, Engineering, and Mathematics). Moreover, it is very important for good quality teaching to activate previous experience, knowledge, and competence (Ausubel, 1963). Therefore, we wanted to know which level of knowledge our students have when they begin the course in Natural Sciences, after completing high school, and uncover possible misconceptions on the structure of the solar system, in order to adjust our teaching accordingly.

2. Methods

2.1 Norwegian study context

In Norway, students have to undergo a minimum of ten years of mandatory school (from the age of six years) and three years in high school to access Early Childhood Education. The upper secondary school curriculum at the time our students were attending upper secondary school did not mention the solar system (Norwegian Directorate for Education and Training, 2006a). We then searched the Natural Sciences curriculum for lower secondary education at the time our students were attending lower secondary school, to find out whether it mentioned the solar system. The solar system was one of the main subjects in Natural Sciences and the learning aims upon completion of the 7th year of school said that the pupils should be able to "describe our solar system and Natural Science's theories of how the Earth came to be" and also to "describe a model for the solar system and how it can explain observed phenomena, including day and night, moon phases and the movement of the Sun across the sky" (Norwegian Directorate for Education and Training, 2006b).

2.2 Italian study context

Also in Italy, ten years of mandatory school (from the age of six years) and three years in high school are necessary to access both the Department of Philosophy and the Departments of Educational Science (Bari University, Italy). The Italian national curriculum also assumes some basic knowledge of the solar system, among the learning objectives to be achieved by the end of lower secondary school (13 years). In fact, it quotes that pupils should, after learning about astronomy at the primary school, "continue the development of ideas and interpretative models of the most evident celestial phenomena through the observation of the day and night sky throughout the year" (Ministero della Pubblica Istruzione, 2007). For the higher secondary school, astronomy is only mentioned in the national curriculum for the high schools specializing in Scientific studies (Ministero dell'Università e della Ricerca, 2010)

Science or astronomy outreach centres, and planetaria are rather common both in Italy and Norway, however it is difficult to generalise about their use in the two countries, since it depends on the specific school and teacher whether their visited or not.

2.3 Participants and data collection

At the beginning of the course in Natural Sciences, in September 2018, four classes of students in Early Childhood Education at Queen Maud University College in Early Childhood Education (QMUC, Trondheim, n = 103) were given questionnaire which included several questions aimed at getting an overview of their previous knowledge of Natural Sciences. The Norwegian students in our sample were on average 21.8 years old (±2.73). In April 2019, the questionnaire was translated into Italian, and given to Italian students from the University of Bari (n = 105). The Italian students were on average 21.8 years old (±1.77). These were from the Bachelor course in Educational Science (n = 78) and from the Bachelor course in Philosophy (n = 27). Both the Norwegian and Italian students were informed that the questionnaire was voluntary to fill out and that the results would be used in research and publishing. We did not collect personal data, apart from gender information, to prevent the identification of the participants. Both samples, the Norwegian and Italian ones, comprise of students with similar age who are likely to become teacher of the next generations of children.

2.4 Questionnaire

The questionnaire covered several topics that we teach in the Natural Sciences course at QMUC, such as climate change, knowledge on local species and plant reproduction which have been presented elsewhere (Melis et al., 2021a, b). In addition, there was a large empty box where the students were asked to draw the solar system. The drawing-writing method of assessing students' knowledge and misconception has been widely used in pre-service elementary science teachers, for example, to investigate their conceptual understanding of plant nutrition (Barrutia & Díez, 2019), the digestive system (Ören & Ormanci, 2014), the photosynthesis, and the greenhouse effect (Celikler & Aksan, 2014). Previous studies comparing misconceptions, assessed by using both drawings and interviews, found similar results between these two methods, concluding that the drawing method is effective in determining students' misconceptions (Köse, 2008).

The dataset included 104 questionnaires from Italy and 102 questionnaires from Norway (after removing two samples without gender information). In total, 170 females (89 from Italy and 81 from Norway) and 36 males (15 from Italy and 21 from Norway) participated in the study.

