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# Exploring the association between non-specialised science teacher rates and student science literacy: an analysis of PISA data across 18 nations

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**ABSTRACT**
Out-of-field teaching is viewed as inferior to subject-specific instruction, but its impact on student outcomes varies depending on the criteria used for evaluation. The present study investigated the consequences of out-of-field teaching in science on different student outcomes on an international scale. Analyses were based on the sixth cycle of PISA data, using a subsample of $N = 128{,}438$ students (51% girls) and $N = 27{,}819$ teachers (44% women) from 4,037 schools in 18 countries. Results show that higher specialised science teachers rates in schools were linked to improved scientific literacy and students enjoyment. Science teachers with specialised science training in a school were associated with higher science competencies in students, while the impact on the enjoyment of science was smaller. However, the share of specialised teachers was not associated with students' self-efficacy or perceived teaching practices. The findings suggest that specialised teachers are critical in positively influencing students' literacy and enjoyment. Moreover, it informs policymakers and school administrators about the need to prioritise hiring specialised science teachers to improve the overall quality of science education. Further research is needed to understand how specialised teachers affect student outcomes and to identify other factors impacting science literacy.

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Scientific literacy; non-specialised teaching

## Introduction

Out-of-field teaching refers to teaching subjects and grades regularly without appropriate subject-specific training. There is a range of how teachers are trained for their jobs and what kind of qualification is required in different countries to teach a specific subject or to be perceived as out-of-field teachers (Price et al., 2019). Terms such as 'less qualified'

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for non-subject teaching or 'specialist teacher' for those not out-of-field suggest that dealing with the issue is more of a downplaying strategy than focusing on solutions. However, experts consider that teachers' lack of qualifications and expertise might lead to even less knowledge on the part of students (e.g. Porsch & Whannell, 2019; Vale et al., 2022). This view is supported by the model of the determinants and consequences of professional competence (Kunter et al., 2013), which suggests that providing learning opportunities enables the acquisition of professional competence. They are needed for teachers' professional practice, which is expected to have positive learning outcomes and motivational and emotional development. Teachers who teach a subject without having a subject-specific qualification obtained during initial teacher education may have a substantial knowledge deficit in the subject as they may lack the requisite learning opportunities. Since in some countries, science is taught as general science in elementary or lower secondary education without differentiating between the science subjects, teachers with a physics background must also teach other science subjects, such as chemistry (Mizzi, 2020). At the same time, science education is valued as one of the most critical investments for functioning societies in times of climate change and multiple health crises (Erduran, 2020; Klenert et al., 2020; Rousell & Cutter-Mackenzie-Knowles, 2020), helping to educate against fake news (e.g. Hopf et al., 2019). Therefore, neglected science education greatly exacerbates our current societal challenges.

## Theoretical background

Although out-of-field teaching seems to be a worldwide phenomenon, only a little body of research on the consequences of out-of-field teaching has been done so far, and almost none has explored, for example, the effects on students' cognitive or affective characteristics. Primarily, researchers from the field have focused on the impact on students' academic performance explained by teacher qualification. Although there are studies that reveal disadvantages for students taught by non-specialised teachers (e.g. Van Overschelde, 2022), overall, the studies reveal mixed findings when investigating the hypothesis that qualified teachers obtain better student outcomes than unqualified teachers, as reviewed by Porsch and Whannell (2019). It should be noted that the operationalisation of out-of-field differs between the studies and the research designs and statistical methods. None of the studies on researching science or other subjects considers data from various countries. The authors suggest that to produce an empirical base of sound evidence, researchers require methodological techniques such as multi-level regression modelling on an appropriately sized dataset. Few studies are known concerning science and the effect of teaching out-of-field, as most quantitative studies researching the effect have focused on mathematics. Dee and Cohodes (2008) found no differences in eighth-grade students' proficiency explained by teacher qualification. Findings from multi-level regression analyses based on data from a nationwide large-scale assessment in Germany, the *Trends in Student Achievement 2018*, give no explanation for variance in students' achievement in biology, chemistry, and physics in Grade 9 provided by the subject-specific teacher qualification (Richter et al., 2019). Also, analyses using data from the TIMS studies (Trends in International Mathematics and Science Study) do not conclusively show a positive and statistically significant relationship between students' proficiency in Grade 4 and teacher qualification (Monk, 1994;

Porsch & Wendt, 2015, 2016; Zuzovsky, 2009). With data from TIMSS-2011 conducted in Germany, no differences in the students' self-concept in science and teacher qualification for teaching social and science studies could be found (Porsch & Wendt, 2015).

Price and colleagues (2019), presenting data from six countries, reported an international average of 8% to 12% of teachers teaching out-of-field, with numbers of 14% in science and 34% in mathematics, in year 8 in Australia. In Germany, 48% of all mathematics teachers regularly teach out-of-field. In Indonesia, 21% of elementary school classroom teachers and 54% of religion teachers nationwide are out-of-field. In Ireland, an estimated 28% to 80% of mathematics teachers in secondary schools were trained in subjects that did not include mathematics as a significant component. The United Kingdom Department for Education reports that in 2013, non-professionals taught about 18% of students ages 7–13, with the number rising to 25% two years later. Finally, 50% of the teachers in the United States teach out-of-field between 60 and 100% in their first or second year. Later in their careers, 60% of middle school teachers report out-of-field teaching about 50% of the time. All in all, out-of-field teaching is more common in rural schools, schools with low socioeconomic status, and schools catering to families with lower educational backgrounds (Price et al., 2019; Vale et al., 2022; Weldon, 2016).

