European
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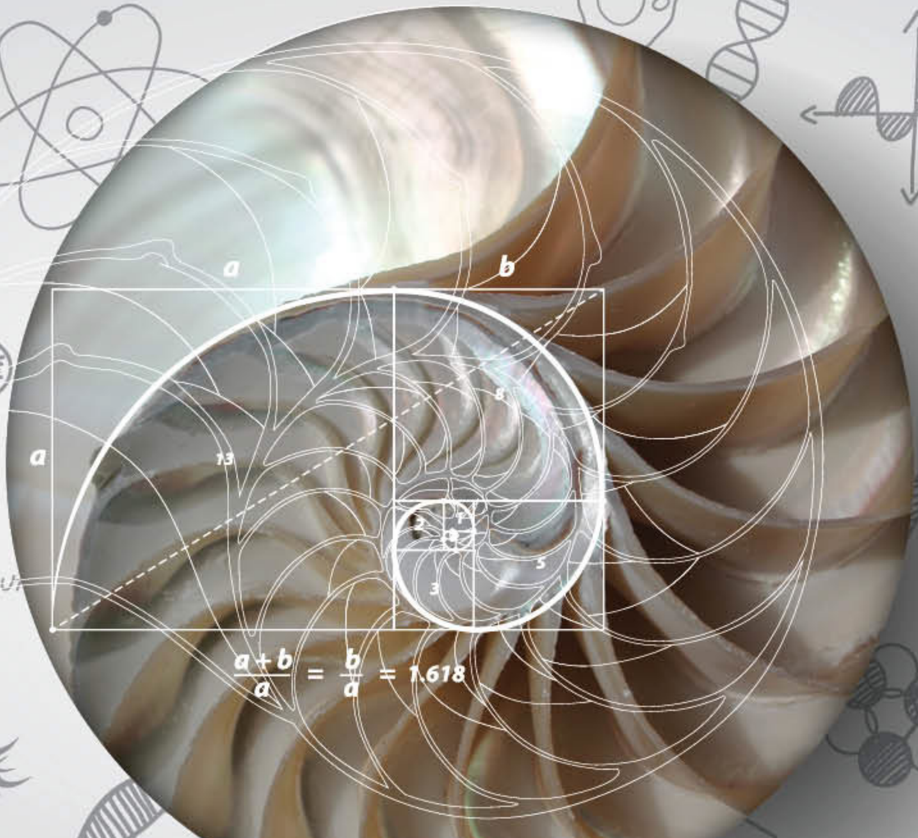
Increasing achievement and motivation in mathematics and science learning in schools

Eurydice report



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CHAPTER 7: TOWARDS A CONCLUSION: EXPLAINING DIFFERENCES IN LOW-ACHIEVEMENT RATES

After setting the scene by presenting the situation of European education systems in terms of low achievement rates in mathematics and science, and the challenges education systems faced during the COVID-19 pandemic, this report has provided a broad overview of mathematics and science teaching and learning. It examined how mathematics and science teaching and learning are organised in Europe, how learning outcomes are assessed, how instruction is contextualised and how students are supported when facing difficulties in the learning process.

This final chapter aims to bring together all this information by examining the common characteristics of education systems that have relatively low shares of low achievers. Combining qualitative and quantitative methods, the analysis aims to identify links between education structures and policies and percentages of low achievers in mathematics and science in European education systems.

The first section presents two 'path analysis' models (see, for example, Bryman and Cramer, 1990) – one for mathematics and one for science – which view low-achievement rates at the different educational levels as outcomes dependent on how mathematics and science education is organised in European education systems. The second section looks at additional factors that can be associated with lower percentages of underachieving students. Both sections aim to answer the same question: which types of education system tend to have higher shares of students with at least a basic knowledge of mathematics or science?

