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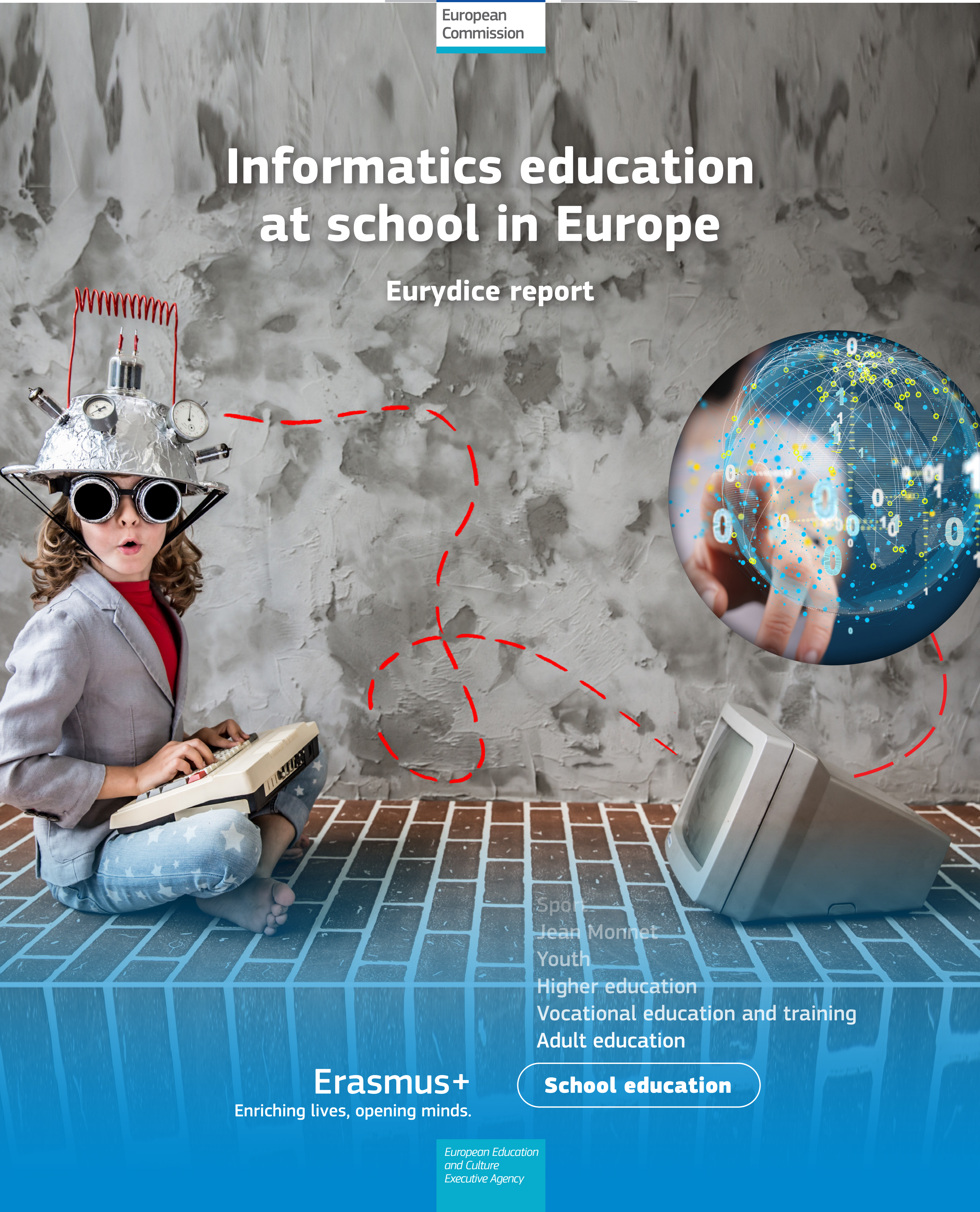

Informatics education at school in Europe

Eurydice report

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FOREWORD

The space digital technologies take up in our daily lives grows bigger every day. From personal phones to remote teaching, listening to music or making a bank transfer. They shape our societies and economies and are in a constant and fast evolution.