Despite scientific literacy being considered one of the critical competencies of our civilisation to master future challenges, systematic research on its conditions, requirements, and consequences has not been started fully. Only single studies and case studies have been published (e.g. Shamos, 1995; Suroso et al., 2021; Vogelzang et al., 2020), with few exceptions (e.g. Eisenhart et al., 1996; Oliver & Adkins, 2020). Similarly, research examining the effect of out-of-field teaching evidence on student outcomes beyond academic achievements, such as enjoyment of science, is scarce. There are several factors considered to enhance the enjoyment of learning science, for example, experiential learning (Blunsdon et al., 2003), science self-concept, personal value of science, and utility value of science (Mercan, 2020), and scientific interest (Lu et al., 2022). On the other hand, scientific enjoyment is also assumed as a predictor of interest in science (Ainley & Ainley, 2011), science achievement (Long et al., 2022), science self-efficacy (Lu et al., 2022), and science literacy (Ustun et al., 2022). Further, students' science self-efficacy is suggested as an influential factor for success in and outside of school and later career (e.g. Andrew, 1998; Lent et al., 1986; Lu et al., 2022; Pajares & Britner, 2001; Robinson et al., 2022), but also for science literacy (Ma, 2022; She et al., 2019) and academic growth (e.g. Mercer et al., 2011).

Other factors, and probably more controllable by teachers, include the possible influence of students' perceived inquiry-based instruction and students' perceived teacher support. Several studies report a positive influence of inquiry-based instruction (e.g. Gormally et al., 2009; Oliver et al., 2021) on science literacy. However, others report negative connections between inquiry-based instruction and science literacy (e.g. Ma, 2022), also with data from PISA 2015 (Forbes et al., 2020), even with a positive connection between inquiry-based instruction and student self-efficacy (Liu & Wang, 2022). According to Kang (2022), these contradictory results emerge due to ignoring the instructional quality and different types of inquiry-based teaching, emphasising the moderating influence of the teacher-student relationship between inquiry-based teaching and science literacy. The teacher-student relationship, operationalised as students' perceived teacher support, is suggested to positively influence science literacy (Saroughi & Cheema, 2022) and academic growth, especially for students with low science self-efficacy (Mercer et al., 2011).

All in all, instruction characteristics, teacher support, and the reported student outcomes interact with each other. However, little is known about the effects of out-of-field teaching on the reported student outcomes. Even less is known about the long-lasting consequences of reduced qualifications for science teachers (Porsch & Whannell, 2019).

## Research questions

As many of these results focus on different student samples and single school systems, this paper aims to take an overarching approach by looking at out-of-field teaching across countries. This study examines the effects and consequences of out-of-field teaching on several variables considered crucial outcomes of science education at the student level. We analyse the following research questions:

> Research question 1. What percentage of teachers across countries have science as part of their education?
>
> Research question 2: To what extent does the percentage of specialised science teachers in a school predict students' scientific literacy, enjoyment of science, self-efficacy, and perceived teaching practices, after controlling for student- and school-level covariates and between-country differences?

## Materials and methods

In the OECD's *Programme for International Student Assessment* (PISA), scientific literacy has been one of the main areas of investigation since 2000, when this large-scale assessment was first implemented. Scientific literacy as measured in PISA includes three dimensions: (1) 'the ability to provide explanatory accounts of natural phenomena, technical artefacts and technologies and their implication for society', (2) the competence to use this 'knowledge and understanding of scientific enquiry to identify questions that can be answered by scientific enquiry', and (3) the competence 'to interpret and evaluate data and evidence scientifically and evaluate whether the conclusions are warranted' (OECD, 2019, p. 98).

PISA assesses the main competencies of reading, mathematics, and science of 15-year-old students around the globe every three years. Alongside the proficiency tests, questionnaires for students, principals, and teachers are administered. As the assessment instruments focus on a different domain in every round, the PISA 2015 dataset (published in 2016) is currently the only one on an international scale that provides the latest representative information on both the teachers' in-field / out-of-field experience and students' outcomes in science for the age group of 15-year-olds.

According to the research questions, we investigated the impact of out-of-field teaching on the target variables: scientific literacy, enjoyment of science, science self-efficacy, perceived inquiry-based teaching, and perceived teacher support. As control student variables, we included gender, migration and socio-economic background, percentage of female students, percentage of students with migration background, and social background on the school level (Tang et al., 2019). Controlling teacher variables were the percentage of female science teachers, the mean age and mean numbers of working as a science teacher, and the percentage of science teachers with master's degrees.

## Participants and samples

A subsample of $N = 128{,}438$ students (51% girls) with an average age of 15.80 years ($SD = 0.29$) was selected from the sixth cycle of PISA (OECD, 2016). We considered all countries in which the optional teacher questionnaire was administered. This resulted in 18 countries, including 4,037 schools (see Table 1). At each school, up to ten teachers sampled that currently instructed a science course such as physics, chemistry, biology, or earth sciences at the modal grade of the studied student sample. This resulted in a sample of 27,819 teachers (44% women) with a mean age of 42.90 years ($SD = 6.22$). About 36% had at least a master's degree and worked as a teacher since $M = 15.84$ years ($SD = 7.02$).