7.1. Modelling relationships between low-achievement rates

The percentage of low achievers can be measured at different educational levels. Chapter 1 presented low-achievement rates at two points in students' educational careers: in grade 4 (primary education), based on the 2019 Trends in International Mathematics and Science Study (TIMSS) survey administered by the International Association for the Evaluation of Educational Achievement (IEA), and at the age of 15 years (secondary education), based on the 2018 Programme for International Student Assessment (PISA) survey carried out by the Organisation for Economic Co-operation and Development (OECD). As Chapter 1 showed, low-achievement rates correlate strongly across educational levels. Nevertheless, differences remain: some education systems with relatively high percentages of low achievers in primary education have relatively low rates in secondary education and vice versa. Some of these differences can certainly be a result of dissimilarities in the design of the two international assessment surveys (see Chapter 1). Nevertheless, the way mathematics and science education is organised in European education systems can also contribute to these differences.

International student achievement surveys also established that achievement levels tend to correlate across subject areas (i.e. those education systems that do well in mathematics tend to also have good results in science) (see Chapter 1). However, there are some differences in how mathematics and science teaching and learning are organised. As Chapter 3 showed, the number of hours dedicated to mathematics exceeds the number allocated to science in all education systems in primary education, and in the majority of them at lower secondary level. In addition, it is more difficult to obtain clear information on science education than on mathematics education in this regard, as science is often taught together with other subject areas – such as social studies – especially in primary education (see Chapter 3). The organisation of science education can differ considerably between European education systems, as science subjects can be taught in an integrated way or separately. Even definitions of what constitutes 'natural sciences' differ; for example, geography is considered to be part of natural sciences in some education systems but not in others (see Chapter 4 and Annex I).

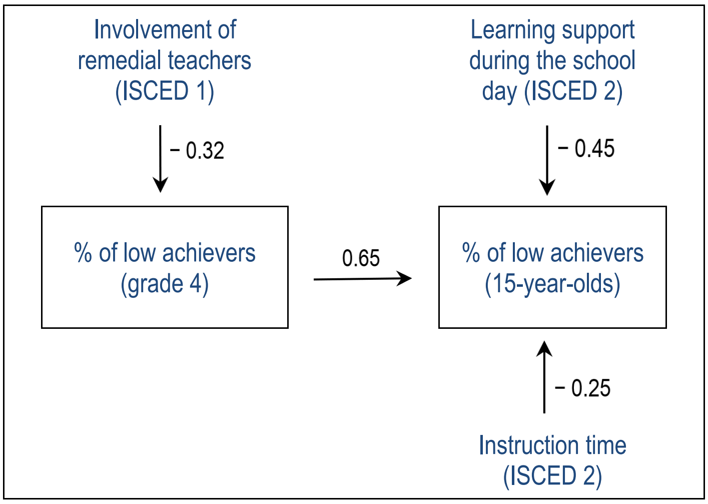
Chapter 4 pointed out that national tests and certified examinations are more commonly organised in mathematics than in science, especially when it comes to tests that are compulsory for all students. This is also true of national tests that aim to identify individual learning needs (Chapter 6). Chapter 5 revealed that, to increase interest and show the usefulness of mathematics, real-life applications in various contexts are part of almost all curricula in primary and lower secondary education. In contrast, history-of-science and especially socioscientific topics are not as common in science curricula at these educational levels. In addition, as Chapter 6 showed, while learning support measures are most often organised similarly for all subjects, subject-specific learning support is specified in steering documents only in mathematics, and not in science.

To analyse relationships between the characteristics of mathematics and science education and low achievement levels, this section uses the method of path analysis (see, for example, Bryman and Cramer, 1990). Path analysis allows for the modelling of complex patterns of relations, including indirect relationships between explanatory and outcome variables. Thus, path analysis models build on the assumption that certain combinations of factors could produce better results than a single policy measure.

To account for differences in the organisation of instruction between mathematics and science, two path analysis models were constructed: one for each subject. These models aim to explain the differences in percentages of low achievers between primary and secondary education levels. In other words, they show which characteristics of mathematics and science education could explain differences in low-achievement rates among 15-year-olds, controlling for the percentages of low achievers in grade 4.

Figures 7.1 and 7.2 illustrate the two path analysis models exploring this complex relationship between characteristics of education systems and low-achievement rates in mathematics and science. The analysis found some common characteristics that can ensure that more students have basic knowledge in both mathematics and science.