We often make the wrong assumption that young people are naturally digitally savvy and computer literate. Of course, this is not always the case, particularly for those with less opportunities, coming from a disadvantaged background. If we want our youth to become active, responsible and engaged citizens, it is our duty to equip them with the necessary skills. Not only for their own personal developments, but also to secure their place on the labour market.

And it all starts in the classroom. This is where the interest of girls and boys is triggered, this is where their motivation grows, this is where we can ensure they receive proper training and ultimately develop their skills.

To this end, to give us the means to successfully complete the digital transition, the European Commission has, among others, launched the Digital Education Action Plan (2021-2027), which is meant to support the education and training systems of Member States to adapt to the digital age, but also to make high quality digital education more accessible and more inclusive.

This new Eurydice report provides insights into how informatics can be integrated as a scientific discipline in school education in Europe. It analyses the status of the discipline as a separate subject or integrated into other subjects, the most common areas covered by the national curricula, and teachers' qualifications.

I am confident that this report will be of great support to education policymakers across Europe. I also believe that it will be a helpful and inspiring source of information for all stakeholders across the European Union working towards achieving the EU digital skills targets and fostering the digital transformation of our education and training systems.

Mariya Gabriel

Commissioner responsible for
Innovation, Research, Culture, Education and Youth

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CODES AND ABBREVIATIONS

Country codes

EU	European Union				**EEA and candidate countries**
BE	Belgium	**CY**	Cyprus	**AL**	Albania
BE fr	Belgium – French Community	**LV**	Latvia	**BA**	Bosnia and Herzegovina
BE de	Belgium – German-speaking Community	**LT**	Lithuania	**CH**	Switzerland
BE nl	Belgium – Flemish Community	**LU**	Luxembourg	**IS**	Iceland
BG	Bulgaria	**HU**	Hungary	**LI**	Liechtenstein
CZ	Czechia	**MT**	Malta	**ME**	Montenegro
DK	Denmark	**NL**	Netherlands	**MK**	North Macedonia
DE	Germany	**AT**	Austria	**NO**	Norway
EE	Estonia	**PL**	Poland	**RS**	Serbia
IE	Ireland	**PT**	Portugal	**TR**	Turkey
EL	Greece	**RO**	Romania		
ES	Spain	**SI**	Slovenia		
FR	France	**SK**	Slovakia		
HR	Croatia	**FI**	Finland		
IT	Italy	**SE**	Sweden		

Statistics (tables an graphs)

(:)	Data not available
(–) or –	Not applicable or zero

Abbreviations and acronyms

International conventions

CPD	Continuing Professional Development
ECTS	European Credit Transfer and Accumulation System
HEI	Higher Education Institutions
ICT	Information and Communication Technologies
ISCED	International Standard Classification of Education (see the glossary)
IT	Information Technologies
ITE	Initial Teacher Education
PC	Personal Computer
STEM	Science, Technology, Engineering and Mathematics

MAIN FINDINGS

This Eurydice report provides a comprehensive comparative analysis of informatics education, as a distinct discipline, in primary and general secondary education in 2020/2021 in 39 education systems. Informatics is still a relatively new discipline in school education, and the content, name and focus of the related school subjects vary across European countries. The analysis of existing competence and curricular frameworks with associated learning outcomes contributes to building a shared understanding and comparability. From this analysis, 10 core areas of informatics as a scientific discipline have been identified: data and information, algorithms, programming, computing systems, networks, people–system interface, design and development, modelling and simulation, awareness and empowerment, and safety and security (see Annex 2). Informatics is considered a distinct discipline when the learning outcomes for these areas are included in the curriculum in a separate informatics subject (compulsory or optional) or integrated into another subject.

Starting age

Students start learning informatics from the 1st grade of primary education in almost one third of the education systems, but informatics is only a separate, compulsory subject in Greece, Serbia and some cantons in Bosnia and Herzegovina (see Figure 1.1). In this grade, informatics is usually taught as part of another compulsory subject or schools have the authority to decide on the teaching approach (as is the case in Estonia, Latvia and Poland).