3. Data analysis

We classified each students drawing according to a 10 points scale of increasing complexity in representing the solar system, assuming it reflected their knowledge. Based on this classification, we could assign to each student a score ranging from zero to nine. We gave a score equal to zero if the student left the drawing square empty and a score equal one if the student represented the planets in a ring around the sun or put the Earth at the centre of the solar system (geocentric view). Whereas we gave progressively higher score according to the degree of correct information present in the drawings. For example, the score was equal two if the drawing included the Sun and some planets in a row, and it was equal three if there were also some planets' names. The score increased when the students added other details to their drawings, such as the planets' orbits and the differences in sizes between the terrestrial planets and the giant gas planets. (Figure 1).

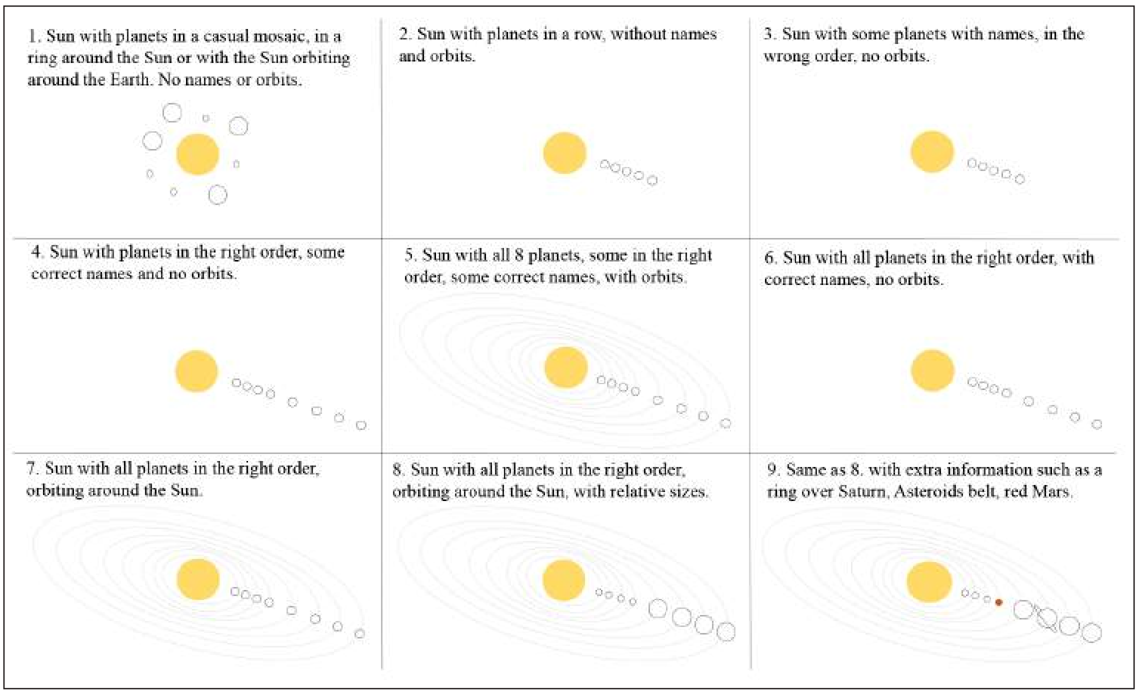

Figure 1: Schematic representation of nine scores of increasing complexity of the solar system as depicted by students in teacher education in 2018 (Norway) and 2019 (Italy). If the square was left empty, we assigned a score of zero

3.1 Statistical analyses

Analyses were done in R (R Core Team, 2021). We used Mann–Whitney U-tests to assess differences between groups (countries and genders) in knowledge score. We fitted a generalized linear model with Poisson distribution to the data, to test whether gender, country, and the interaction between these two variables were associated with the score of knowledge of the solar system that could be evinced from the drawings. The final model was selected by model reduction, starting from the model: Index in knowledge ~ Country + Gender + Country:Gender, where only explanatory variables with significance P < 0.05 were retained in the model. We used the R package *sandwich* (Zeileis, 2006) to obtain robust standard errors and recalculated the P-values accordingly (Table 1). The goodness of fit test was performed with the R package *epiDisplay* with the command poisgof (Chongsuvivatwong, 2018).