## Instruments

### *Student-level measures*

A student's ability to understand and engage with topics related to science and technology was measured with an achievement test including 184 items distributed across six booklets. Thus, each student only received a subset of the full item set. Different response formats, such as multiple-choice or open-response fields accompanied each item. The test development framework defined scientific literacy in terms of three dimensions

**Table 1.** Sample characteristics.

| | | Schools | Science teachers | | | | Students | | |
|---|---|---|---|---|---|---|---|---|---|
| Country | Mode | *N* | *N* | Women (%) | Age (*Mdn*) | Experience (*Mdn*) | *N* | Girls (%) | Age (*Mdn*) |
| Argentina | PBA | 350 | 2358 | 25.0 | 38.6 | 12.0 | 12174 | 50.9 | 15.8 |
| Australia | CBA | 614 | 3964 | 50.0 | 42.8 | 13.0 | 12340 | 49.7 | 15.8 |
| Brazil | CBA | 430 | 2391 | 40.0 | 38.3 | 13.0 | 14298 | 53.8 | 15.9 |
| Chile | CBA | 147 | 794 | 33.3 | 42.3 | 15.0 | 5372 | 49.9 | 15.8 |
| China: B-S-J-G | CBA | 258 | 2385 | 50.0 | 38.5 | 14.5 | 9627 | 47.7 | 15.7 |
| China: Hong Kong | CBA | 136 | 1039 | 66.7 | 41.9 | 19.0 | 5281 | 50.0 | 15.8 |
| China: Macao | CBA | 40 | 383 | 56.3 | 36.6 | 10.0 | 4434 | 49.8 | 15.8 |
| Chinese Taipei | CBA | 187 | 1508 | 57.1 | 42.0 | 14.5 | 6848 | 49.6 | 15.7 |
| Colombia | CBA | 227 | 1182 | 50.0 | 44.5 | 17.0 | 8277 | 52.1 | 15.8 |
| Czech Republic | CBA | 251 | 1804 | 37.5 | 46.4 | 20.0 | 6104 | 49.5 | 15.8 |
| Dominican Republic | CBA | 74 | 361 | 33.3 | 41.4 | 12.0 | 2289 | 55.6 | 15.8 |
| Germany | CBA | 218 | 1930 | 42.9 | 45.3 | 14.0 | 5830 | 49.2 | 15.8 |
| Italy | CBA | 343 | 2290 | 33.3 | 50.4 | 21.0 | 9301 | 49.4 | 15.8 |
| Korea | CBA | 128 | 897 | 50.0 | 43.0 | 15.0 | 4495 | 48.8 | 15.8 |
| Peru | CBA | 138 | 722 | 50.0 | 45.0 | 17.0 | 4481 | 51.8 | 15.8 |
| Portugal | CBA | 162 | 1405 | 20.0 | 46.9 | 22.5 | 5726 | 51.6 | 15.8 |
| Spain | CBA | 182 | 1328 | 44.4 | 46.0 | 17.0 | 6325 | 50.3 | 15.8 |
| United States | CBA | 152 | 1078 | 44.4 | 41.5 | 13.0 | 5236 | 49.7 | 15.8 |

Note. PBA = Paper-based assessment; CBA = Computer-based assessment; Experience = Number of years worked as a teacher.

(see OECD, 2017), that is, (a) competencies related to the process of scientific inquiry, such as explaining and interpreting evidence scientifically, (b) knowledge about science and technology, and (c) different contexts of scientific discovery (e.g. earth and space). Although the items were constructed to cover different dimensions, they were designed to measure a single latent construct of scientific literacy. Students' proficiencies were estimated as ten plausible values based on a two-parametric item response model (Muraki, 1992). The test was presented on the computer except for one country that administered a paper-based test version (see Table 1). The different administration modes were linked to allow for comparable proficiency estimates (Jerrim et al., 2018). The average test reliability across the studied countries was .91 and varied between countries from .84 to .94.

Data from the student questionnaire included four self-report scales assessing students' science-related dispositions and evaluations of their learning environment in science classes. Enjoyment of science was measured with five items (e.g. 'I enjoy acquiring new knowledge in broad science.') on four-point response scales from 1 = 'strongly agree' to 4 = 'strongly disagree', whereas science self-efficacy, that is, students' competency beliefs to be able to perform tasks related to science successfully was rated with eight items (e.g. 'Describe the role of antibiotics in the treatment of disease.') on four-point response scales from 1 = 'I couldn't do this' to 4 = 'I could do this easily'. The average coefficient alpha reliabilities were .94 and .90, respectively. Students' perceptions of science teachers' inquiry-based science teaching and learning practices were rated on eight items (e.g. 'Students are allowed to design their own experiments.') on four-point response scales from 1 = 'never or hardly ever' to 4 = 'in all lessons', resulting in an average coefficient alpha reliability of .87. Finally, students' evaluations of teacher support in the science class (e.g. 'The teacher helps students with their learning.') was measured with five items on four-point response scales from 1 = 'never or hardly ever' to 4 = 'every lesson'. The average reliability across all countries was .90. The full scales are provided in the supplemental material (see also OECD, 2017). Person scores for each measure were derived as a weighted likelihood estimate (Warm, 1989) based on a two-parametric item response model (Muraki, 1992).

As control variables, we considered the students' sex (coded 0 for girls and 1 for boys) and age (in years). Moreover, their social background was measured with the index of economic, social, and cultural status (ESCS), which is a composite score derived from the highest parental education, highest parental occupation, and cultural home possessions (see Avvisati, 2020). The respective measure had an average coefficient alpha reliability of .71.

### *School-level measures*

Indicators for the school-level measures were created from responses to the student or teacher questionnaires that were aggregated to the school level. Each teacher indicated whether science was included in her or his education or training programme or other professional qualification. Based on these responses, an indicator of specialised training was created that reflected the relative share of science teachers in each school for which the subject science was part of their initial training. The indicator ranged from 0 ( = all non-specialised teachers) to 1 ( = all specialised teachers).