More than one third of the education systems start teaching informatics from grades 3 to 5, generally as a separate, compulsory subject or integrated into other compulsory subjects (see Figures 1.1 and 1.2).

In nearly a third of the education systems, informatics is introduced at a later stage, usually as an optional subject or integrated into other subjects (see Figures 1.2 and 1.3).

Informatics in primary and general lower secondary education

In primary education, informatics is taught as a distinct discipline in 23 education systems. Around half of them provide for a separate informatics subject that is compulsory for all students (although often not in the first grades). More than a quarter of these education systems teach informatics mainly as part of other compulsory subjects. Informatics is an optional subject in only Croatia and Slovenia at this education level. The curricular approach to teaching informatics is decided by schools in Estonia (Chapter 1, Section 1.2).

In general lower secondary education, informatics is taught as a distinct discipline in 35 education systems. Around half of them provide for a separate informatics subject that is compulsory for all students (usually in all grades). Approximately a quarter of these education systems teach informatics mainly as part of other compulsory subjects. Informatics is an optional subject in only Ireland, Albania and some German *Länder*. In the three Communities of Belgium, Estonia and Slovenia, schools decide whether to provide the subject (Chapter 1, Section 1.3).

Informatics in general upper secondary education

In general upper secondary education, almost all the countries teach informatics as a distinct discipline, and the vast majority include one or more informatics subjects (compulsory and/or optional) in at least one grade. In contrast with lower education levels, it is unusual to teach informatics only as part of other subjects (although some countries combine both approaches) (Chapter 1, Section 4.1).

Half of the education systems provide for informatics subjects that are compulsory for all students in one or more grades at upper secondary level. In Romania, Bosnia and Herzegovina and Serbia, informatics is compulsory for all students in all four grades, and in Bulgaria and Poland it is compulsory for all students in three grades. The school authorities in Czechia and Slovakia and the cantons in Switzerland decide on which grades are taught the subject, which is compulsory for all students. In 10 education systems, informatics is compulsory only in the 1st and/or 2nd grades and optional or compulsory for some students in the other grades (Chapter 1, Section 4.1).

In around one third of the education systems, informatics is only an optional subject or is only offered in certain programmes or in some schools. Therefore, some students do not receive any instruction in informatics at general upper secondary level (Chapter 1, Section 4.1).

Czechia, Greece, Romania, Bosnia and Herzegovina and Serbia provide for the largest number of teaching hours in the whole of general upper secondary education for informatics subjects that are compulsory for all students.

Generally, more hours of instruction are allocated to informatics subjects that are optional or compulsory only in certain programmes or specialisations than to informatics subjects compulsory for all.

General patterns across countries

Some countries teach informatics predominantly as a separate, compulsory subject from primary to upper secondary education. This is the case in Bulgaria, Greece, Latvia, Hungary, Poland, Slovakia, Liechtenstein, Serbia, some cantons in Bosnia and Herzegovina and the German-speaking cantons in Switzerland. Romania applies the same approach but only at secondary level.

In a second group of countries, including Croatia, Montenegro and North Macedonia, informatics is taught as a separate subject throughout school education but in some grades it is not compulsory. Malta applies the same approach but only at secondary level.

In a third group of countries, informatics is integrated into other subjects from primary education and introduced as a separate subject (compulsory or optional) in secondary education. For instance, informatics is taught as part of other subjects in primary education in Cyprus, in primary and lower secondary education in Czechia and Norway, and in primary and general lower and upper secondary education in France and Sweden. In addition, informatics subjects are offered at upper secondary level in all of them, and at lower secondary level in Cyprus and Norway. Similarly, informatics is initially taught as part of other subjects at lower secondary level and later introduced as a separate subject in Spain, Italy, Luxembourg, Austria and Portugal. Informatics is integrated into ICT in Turkey and, at upper secondary level, in Albania.