Figure 7.1: Model 1 on low achievement in mathematics



Explanatory notes

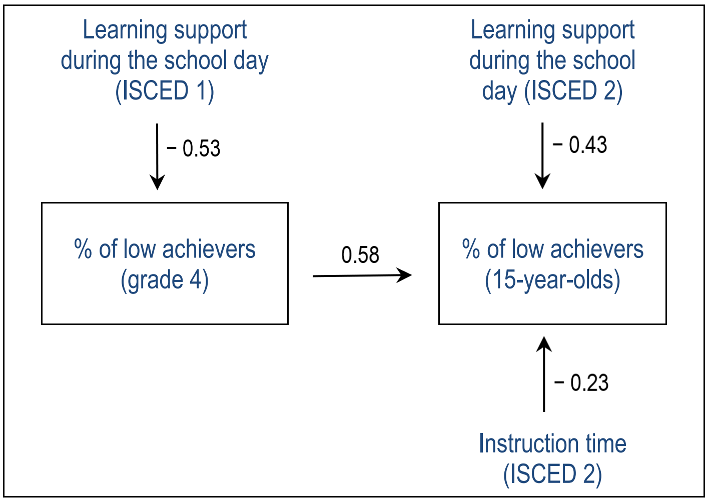
Parameter estimates are standardised and significant at the 5% level.

The R^2 values are 0.10 for the percentage of low achievers among grade 4 students and 0.79 for the percentage of low achievers among 15-year-olds. Fit indices for the model: chi-square = 3.491, degrees of freedom = 3, *p*-value = 0.32, comparative fit index = 0.990, Tucker–Lewis index = 0.977 and root mean square error of approximation = 0.066.

Due to the non-random sample, *p*-values should be interpreted with caution.

Source: Eurydice.

Figure 7.2: Model 2 on low achievement in science



Explanatory notes

Parameter estimates are standardised and significant at the 5% level.

The R^2 values are 0.28 for the percentage of low achievers among grade 4 students and 0.77 for the percentage of low achievers among 15-year-olds. Fit indices for the model: chi-square = 0.986, degrees of freedom = 3, *p*-value = 0.80, comparative fit index = 1.000, Tucker–Lewis index = 1.098 and root mean square error of approximation = 0.000.

Due to the non-random sample, *p*-values should be interpreted with caution.

Source: Eurydice.

Explaining the differences between low achievement rates across education levels

The models confirm the significant relationship between the percentage of low achievers at grade 4 and among 15-year-old students (i.e. the higher the share of underachieving students is in primary education, the higher it is in secondary education). This relationship holds for both mathematics and science. With the highest standardised regression coefficients in the path analysis models (0.65 in mathematics and 0.58 in science), low-achievement rates at primary level are the strongest predictors of the shares of underachieving students at secondary level.

Therefore, controlling for the percentages of low achievers in primary education allows for a better identification of measures that can contribute to the rate of low achievers specifically in secondary education. Two such characteristics of mathematics and science teaching are identified: (1) whether learning support provided to students with learning difficulties takes place during the formal school day (as opposed to only after formal the school day) and (2) how much time is dedicated to mathematics or science education at lower secondary level (per notional year). These factors can explain the differences between education levels in terms of the relative share of students who lack a basic understanding of mathematics or science. Education systems in which relatively more time is spent teaching mathematics or science and providing learning support during the formal school day have the potential to lower underachievement rates for 15-year-olds relative to their rates for primary education.

As Chapter 6 discussed, although the importance of learning support measures is widely accepted, there is little evidence on the relative effectiveness of the different ways of providing support to low-achieving students. Research has found positive effects on achievement levels of both within-class interventions (Montague, 2011; Moser Opitz et al., 2017) and after-school support (Ariyo and Adeleke, 2018; Laurer et al., 2006; Scheerens, 2014; Yin, 2020). However, research has not focused much on comparing the effectiveness of support organised during and after the school day, mostly due to the lack of reliable comparative research design in this area.

This report collected information on learning support measures as they are specified in top-level regulations, recommendations and guidelines. However, not all education systems have such top-level frameworks. Where local authorities or even schools are responsible for defining how learning support is provided, data on the actual support provided by the schools can be scarce. Nevertheless, the majority of education systems do provide definitions (with varying levels of detail) of support measures, including whether such support should be provided during the formal school day (i.e. during classes) or as a form of after-school support.