Furthermore, several control variables were acknowledged. These included characteristics of the science teachers, including their average age (in years), the percentage of female science teachers, the percentage of science teachers with at least a master's degree, and the average number of years working as a teacher (in years). Moreover, the student population in each school was characterised by their mean age (in years), the percentage of female students, the percentage of students with migration backgrounds, and their average ESCS.

### *Statistical analyses*

Each outcome was regressed on the percentage of teachers with science as part of their training in the *lme4* package (Version 1.1-31; Bates et al., 2015) of the *R* software (Version 4.2.1; R Core Team, 2022). The nesting of each student within schools was acknowledged by specifying a respective random effect and, thus, extending the model to a mixed-effect specification. Moreover, dependencies resulting from the different countries were modelled as fixed effects by including 17 effect-coded country indicators in the analyses. To facilitate interpretations, the outcomes were *z*-standardized (with $M = 0$ and $SD = 1$). However, the predictors were examined on their original metric. The explained variance on the school level was calculated following Raudenbush and Bryk (2002) with *mitml* (Version 0.4-3; Grund et al., 2021). To correct for the over- or undersampling of specific student populations and school non-response, these analyses were weighted using the survey weights provided for PISA (see OECD, 2017). Missing values for some students and teachers were imputed ten times using multilevel predictive mean matching with chained equations in *mice* (Version 3.14.0; Van Buuren & Groothuis-Oudshoorn, 2011). Then, the analyses were repeated for each fully imputed data set and combined using Rubin's (1987) rules. The raw data and survey material are available at https://www.oecd.org/pisa/data/2015database/, whereas our analyses' computer code and results are provided at https://osf.io/9374x/?view_only=4b8529f95ffa42f094830be138d489cd, thus, allowing full reproducibility of our findings.

## Results

To address the first research question about the percentage of teachers who have science as part of their education and how that percentage relates to various student outcome variables, we analysed the means, standard deviations, and correlations of the study variables (Table 2).

**Table 2.** Means, standard deviations, and correlations for study variables.

| | | | | Correlations | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *M* | *SD* | 1. | 2. | 3. | 4. | 5. |
| 1. | Scientific literacy | −0.01 | 0.69 | | | | | |
| 2. | Enjoyment of science | −0.02 | 0.25 | .13 | | | | |
| 3. | Science self-efficacy | 0.00 | 0.30 | .21 | .52 | | | |
| 4. | Inquiry-based teaching | 0.01 | 0.42 | −.30 | .37 | .34 | | |
| 5. | Teacher support | −0.01 | 0.39 | −.23 | .48 | .26 | .52 | |
| 6. | Specialised training | 0.84 | 0.20 | .16 | .14 | .11 | .10 | .14 |

Note. Presented are the results for 4,037 schools. Based upon multiply imputed data sets. All correlations are significant at $p < .05$.

In about 45% of all examined schools, all science teachers had received training in science instruction. The median share of specialised teachers was 90%, with the first quartile falling at 75% (see Figure 1). The share of teachers with specialised science training in a school correlated at $r = .16$, $p < .001$, with the students' average scientific literacy in a school. Similarly, the students' average enjoyment of science and science self-efficacy was positively associated with the percentage of specialised teachers, $r = .14$ / $.11$ (see Table 2). Also, students' perceived teaching practices, the degree of inquiry-based teaching and teacher support were related to the share of specialised teachers in a school with *r*s of .10 and .14, respectively.

Following the second research question, we investigated to what extent the percentage of specialised science teachers in a school does predict students' scientific literacy, enjoyment of science, self-efficacy, and perceived teaching practices, after controlling for student- and school-level covariates and between-country differences. For this, we studied the effect of teacher specialisation using mixed-effect regression analyses. These analyses were conducted twice for each outcome, without and with controlling for student- and school-level covariates suspected of distorting the effect of teacher