4. Results

When considering differences between genders in knowledge score of the solar system, we found that overall men had a median score of 3 and women had a median score of 2. This difference was not significant (Mann-Whitney U = 2526, $n_1 = 170$, $n_2 = 36$, $P = 0.096$). Whereas, when comparing the scores between Italy and Norway, we found a significant difference in knowledge of the solar system between the Italian and Norwegian students (Mann-Whitney U = 2496.5, $n_1 = 104$, $n_2 = 102$, $P < 0.001$), where Italy had a median score of 1 and Norway a median score of 4 (Figure 2). Figure 2 clearly shows that there is a statistically significant difference between the two groups, since the two boxes do not overlap (and sample size between the two groups is very similar).

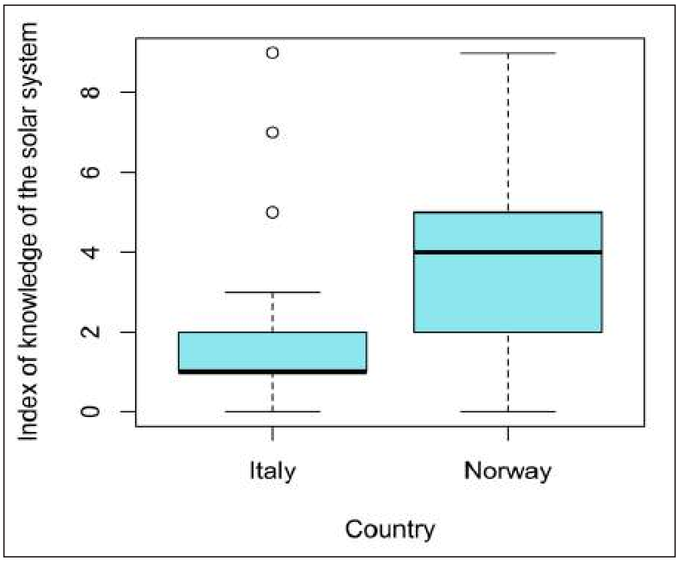

Figure 2: Boxplots showing the knowledge's score of the solar system in 104 Italian and 102 Norwegian teacher students. The two boxes are the interquartile range and include 50% of the observations. The extreme lines show the highest and lowest value excluding outliers. The ends of the box show the upper (Q3) and lower (Q1) quartiles. The value of the upper quartile indicates that 75% of the scores are below this threshold

In Figure 3 it is possible to see more in details how the data are distributed, both by country and by gender. We can see that the data are skewed, which means that they are not symmetrical distributed around the mean but, especially for Italy, most of observations are around the lower part of the histogram. When comparing the scores within the Italian and Norwegian, we found a significant difference in knowledge of the solar system between genders in Italy (Mann-Whitney U = 437.5, $n_1 = 89$, $n_2 = 15$, $P < 0.05$), but not in Norway (Mann-Whitney U = 862.5, $n_1 = 81$, $n_2 = 21$, $P = 0.927$)