The present analysis therefore distinguished between education systems that organise learning support in mathematics and/or science during the formal school day and those that define learning support measures only as after-school activities. Education systems in which the top-level authority does not define support measures and in which there is no top-level information on when learning support takes place (251) are excluded from the analysis (considered missing). As there are more education systems that do not have a top-level framework for learning support in science than in mathematics, more education systems are regarded as missing in the analysis for science.

Concerning instruction time, as Chapter 3 explained, although research evidence points towards the positive effects of increased instruction time, most studies argue that instruction time alone cannot account for students' academic achievement. What happens during the lessons also matters: scholars investigating the relationships between instruction time and students' academic achievement emphasise the quality of teaching as a key factor in students' successful learning (Lavy, 2015; Meyer and Klaveren, 2013; Phelps et al., 2012; Prendergast and O'Meara, 2016).

Chapter 3 also showed that more instruction time is dedicated to mathematics at primary level than at lower secondary level in most education systems. In contrast, for science, data show that instruction time is greater at lower secondary level in nearly all education systems/tracks (252). In more than half of the education systems/tracks, the number of notional hours (253) per year in science at least doubles compared with primary education.

However, again some cases had to be excluded from the analysis due to high degrees of local or school autonomy. As Chapter 3 indicated, in some education systems, top-level education authorities set only a total number of teaching hours for a range of compulsory subjects within a given grade, and schools / local authorities have the autonomy to decide how much time to allocate to each subject. In addition, the number of hours dedicated to mathematics and/or science may also include the time to be spent on other subjects. The education systems concerned are excluded from the analysis (considered missing), together with systems in which instruction time has been considerably affected by school closures and distance learning (254). For education systems with multiple educational pathways/tracks at lower secondary level, the pathway/track with the smallest number of hours was taken into consideration.

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(251) In mathematics, these are Belgium (German-speaking Community), Denmark, Italy, Latvia, the Netherlands and Albania at both education levels, Belgium (French and Flemish Communities) at primary level and Norway at lower secondary level. In science, these are Belgium (German-speaking Community), Denmark, Italy, Latvia, Malta, the Netherlands, Austria, Albania and Switzerland at both levels, Belgium (French and Flemish Communities), Ireland and Greece at primary level and Norway at lower secondary level.

(252) Differentiated tracks are clearly distinct education pathways that students can follow during secondary education (see also the Glossary). Instruction time can differ between these tracks already at lower secondary level (see Chapter 3).

(253) Instruction time per notional year at a given education level corresponds to the total taught time in hours at that education level divided by the number of years of that education level.

(254) These education systems are as follows: Horizontal flexibility (see Chapter 3): Belgium (French Community at ISCED 1, German-speaking and Flemish Communities at both ISCED 1 and 2), Italy (ISCED 1), the Netherlands (ISCED 1 and 2) and Poland (ISCED 1). Time dedicated to mathematics includes taught time dedicated to other subjects: France (ISCED 1) and Italy (ISCED 2). Time dedicated to science includes taught time dedicated to other subjects: France (ISCED 2) and Italy (ISCED 2). Science is a compulsory flexible subject chosen by schools: Ireland (ISCED 2). Large impact of the COVID-19 pandemic on instruction time: North Macedonia (ISCED 1 and 2). The analysis does not include instruction time in science at primary level, as science education includes other knowledge areas in too many cases.

In accordance with the research literature, differences in instruction time alone cannot explain differences in low-achievement rates at either educational level ([255]). However, when controlling for the pre-existing level of low achievement and the type of learning support students receive, the conclusions are different: increasing the time spent on learning mathematics or science in lower secondary education together with support measures provided during the school day to students with learning difficulties has the potential to lower underachievement rates.

Explaining low achievement rates among grade 4 students

When it comes to explaining low achievement rates among grade 4 students, the models depicted on figures 7.1 and 7.2 highlight the role of two different factors in mathematics and science: (1) in mathematics, whether teachers with a specialisation in supporting low-achieving students ('remedial teachers') provide learning support, and (2) in science, whether learning support for students with learning difficulties is provided during the formal school day.