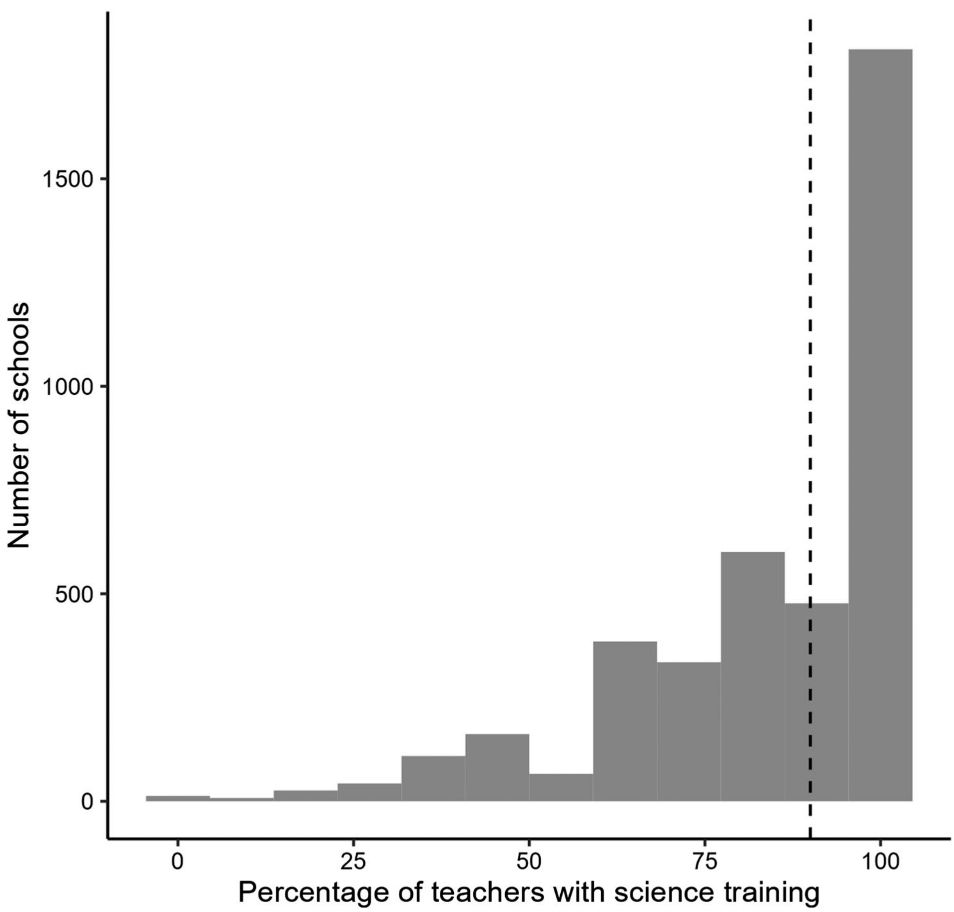


**Figure 1.** Histogram of percentage of teachers in schools with science training.
Note: The dashed line represents the median.

**Table 3.** Regressions of student scientific literacy on teacher specialisation.

| | | Model 0 | Model 1 | Model 2 |
|---|---|---|---|---|
| 1. | Intercept | −0.01 (0.01) | −0.48 (0.04) | −3.61 (1.05) |
| 2. | Share of specialised teachers | | 0.56* (0.05) | 0.29* (0.04) |
| | *Student characteristics* | | | |
| 3. | Sex (0 = boy, 1 = girl) | | | 0.10* (0.01) |
| 4. | Age (in years) | | | 0.12* (0.01) |
| 5. | Migration background (0 = no, 1 = yes) | | | −0.14* (0.01) |
| 6. | Social background | | | 0.12* (0.00) |
| | *School characteristics* | | | |
| 7. | Percentage of female students | | | −0.19* (0.04) |
| 8. | Mean age of students (in years) | | | 0.23* (0.07) |
| 9. | Percentage of students with migration background | | | 0.31* (0.05) |
| 10. | Mean social background | | | 0.48* (0.01) |
| 11. | Percentage of female science teachers | | | 0.04 (0.03) |
| 12. | Mean age (in years) of science teachers | | | −0.01* (0.00) |
| 13. | Percentage of science teachers with a master's degree | | | 0.10* (0.03) |
| 14. | Mean number of years working as teacher | | | 0.01* (0.00) |
| | Random variance | 0.23 | 0.22 | 0.09 |
| | Residual variance | 0.59 | 0.59 | 0.56 |
| | Explained school variance | .46 | .48 | .79 |

Note. Based upon multiply imputed data sets. Fixed country effects are not presented. The dependent variable was *z*-standardised.
* $p < .05$.

specialisation. The results of these analyses of students' scientific literacy are summarised in Table 3. Schools in which all science teachers had specialised science training resulted in average student science competencies that were, on average, 0.56 points larger ($p < .001$) on a $z$-standardized scale as compared to schools without any specialised science teachers (see Model 1). Thus, about 10% of non-specialised teachers in a school corresponded to a drop of about 0.06 standard units in scientific literacy. After controlling for several covariates, the respective effect remained significant at $p < .05$ but reduced to about half its original size (see Model 2 in Table 3).

The respective effects on students' self-reported enjoyment of science (see Table 4) exhibited a similar pattern with significant effects without and with covariates. However, the size of these effects was substantially smaller. An increase in about 10% of non-specialised teachers in a school resulted in reduced enjoyment by less than 0.02 or 0.01 standard units. For the remaining outcomes, no robust effects could be identified (see Tables 5–7). Students' self-efficacy and perceived teaching practices were not significantly ($p > .05$) associated with the share of specialised teachers in a school after controlling for several third variables.

Additionally, we plotted the distribution of average science literacy in schools with different proportions of specialist science teachers. The distribution of the average scientific literacy of schools depending on the share of specialised teachers is visualised in Figure 2.

The plot highlights that schools with a larger share of science teachers without specialised science training are associated with substantially lower student competencies.

## Discussion

Science education is rated as one of the most important investments for a functioning society in times of climate change, numerous health crises, and the prevention of

**Table 4.** Regressions of student enjoyment of science on teacher specialisation.

| | | Model 0 | Model 1 | Model 2 |
|---|---|---|---|---|
| 1. | Intercept | −0.00 (0.01) | −0.13 (0.03) | 1.82 (0.86) |
| 2. | Share of specialised teachers | | 0.15* (0.03) | 0.08* (0.03) |
| | *Student characteristics* | | | |
| 3. | Sex (0 = boy, 1 = girl) | | | 0.15* (0.01) |
| 4. | Age (in years) | | | 0.01 (0.01) |
| 5. | Migration background (0 = no, 1 = yes) | | | 0.09* (0.01) |
| 6. | Social background | | | 0.09* (0.00) |
| | *School characteristics* | | | |
| 7. | Percentage of female students | | | −0.02 (0.03) |
| 8. | Mean age of students (in years) | | | −0.11* (0.05) |
| 9. | Percentage of students with migration background | | | 0.06 (0.04) |
| 10. | Mean social background | | | 0.12* (0.01) |
| 11. | Percentage of female science teachers | | | 0.04 (0.02) |
| 12. | Mean age (in years) of science teachers | | | −0.01* (0.00) |
| 13. | Percentage of science teachers with a master's degree | | | 0.05 (0.03) |
| 14. | Mean number of years working as teacher | | | 0.00 (0.00) |
| | Random variance | 0.04 | 0.04 | 0.03 |
| | Residual variance | 0.90 | 0.90 | 0.88 |
| | Explained school variance | .38 | .39 | .51 |