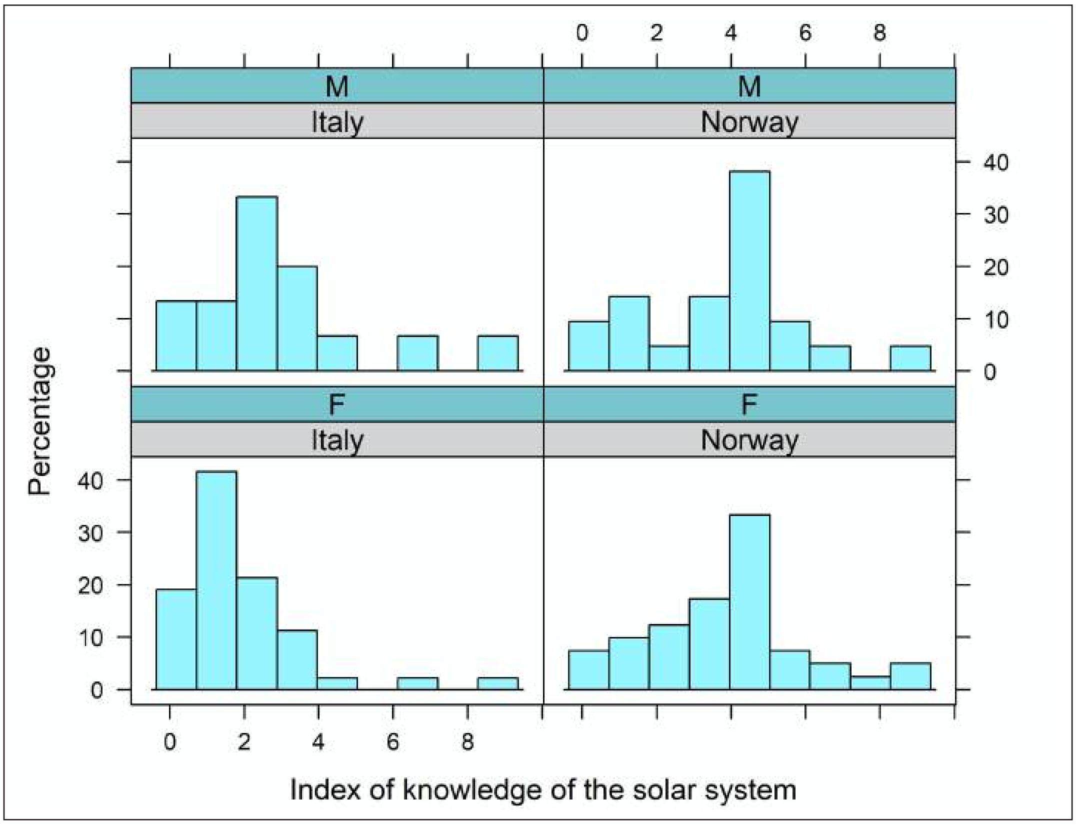

Figure 3. Histograms showing the knowledge score of the solar system in 104 Italian and 102 Norwegian teacher students by country and gender

According to the general linear model (with Poisson distribution), explaining the variation in knowledge of the solar system by means of the variables Country and Gender and their interaction, being male and Norwegian increased the probability of a high score in knowledge of the solar system, the effect of the gender was more evident in Italy (Table 1). The goodness of fit test for modelling of count data confirmed that the model fit well (Chi-sq = 330.16, df = 202, $P < 0.001$). As we can also see from the boxplots in Figure 4, in Norway there is no difference between men and women, whereas in Italy men have a better knowledge score compared to women.

	Estimate	Robust SE	P-value	Lower CI	Upper CI
Intercept	0.502	0.134	0.000	0.239	0.765
Country (Norway)	0.817	0.148	0.000	0.528	1.107
Gender (M)	0.528	0.235	0.024	0.068	0.988
Country:Gender	-0.561	0.273	0.040	-1.097	-0.025

Table 1: Estimates of the model explaining variation in the knowledge's score of the solar system in 104 Italian and 102 Norwegian teacher students. The final model was selected by model reduction, starting from the model: Index in knowledge ~ Country + Gender + Country:Gender, where only explanatory variables with significance P < 0.05 were retained in the model. SE = standard error, CI= 95% confidence intervals