The involvement of different professionals in helping students with learning difficulties, as envisaged by top-level regulations, guidelines or recommendations, is another characteristic of learning support provision (see Chapter 6). Several studies emphasise the importance of adequate human resources and teacher training to ensure effective support within the classroom (Montague, 2011; Moser Opitz et al., 2017). Motiejunaite, Noorani and Monseur (2014) highlight the significant role of teachers specialised in supporting low-achieving students in reading literacy.

Whereas class teachers are intended to participate in learning support provision in all education systems with regulations or recommendations in this area, the involvement of remedial teachers is less commonly required (see Chapter 6, Figure 6.5). Nevertheless, according to Model 1, education systems in which remedial teachers are intended to provide learning support have, on average, lower percentages of low achievers. Thus, including such professionals in learning support provision in mathematics could increase its effectiveness. This relationship is not significant in science.

In science, according to Model 2, learning support provision during the formal school day is associated with lower percentages of low-achievers among fourth grade students. Thus, in this case, similar factors play a role in both primary and lower secondary education. The relationship shown in Model 2 could also apply to mathematics.

7.2. Other factors associated with lower percentages of low achievers in mathematics or science

The above models provide one explanation of the differences in low-achievement rates between primary and secondary education, focusing on the relationship between underachievement rates at primary and secondary levels. Although these models have a relatively high explanatory value, they can include only a limited number of explanatory factors due to the small number of education systems. However, other factors not included in the models may also be associated with higher percentages of students with at least a basic knowledge in mathematics or science. These characteristics of mathematics and science education are discussed in the following subsections. These subsections rely on bivariate analysis.

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(255) Spearman's rank correlation coefficients between the number of notional hours dedicated to mathematics in primary education and the percentage of low achievers among fourth grade students, and between the number of notional hours in lower secondary education in mathematics/science and the percentage of low achievers among 15-year-old students in mathematics/science are all negative but not statistically significant.

National tests in mathematics in primary education

National tests and certified examinations are generally regarded as important accountability tools in education systems (Allmendinger, 1989; Hooge et al., 2012; Horn, 2009). School accountability broadly refers to the practice of holding schools responsible for the results of their students, and national tests can serve as tools to monitor the performance of students, schools and the education system as a whole.

Previous analyses could not always draw firm conclusions about the impact of accountability policies on student performance due to the diversity of policy goals, designs and implementation methods, in addition to the complex interrelationship between accountability and other policies (Brill et al., 2018; Fahey and Köster, 2019; Faubert, 2009; Figlio and Loeb, 2011; Skrla and Scheurich, 2004). Chapter 4 discussed some potential adverse effects of national tests (e.g. lower student performance due to increased anxiety), especially concerning low achievers. Nevertheless, some research points towards the positive effects of national tests on average student performance, especially for low- and medium-performing countries (Bergbauer, Hanushek and Wößmann, 2018).

When examining data collected for this report, the analysis of 2018 PISA data shows that education systems organising certified examinations or national tests in mathematics at primary level tend to have lower percentages of low achievers among 15-year-olds. This remains true regardless of whether national tests are compulsory for all students or are sample-based, and whether or not they have the explicit aim of identifying individual learning needs. Having any kind of national examination or test in mathematics at primary level tends to go hand in hand with lower percentages of underachieving students in mathematics. The 10 education systems without certified examinations or national tests in mathematics have, on average, higher percentages of low-achieving 15-year-old students: 31.7% on average across these education systems. In comparison, the average low-achievement rate is 22.7% in the 28 education systems that organise certified examinations or national tests in mathematics. The difference between the two groups is statistically significant ([256]). However, this relationship is not present for certified examinations or national tests at lower secondary level.

This finding certainly does not mean that certified examinations or national tests guarantee higher achievement levels; neither does it suggest that examinations or tests are necessary for reducing the percentage of low achievers. There are education systems with relatively low percentages of low achievers that do not organise national tests in mathematics at primary level (e.g. Poland and Switzerland; see Chapter 1, Figure 1.2, for the percentages of low achievers, and Chapter 4, Figure 4.6, for information on certified examinations and national tests), and some education systems (most notably Bulgaria and Romania) have relatively high percentages of low achievers despite having such national tests. Nevertheless, there are important differences between the two groups in terms of the average percentage of low achievers.