Note. Based upon multiply imputed data sets. Fixed country effects are not presented. The dependent variable was *z*-standardised.
* $p < .05$.

belief in fake news (Erduran, 2020; Hopf et al., 2019; Klenert et al., 2020; Rousell & Cutter-Mackenzie-Knowles, 2020). This study investigated the impact of out-of-field teaching on the target variables of scientific literacy, enjoyment of science, science self-efficacy, perceived inquiry-based teaching, and perceived teacher support. The analyses were controlled for gender, age, and social background at the student level and the relative share of trained science teachers, teachers' average age, the percentage of female science teachers, the percentage of science teachers with at least a master's degree,

**Table 5.** Regressions of students' science self-efficacy on teacher specialisation.

| | | Model 0 | Model 1 | Model 2 |
|---|---|---|---|---|
| 1. | Intercept | −0.00 (0.01) | −0.12 (0.03) | 3.52 (0.81) |
| 2. | Share of specialised teachers | | 0.14* (0.03) | 0.04 (0.03) |
| | *Student characteristics* | | | |
| 3. | Sex (0 = boy, 1 = girl) | | | 0.12* (0.01) |
| 4. | Age (in years) | | | 0.07* (0.01) |
| 5. | Migration background (0 = no, 1 = yes) | | | 0.01 (0.02) |
| 6. | Social background | | | 0.13* (0.00) |
| | *School characteristics* | | | |
| 7. | Percentage of female students | | | −0.06* (0.03) |
| 8. | Mean age of students (in years) | | | −0.22* (0.05) |
| 9. | Percentage of students with migration background | | | 0.00 (0.05) |
| 10. | Mean social background | | | 0.15* (0.01) |
| 11. | Percentage of female science teachers | | | 0.01 (0.02) |
| 12. | Mean age (in years) of science teachers | | | −0.00 (0.00) |
| 13. | Percentage of science teachers with a master's degree | | | 0.04 (0.03) |
| 14. | Mean number of years working as teacher | | | 0.00 (0.00) |
| | Random variance | 0.04 | 0.04 | 0.03 |
| | Residual variance | 0.96 | 0.96 | 0.94 |
| | Explained school variance | .21 | .22 | .47 |

Note. Based upon multiply imputed data sets. Fixed country effects are not presented. The dependent variable was *z*-standardised.
* $p < .05$.

**Table 6.** Regressions of student perceived inquiry-based teaching on teacher specialisation.

| | | Model 0 | Model 1 | Model 2 |
|---|---|---|---|---|
| 1. | Intercept | 0.01 (0.01) | −0.06 (0.03) | 7.12 (0.98) |
| 2. | Share of specialised teachers | | 0.08* (0.03) | 0.05 (0.03) |
| | *Student characteristics* | | | |
| 3. | Sex (0 = boy, 1 = girl) | | | 0.12* (0.01) |
| 4. | Age (in years) | | | −0.03* (0.01) |
| 5. | Migration background (0 = no, 1 = yes) | | | 0.11* (0.02) |
| 6. | Social background | | | 0.04* (0.00) |
| | *School characteristics* | | | |
| 7. | Percentage of female students | | | 0.10* (0.03) |
| 8. | Mean age of students (in years) | | | −0.45* (0.06) |
| 9. | Percentage of students with migration background | | | −0.10 (0.05) |
| 10. | Mean social background | | | −0.01 (0.01) |
| 11. | Percentage of female science teachers | | | −0.07* (0.03) |
| 12. | Mean age (in years) of science teachers | | | −0.00* (0.00) |
| 13. | Percentage of science teachers with a master's degree | | | 0.07* (0.03) |
| 14. | Mean number of years working as teacher | | | 0.00 (0.00) |
| | Random variance | 0.06 | 0.06 | 0.05 |
| | Residual variance | 0.90 | 0.90 | 0.89 |
| | Explained school variance | .58 | .59 | .61 |

Note. Based upon multiply imputed data sets. Fixed country effects are not presented. The dependent variable was *z*-standardised.
* $p < .05$.

**Table 7.** Regressions of student perceived teacher support on teacher specialisation.

| | | Model 0 | Model 1 | Model 2 |
|---|---|---|---|---|
| 1. | Intercept | −0.01 (0.01) | −0.05 (0.03) | 3.39 (0.93) |
| 2. | Share of specialised teachers | | 0.05 (0.03) | 0.04 (0.03) |
| | *Student characteristics* | | | |
| 3. | Sex (0 = boy, 1 = girl) | | | 0.01 (0.01) |
| 4. | Age (in years) | | | −0.01 (0.01) |
| 5. | Migration background (0 = no, 1 = yes) | | | 0.01 (0.02) |
| 6. | Social background | | | 0.01* (0.00) |
| | *School characteristics* | | | |
| 7. | Percentage of female students | | | −0.02 (0.03) |
| 8. | Mean age of students (in years) | | | −0.20* (0.06) |
| 9. | Percentage of students with migration background | | | 0.00 (0.05) |
| 10. | Mean social background | | | 0.01 (0.01) |
| 11. | Percentage of female science teachers | | | 0.01 (0.03) |
| 12. | Mean age (in years) of science teachers | | | −0.01* (0.00) |
| 13. | Percentage of science teachers with a master's degree | | | 0.01 (0.03) |
| 14. | Mean number of years working as teacher | | | 0.00 (0.00) |
| | Random variance | 0.05 | 0.05 | 0.05 |
| | Residual variance | 0.90 | 0.90 | 0.90 |
| | Explained school variance | .53 | .53 | .55 |

Note. Based upon multiply imputed data sets. Fixed country effects are not presented. The dependent variable was *z*-standardised.
* $p < .05$.

teachers' work experience, the mean age of the student population, the percentage of female students and students with migration background, and their average social background on school level. For the analyses, we used a linear mixed-effects model to account for the nested structure of the data, with students nested within schools. To address missing data, multiple imputations were used, which is a recommended approach (Van Buuren & Groothuis-Oudshoorn, 2011).