In a few countries, not all students receive instruction in informatics in school, because schools have no obligation to provide the subject and/or students can choose whether or not they take it. This is the case in Belgium, Estonia, Ireland, the Netherlands and most German *Länder*. In Iceland, informatics is not taught as a distinct discipline.

Curricular reforms under development or implementation

More than two thirds of the education systems are implementing or developing reforms that envisage the introduction of an informatics subject or the provision or updating of related learning outcomes (Chapter 1, Section 1.5). The recovery and resilience facility has provided some of them with additional funding.

The vast majority of the reforms under implementation introduce a new informatics subject into the curriculum of primary (Lithuania and Serbia), lower secondary (Bulgaria and Germany), primary and lower secondary (Czechia and some cantons in Bosnia and Herzegovina and in Switzerland), general secondary (Ireland, Spain and Malta), general upper secondary (North Macedonia) or the three education levels (Estonia, Latvia and Hungary). In the German-speaking and Flemish Communities of Belgium and Austria, reforms have introduced a new key competence relating to informatics into the curriculum, giving schools the prerogative to decide on the teaching approach.

Almost a dozen education systems are planning the development of curricular reforms on informatics education. Pilot projects are taking place in some schools in Denmark, Greece and Luxembourg before further curricular reforms are implemented.

Comprehensiveness of learning outcomes across education levels

The aggregated data of European education systems clearly shows that the number of education systems defining learning outcomes relating to informatics increases from primary to upper secondary education. Moreover, a wider variety of areas is covered as pupils progress through the education levels (see Figure 2.2).

In primary education, the most common areas covered in school curricula across Europe are algorithms, programming, and safety and security. Fewer than a third of the European education systems explicitly include in their curricula learning outcomes relating to data and information, networks, and awareness and empowerment. Only a few include learning outcomes relating to computing systems, modelling and simulation, people–system interface, and design and development (see Figure 2.3).

In general, the teaching of informatics becomes more common from lower secondary education, as is clearly reflected by the significantly higher number of learning outcomes related to the different areas of informatics. At this education level, the majority of European education systems explicitly address the areas of programming, algorithms, safety and security, networks, data and information, awareness and empowerment, and computing systems. However, for the modelling and simulation, people–system interface, and design and development areas, this is the case only in fewer than a quarter of European education systems (see Figure 2.4).

In upper secondary education, more than 30 European education systems explicitly include the areas of algorithms, programming, and safety and security. A majority of education systems also address networks, data and information, awareness and empowerment, and computing systems. The three remaining areas – design and development, modelling and simulation, and people–system interface – are included in more than a dozen education systems, which is more than at lower levels of education (see Figures 2.3 and 2.4). Unlike in primary and lower secondary education, where learning outcomes tend to be compulsory for all students, at this education level often only students choosing the optional informatics subjects pursue those learning outcomes. Still, more than a dozen countries cover a comprehensive range of areas in compulsory informatics subjects (see Figure 2.5).

Main areas of informatics education in terms of learning outcomes

Learning outcomes related to algorithms and programming are the most widespread. More than half of the countries in Europe already have learning outcomes relating to **algorithms** in primary education. Nearly half of the countries explicitly cover this area at all three education levels. Algorithms is an area that is regularly integrated into mathematics teaching.

The area of **programming** is strongly linked to the area of algorithms and in some curricula these are treated as one area. In general, school curricula do not mention specific programming languages. Instead, they focus on basic principles, and the schools or the individual teachers choose the programming language. Learning objectives linked to programming, such as for the area of algorithms, are already quite common in European school curricula. In nearly half of the countries, these are included from primary education to upper secondary education.

Given its relevance to digital competence as a key competence, learning outcomes relating to **safety and security** are rather common in European school curricula. However, especially in secondary education, their content can go beyond the safe use of technology to cover the technical means to prevent and mitigate security threats. Nearly half of the countries already address this area in primary education, while three quarters do so in secondary education. In more than one third of the countries, curricula at all three education levels include learning outcomes relating to safety and security.