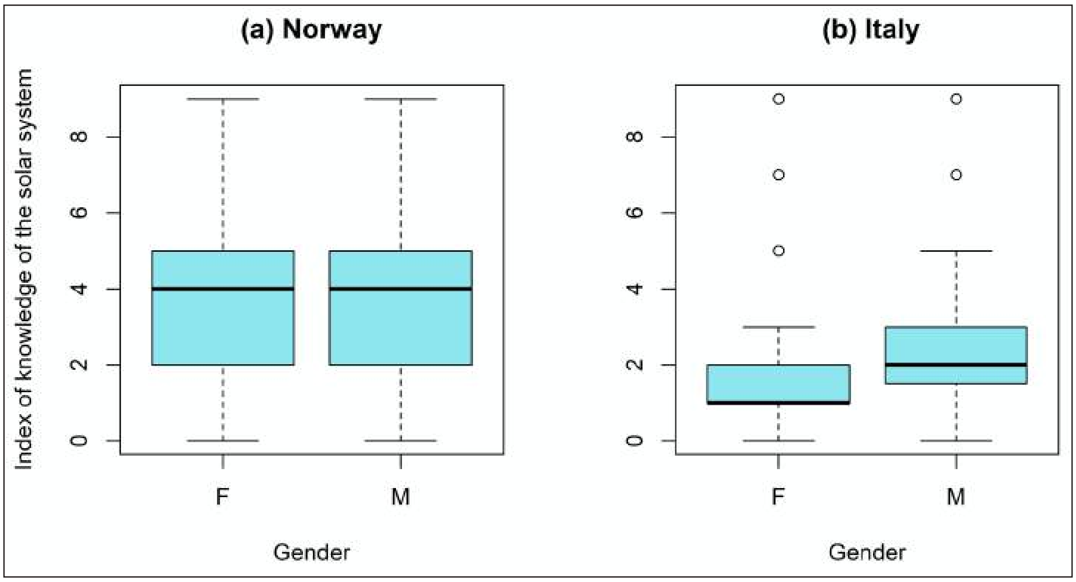

Figure 4. Boxplots showing the knowledge score of the solar system in 104 Italian and 102 Norwegian teacher students by country and gender. For further explanations, see Figure 2

5. Discussion

This study examined differences in knowledge about the solar system between teacher students in Italy and Norway, assuming that students' drawings reflected their level of knowledge, according to a scale ranging from zero to nine. One limitation with the study is the relatively small size of the dataset. Another limitation with the study is that some of the students might have decided not to draw the solar system based on their perceived low drawing skills. In this case, the differences among countries and genders, might instead reflect differences in perceived drawing skills. However, the task of sketching the solar system can be easily solved by drawing nine circles in a row and writing down the name of the Sun and the planets. Even without drawing the orbits, this would result in a knowledge score of six, which is more than double the recorded average score across countries and genders. Another possibility is that students who were unsure about their knowledge did not draw anything and, thus, their knowledge was underestimated.

We found a significant difference in knowledge of the solar system between Italian and Norwegian teacher students, and a significant difference between genders, with men having a higher score than women in Italy, but not in Norway. The difference between countries might reflect differences in teaching curricula, teaching efficacy (Tschannen-Moran & Hoy, 2001) and attitudes towards astronomy in science teachers. When examining teaching curricula for lower secondary school in the two countries we found that they both specify, among the aims to be reached, that pupils in their 7th and 8th class, in Italy and Norway respectively, should learn about astronomy. However, in Norway the competence aim has been revised twice in 2013 and 2020 and is currently specifically focused on connecting the astronomical facts with understanding why the Earth is suitable for life, stating "The aim of the teaching is for the student to be able to account for the Earth's prerequisites for life and compare with other celestial bodies in the universe" (Norwegian Directorate for Education and Training, 2020). Whereas the Italian teaching curriculum, has also been updated, but the part about astronomy has not been changed and is not explicitly connecting it to understanding the occurrence of life on Earth. The Italian curriculum is generally leaving it more up to the teacher and the learning context and quotes "standardized and normative transmissions of knowledge, which communicate unchanged content designed for average individuals, are no longer adequate" (Ministero della Pubblica Istruzione, 2012). In general, however, the teaching of astronomy in Italian schools has little relevance, unless schools offer specific teaching packages or accept courses from outside, such as astronomers' associations. The interdisciplinary approach suggested by the Norwegian curriculum might not only increase curiosity and thus motivation to learn, but also make information easier to remember, by connecting it to an interesting question (Başpınar, 2020; Ivanitskaya et al., 2002; Kelley & Knowles, 2016) and thus build the foundations for in-depth learning (Biggs & Moore, 1993). Moreover, a study carried out in 2011 showed that Norwegian 8th graders generally find astronomy fascinating and easier to learn about, with respect to other STEM subjects (such as for example electricity), because it does not involve a lot of mathematics (Nilsen & Angell, 2014), and thus learning astronomy at school might be a way to promote a positive attitude towards STEM subjects generally.