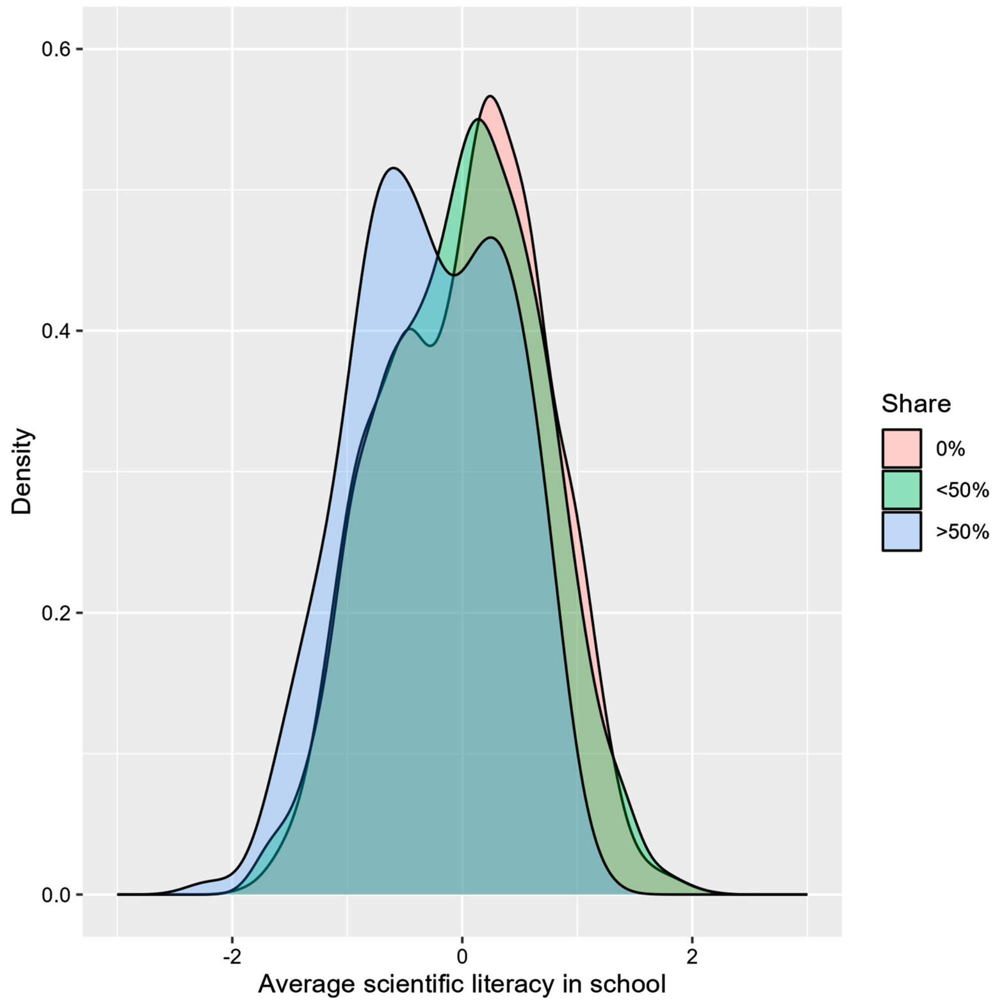


**Figure 2.** Distribution of average scientific literacy of schools conditional on the share of non-specialised teachers.

The analyses showed a positive correlation between the share of specialised teachers and students' scientific literacy, enjoyment of science, and science self-efficacy. Specifically, schools, where all science teachers had specialised science training, resulted in higher average student science competencies than schools without specialised science teachers. We found that the effect of teacher specialisation on students' scientific literacy remained significant even after controlling for several student- and school-level covariates. However, no significant association was found between the share of specialised teachers and students' self-efficacy or perceived teaching practices.

Our analyses revealed significant effects of small to medium size, with the highest effect on science literacy (.56). Overall, large effect sizes according to Cohen's fifty-year-old standard of small (.2), medium (.5), and large (.8) effects (Cohen, 1969) are difficult to find in educational studies. Meanwhile, several researchers argue that Cohen's standard provokes over-expectations for educational studies (e.g. Evans &

Yuan, 2022; Kraft, 2020; Yeager & Dweck, 2020). In one of their influential meta-analyses, Hattie et al. (1996) reported a mean effect size of 0.57 for performance across 51 studies. Notably, this effect size was considered the most substantial compared to the effects observed on study skills (0.16) and affect (0.48). Yeager and Dweck (2020) argued that under real-world conditions, effect sizes should not be expected to exceed .20, aligning with the findings of Evans and Yuan (2022) who meta-analysed 234 studies. Notably, Evans and Yuan (2022) concluded that large sample analyses generally produce smaller effect sizes than small sample analyses. In this context, our findings show that science instruction by specialised science teachers notably impacts students, and the highest effect is found on higher science literacy.