Nearly a dozen countries already address the area of **networks** in primary education and have related learning outcomes at all three education levels. In upper secondary education, three quarters of European education systems include explicit learning outcomes relating to this area in their curricula. Similarly, the majority of education systems address **data and information** at secondary level, but fewer than a dozen education systems address this area from primary level to upper secondary level.

The area of **awareness and empowerment** is widely addressed in school curricula related to informatics. While a quarter of European countries already have explicit learning outcomes relating to this area in primary education, more than half of the countries address this in lower and upper secondary education. Therefore, the present analysis of European school curricula confirms that an awareness of the importance of the social impact elements in informatics education is emerging.

Computing systems is an area that is rather rarely addressed from primary education, and only few countries, namely Greece, Switzerland, Liechtenstein, Montenegro, and North Macedonia, have related learning outcomes at all three education levels. However, more than half of the countries explicitly include this area in their curricula related to informatics from lower secondary education.

Modelling and simulation is an area that informatics school curricula do not often address. Only 5 countries (Bulgaria, Czechia, Greece, France and Slovenia) have explicit learning outcomes for this area in primary education, and only 3 of these address this at all three education levels (Czechia, Greece and France). Still, more than a third of European education systems include this area in upper secondary education.

Design and development is yet another area that does not seem to be very explicitly included in school curricula. Only 3 countries have related learning outcomes at all three education levels (Greece, Poland and Turkey). Another 3 countries address this area in both lower and upper secondary education (Ireland, France and Latvia). This area is mostly present in upper secondary education, where it is included in more than a third of European countries.

Finally, like design and development, the area of **people–system interface** is less developed in school curricula in terms of learning outcomes. Only Greece, Croatia and Hungary already include explicit learning outcomes from primary education, and only slightly more than a dozen countries have related learning outcomes in upper secondary education.

Increasing girls' engagement in informatics

A way to increase the share of women studying informatics and with careers in ICT could be to start teaching informatics as early as possible in school education. The latest Eurostat data shows that in 2021 only 19.1% of employed ICT specialists were women (ESTAT isoc_sks_itsps). According to statistics reported in the Informatics Europe Higher Education Data Portal ([1]) from a sample of

([1]) https://www.informatics-europe.org/data/higher-education/

18 European countries ([2]), the percentage of female students enrolled in the first year of informatics bachelor degree programmes was only 18.4% in the 2019/2020 academic year.

This Eurydice report shows that a few education systems currently have top-level initiatives to engage girls in informatics education at school. These relate, for example, to addressing gender stereotypes in educational resources for teacher training (French Community of Belgium), to developing specific programmes to promote the interest of girls in informatics-related studies (Spain), to providing students with academic and career guidance (Spain, France and Portugal), to promoting laboratories and competitions for female students (Italy), and to organising trial studies for women in informatics at universities (Switzerland).

Professional profiles of teachers teaching informatics

In Europe, informatics curricula can be provided by teachers qualified in informatics, teachers specialising in other school disciplines or generalist teachers. The profile of the teachers involved in the education process usually depends on the education level at which they teach and on the curricular approach to teaching the discipline.

At the level of primary education, generalist teachers are usually responsible for teaching informatics. This confirms the general trend in Europe that generalist teachers hold responsibility for providing the entire or almost entire curriculum in primary education. In some education systems, mainly in the eastern and south-eastern parts of Europe (see Figure 3.1), specialist informatics teachers or teachers specialised in other school disciplines can also teach informatics. This is usually the case in countries where informatics is taught as a separate subject. However, in primary schools, education systems rarely require teachers to have a qualification in informatics. This is the case only in Greece, Montenegro and Turkey.

In both lower and upper general secondary education, all education systems require informatics to be taught by specialist informatics teachers or teachers qualified in other subjects taught in secondary schools (see Figures 3.2 and 3.3). This is possibly due to the greater complexity of informatics concepts, methods, knowledge and learning outcomes at this education level.

When comparing the types of teachers responsible for teaching informatics at lower and upper secondary levels for different curricular approaches, it can be observed that, in all the education systems where informatics is a separate subject, specialist informatics teachers are responsible for teaching it.