It is established that there is an educational gap between genders, especially for STEM subjects (Cimpian et al., 2020). And still common stereotypes associate higher intellectual ability with men more than women (Barthelemy et al., 2016; Bian et al., 2017; Bozzato et al., 2021; Carli et al., 2016). It is therefore not surprising that there was a gender discrepancy in knowledge in Italy, where gender gaps are generally more pronounced than in Norway. Moreover, in the Italian education system, male students are more encouraged to choose STEM subjects, considered "masculine" and female students to choose liberal arts, considered more "feminine" (Berra & Cavaletto, 2020; Biemmi, 2015). This gap in STEM education might be enhanced by the fact that almost 80 percent of the lower secondary school teachers in Italy are women (Tutto Scuola, 2017), although there is apparently no direct relationship between teacher gender and students' performance in science and mathematics (Hastedt et al., 2021).

According to the Sustainable Development Report 2023, the Sustainable Development Goal (SDG) 5 on Gender Equality has been reached in Norway, whereas Italy is moderately improving, although challenges remain (Sachs et al., 2023). Likewise, Norway is ranked at the second place by the Global Gender Gap Report (World Economic Forum, 2023), whereas Italy is ranked number 79. For what concerns the SDG 6, on Quality in Education, both Norway and Italy still have respectively one fifth and one fourth of underachievers in science (21, and 26 % of 15-year-olds), indicating that challenges remain, and the trend is negative in both countries (Sachs et al., 2023).

Although our results are not fully representative for all Italian and Norwegian students at the end of compulsory school, because students who choose Early Childhood Education and Educational Sciences might not be the most interested in scientific subjects, these results are rather concerning. Considering the increasing scepticism about science diffusing in the society (Adam et al., 2020), also due to internet-based conspiracy theories (Del Vicario et al., 2016; Kata, 2010; Landrum et al., 2021), there is an urge to enhance scientific literacy among the public and particularly among future educators, so that already at young age children avoid misconceptions (Agan & Sneider, 2004; Osborne & Pimentel, 2023).

In Norway, at QMUC, we have the possibility to put emphasis on the scientific knowledge that we think our students will need to support children's wondering and curiosity as future early childhood educators (Salmon & Barrera, 2021). As well as the scientific knowledge that all citizens should hold, to be able to take part to the social debate and make facts-based choices. For example, at QMUC all Bachelor students attend a science course including both theoretical teaching about the solar system and a visit to a 3-dimensional planetarium. This is, however, not true for all Norwegian institutions graduating students in Early Childhood Education, despite young children being often very interested in astronomy (Callanan et al., 2019). In Italy the situation is more challenging, since the students attending the Bachelor course in Educational Sciences do not need to attend science courses, although several studies showed that introductory science courses promote positive attitudes towards science and contribute improving science literacy (Wittman, 2009).

5. Conclusion

We conclude that more emphasis should be put into teaching astronomy to future teachers in early childhood education both in Norway and Italy. Moreover, students in Educational Science in Italy should also be required to attend an introductory science course, which would contribute both reducing the number of underachievers in science and promoting a positive attitude towards science among young children.

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Conflict of interests
The authors declare no conflict of interest.

Ethical statement

Since data have been collected anonymously and the participants have been informed that the data would be used in research, our study met the ethics/human subject requirements of our institution and of the Norwegian Centre for Research Data (NSD) at the time the data were collected.

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