The main findings of this study suggest that the share of specialised teachers in a school is a critical factor that positively influences students' scientific literacy and enjoyment of science. This effect remains significant even after controlling several student characteristics such as gender, age, migration, social background, and school characteristics as a percentage of female students, percentage of students with migration background, mean social background, or percentage of female science teachers. These control variables, except for the percentage of female teachers, also significantly impacted scientific literacy and enjoyment of science. Further, analyses revealed that teachers' self-efficacy has no moderating effects on students' science literacy (Table S8).

Further research is needed to examine how specialised teachers influence student outcomes and identify other factors that contribute to student science education outcomes. For example, a study by Ziegler and Richter (2017) found that the effect of out-of-field teaching on student achievement may vary depending on the class composition. This suggests that, as also found in our analyses, differences in the academic and social background of students in a class can affect the relationship between out-of-field teaching and student achievement. Therefore, it is crucial to consider the characteristics of student composition when examining the impact of out-of-field teaching on student outcomes.

However, it is worth noting that the number of non-specialised teachers in a school may be related to the students' educational background. Research by Nilsen and Gustafsson (2016) found a positive association between the proportion of students from low-educated families and the proportion of non-specialised teachers in Norwegian primary schools. This suggests that schools with a higher proportion of students from disadvantaged backgrounds may face more significant challenges in hiring and retaining specialised (science) teachers. This aspect is important because it underscores the need for targeted policies and interventions to address inequities in science education. It also shows us the danger that the gap between well-educated and socially disadvantaged students could steadily increase. Schools serving disadvantaged communities may require additional resources and support to attract and retain specialised science teachers, which could improve the quality of science education for these students. Future research should explore the specific factors contributing to the association between non-specialised teachers and students' educational backgrounds and identify effective strategies for addressing these disparities.

Our findings also suggest that no relationship exists between the share of specialised teachers at schools and students' self-efficacy or perceived teaching practices after controlling for several variables. The reasons behind this may be various. Non-specialised teachers may be as enthusiastic about teaching a subject as their specialised colleagues.

Thus, students may not perceive differences or deficits when evaluating their teaching practices or even appreciate them. Olitsky (2007), for example, reports from an ethnographic research project accompanying a female out-of-field chemistry teacher. In contrast to what the researcher expected, her students enjoyed being taught by her and liked that the teacher did not have the complete content knowledge and still made mistakes. Concerning students' self-efficacy, in our context, the belief in one's ability to perform science-related tasks, we assume that this individual perception is less influenced by a teacher's qualification than by the students' success in performing tasks in or outside the classroom. This assumption is supported by Britner and Pajares (2006), who found that only mastery experiences predicted science self-efficacy, which is the interpretation of previous performance. Future research should further pursue the relationship between teacher practice and the development of affective characteristics by conducting qualitative or ethnographic research.

## Limitations

There are several limitations to the study that need to be considered. First, the operationalisation of 'out-of-field' teaching varies across countries, which could affect the results. The definition of a 'science teacher' may differ between countries, including different scientific subdisciplines, like biology, physics, or chemistry (Price et al., 2019). Additionally, the study considers the school-level percentage of specialised science teachers and does not account for individual teacher-level differences, which could also impact student outcomes. However, the PISA data, to our knowledge, is the only available dataset allowing us to examine the impact of out-of-school instruction with a substantial sample worldwide with a representative significance. The study focuses not only on cognitive outcomes, namely scientific literacy, but also on enjoyment of science, science self-efficacy, perceived inquiry-based teaching, and perceived teacher support, thus broadening the scope of the potential impact of out-of-field teaching. Other important outcomes, such as critical thinking skills or interest in pursuing a career in science, may also be worth examining. However, despite these limitations, the current study contributes highly to the research field by focusing on science and using large-scale assessment data from various countries. We found that the percentage of specialised science teachers in a school is positively associated with students' scientific literacy and enjoyment of science and with perceived teaching practices, indicating that specialised teachers significantly positively impact on student outcomes.

## Conclusion

The issue of out-of-field teaching is a worldwide phenomenon and may have significant consequences for students' scientific literacy and enjoyment of science. This study highlights the importance of having specialised science teachers in schools to improve science education quality and positively influence student outcomes. The findings suggest that the share of specialised teachers in schools differs and that a school is critical for improving students' scientific literacy and enjoyment of science, as well as perceived teaching practices. Therefore, policymakers and school administrators should prioritise hiring and training specialised science teachers to address the problem of out-of-field teaching and improve science education quality.

However, the study also acknowledges the need for further research to explore how specialised teachers influence student outcomes and identify additional factors that contribute to students' science education outcomes. Neglected science education exacerbates current societal challenges, and scientific literacy is increasingly critical for participation in the modern world. Therefore, it is crucial to continue investigating the conditions, requirements, and consequences of scientific literacy to ensure that all students receive a high-quality science education that prepares them for the challenges of the twenty-first century.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Data availability statement

The study was not preregistered. The raw data is available at https://www.oecd.org/pisa/data/2015database/ The computer code and analysis results are provided at https://osf.io/9374x/?view_only = 4b8529f95ffa42f094830be138d489cd.

## Ethics statement

The results of this study were obtained through a secondary analysis of anonymous PISA data. The raw data is freely available at https://www.oecd.org/pisa/data/2015database/ The computer code and analysis results are provided online. This secondary analysis aims to derive valuable insights and make contributions to scientific knowledge while exclusively utilising anonymized data devoid of personal information. The analysis is conducted in compliance with applicable laws and regulations, adhering to ethical principles and guidelines.

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