Including socioscientific issues in science teaching

Chapter 5 of this report discussed certain aspects of mathematics and science curricula that relate to students' lives and give context for abstract concepts. Real-life applications of mathematics were included in the curricula of almost all education systems and thus provided no variation for exploring the relationship with low achievement. During the first eight grades of school, the curricula of every European education system included in this analysis either make some general statements about

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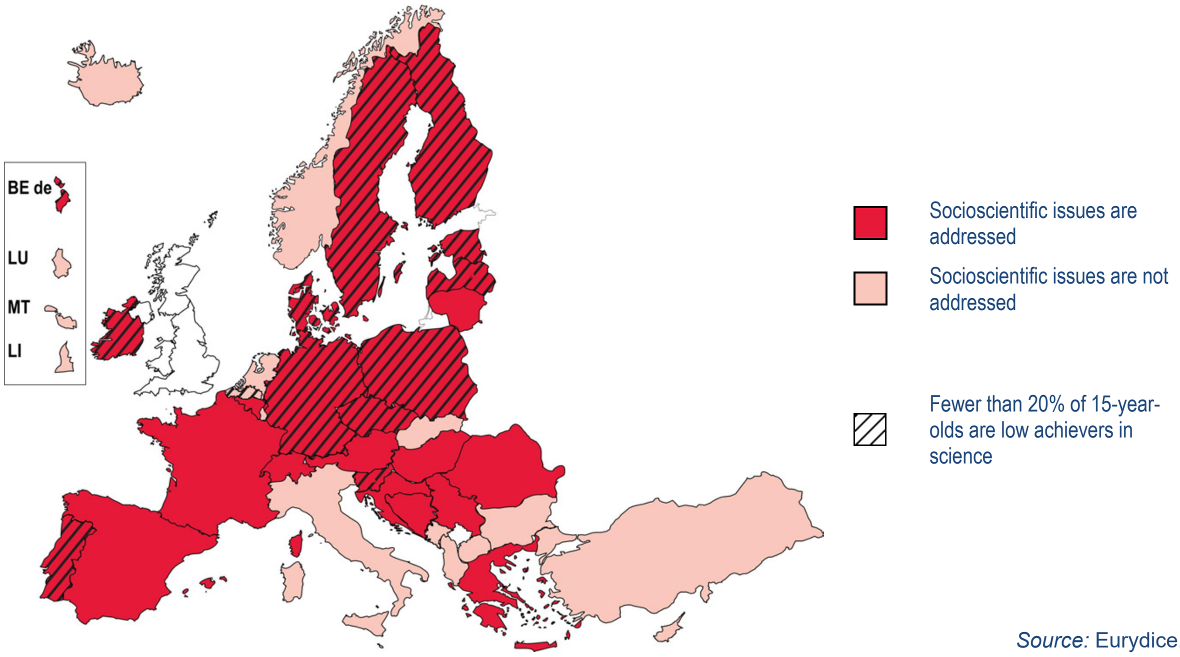
([256]) The difference between the two averages is 8.97 percentage points, with a standard error of 0.63. This difference is significant at the 5% level (*t*-value: 12.93).

mathematics in functional contexts or provide concrete examples of how mathematical concepts should be applied in practice, through handling money, examples from architecture, cooking or do-it-yourself activities (see Annex II, Figure 5.1A). Similarly, learning for environmental sustainability forms a compulsory part of science curricula in all of the European education systems by the end of grade 8 (see Chapter 5, Figure 5.6) and thus was not suitable for explaining country-level variations in student achievement results.

However, emphasis on the philosophical, historical and societal aspects of science was not as evenly spread across Europe; therefore, it was applicable for the statistical analysis. When comparing the proportions of low achievers in science in countries that include certain aspects of contextualisation in their curricula and those that do not, certain aspects proved significant. Those education systems with curricula that mention socioscientific issues seem to have a higher proportion of 15-year-old students who achieve basic scientific literacy. The analysis of 2018 PISA data shows that the average proportion of low achievers in the 24 education systems that include some aspects of science and ethics in their curricula was 22.1%. The average share was 27.1% in the 14 education systems that did not refer to any of the analysed socioscientific questions in their national curricula. The difference between the two proportions is statistically significant ([257]). Figure 7.3 visually illustrates the relationship. Almost all education systems in which fewer than 20% of students are low achievers in science address socioscientific questions in their curricula by the end of grade 8. The only exception is Belgium (Flemish Community), where schools have autonomy over whether and to what extent to include such questions.

Figure 7.3: Inclusion of science and ethics issues in curricula during the grades 1-8, 2020/2021



Source: Eurydice.

Explanatory notes

The category 'socioscientific issues are addressed' refers to those countries that include in curricula any of the aspects mentioned in Annex II, Figure 5.4A, at grades 1–4 and/or grades 5–8.
The percentage of low achievers is based on OECD, 2018 PISA database. For the estimates of these percentages, see Chapter 1, Figure 1.2.

([257]) The difference between the two proportions is 5.0 percentage points, with a standard error of 0.71. This difference is significant at the 5% level (*t*-value: 7.15).

The results highlight the importance of including societal issues and the ethical consequences of scientific developments in lower secondary education. When students are invited to explore moral dilemmas in the field of biotechnology, explain their own opinions on animal testing or name risks to modern civilisation posed by technological progress, general levels of achievement improve. This supports the notion that critical analysis of the social effects of scientific developments forms an important part of scientific literacy (Pleasants et al., 2019; Sadler, 2011; Zeidler, 2015).

Interestingly, the inclusion in curricula of certain factual aspects of history of science did not yield a significant relationship with low achievement levels. This is in line with the studies that highlight the ‘affective’ rather than ‘cognitive’ effect of history-of-science themes. In other words, historical analysis of scientific events relates to students’ interest in and understanding of the nature of science rather than to achievement results (Abd-El-Khalick and Lederman, 2000, 2010; Wolfensberger and Canella, 2015). Moreover, such findings might be due to the factual nature of the curriculum analysis that was conducted. Merely positioning scientific discoveries in time or learning some facts about lives of scientists is not sufficient to raise achievement levels. To improve achievement, history of science should be treated in a way that illuminates particular characteristics of science rather than history (Abd-El-Khalick and Lederman, 2010). Proper integration of historical investigations when teaching modern science concepts is challenging (Henke and Höttecke, 2015). More research is needed to determine the extent to which the reflective aspects of history of science are included in European curricula. However, the analysis presented in this report suggests that reflection of ethics in scientific developments is an essential part of scientific thinking. The science curricula of lower secondary education may benefit from the inclusion of socioscientific questions.

Conclusion

When so many students in Europe lack basic literacy in mathematics and science, it is crucial to know what policies have the potential to influence student achievement. This chapter highlighted the top-level regulations shared by education systems with lower levels of low achievers in mathematics and science. The analysis put together qualitative data on regulations and measures and student achievement results gathered by comparative international surveys (TIMSS and PISA).

The results highlight the importance of timely and competent learning support for students who are falling behind. From the very first grades of school, every student should have the opportunity to receive additional help when needed. The models revealed the importance of this support being provided during school hours, and preferably by teachers who have specific training in remedial pedagogies.

In addition to professional learning support at every school grade, students can also benefit from more instruction time in mathematics or science in general. When controlling for low-achievement rates in early years, the analysis shows that the number of teaching hours in higher grades dedicated to these subjects matters. In addition to time, the learning content also makes a difference: in science, including socioscientific questions in curricula can raise students' motivation and thus can play a role in increasing the share of students achieving basic scientific literacy. Furthermore, national tests can be useful accountability tools contributing to high-quality education. Such standardised tests – especially in early grades – may also help to identify students who are falling behind and thus enable appropriate and timely support.

The analysis was based on top-level information: laws, regulations, recommendations and guidelines issued by the highest level of authority in education systems. This has both advantages and disadvantages. On the one hand, relationships between student achievement and top-level policy approaches could be explored, providing crucial insights for policymakers. On the other hand, top-level information is sometimes incomplete due to high degrees of local or school autonomy. Therefore, the availability of more information on how learning support measures are organised in schools could further enrich such enquiry. Moreover, there is a need for more comparative research to determine the most effective methods of organising learning support in schools.