In only a few education systems, there are no specialist informatics teachers in secondary schools (see Figures 3.2 and 3.3). This happens mainly when informatics content is integrated into other school subjects.

In general secondary education, teachers with specialisations other than informatics are largely involved in teaching this discipline. They are usually qualified in mathematics, sciences, engineering, technologies, natural sciences or economics (see Annex 3), and they tend to teach informatics when its content is integrated into the school subjects they specialise in.

In some countries, other specialist teachers can also teach informatics as a separate subject but only if they have knowledge in this field. For example, in Estonia, Romania, Bosnia and Herzegovina, teachers who had a minor specialisation in informatics during their initial training are allowed to teach it, while to teach informatics in Bulgaria, Germany, Czechia, Austria, Switzerland and Serbia,

([2]) Austria, Bulgaria, Czechia, Estonia, Finland, France, Germany, Ireland, Italy, Latvia, the Netherlands, Norway, Portugal, Romania, Spain, Switzerland, Turkey and the United Kingdom.

secondary school teachers need to extend their qualification by completing mandatory additional training in it.

The involvement of generalist teachers in teaching informatics at lower secondary level is rather exceptional. In Hungary and Serbia, for example, they can teach it only in the absence of specialist teachers and only if they have specialised in informatics during their training.

Training of specialist informatics teachers

To prepare specialist informatics teachers for their future role and responsibilities, all education systems at all levels of education have in place at least one professional development scheme. In almost all education systems, specialist informatics teachers can obtain their qualification through mainstream initial teacher education (ITE).

Alongside ITE, many education systems have introduced alternative and/or retraining schemes (see Figures 3.4–3.6). These expand the pool of informatics teachers by equipping specialists in informatics-related fields with pedagogical and didactic skills or by retraining teachers qualified in other subjects (e.g. teachers of mathematics, physics, engineering or natural sciences).

In around one third of the education systems, however, the only way to qualify as a specialist informatics teacher is to complete mainstream ITE (see Figures 3.4–3.6). This is mainly the case in the countries that traditionally do not offer alternative pathways to a teaching qualification (European Commission / EACEA / Eurydice, 2018, p. 37).

Support measures for teachers

The availability of appropriate continuous teacher training and various teaching materials are the necessary conditions for good-quality teaching and learning. Systematic and continuous support helps informatics teachers to do their job effectively and stay motivated.

Almost all education systems in Europe give in-service teachers the opportunity to undertake training on a variety of subjects related to informatics, usually as part of the regular continuing professional development (CPD). Moreover, Germany, Czechia, Estonia, Ireland, Croatia, Cyprus, Latvia, Lithuania, Luxembourg and Malta, have developed ad hoc training as part of the CPD of teachers to accompany the reforms introducing or updating the informatics curriculum. Many education systems have also developed a wide range of teaching materials for informatics teachers (see Figure 3.7).

Many education systems implementing or developing curricular reforms, for example introducing a new subject or upgrading content and/or learning outcomes, include measures for teachers' professional development and other support measures (Chapter 3, Section 3.4).

Most education systems that are reforming their informatics curricula organise teacher training on the content of the informatics subject and teaching methods. Training is provided as a part of regular CPD, ad hoc courses, webinars, workshops or collective seminars.

There are ongoing reforms of ITE in Czechia and Estonia. While Czechia has been updating its ITE curricula to prepare prospective teachers to provide the new informatics curricula, Estonia is focusing on making structural changes to ITE.

To accompany curricular reforms, Czechia, Estonia, Ireland and Croatia have implemented a comprehensive set of support measures. For example, in addition to teacher training and pedagogical resources, Czechia and Ireland have set up specific professional networks and platforms to facilitate collaboration and exchange of information and best practices between teachers.

INTRODUCTION

Over the past few decades, the rapid digitalisation of our daily lives has brought digital skills to the forefront of European and national education policies. The COVID-19 crisis has further emphasised the need for policy actions in this area and has certainly been a turning point for digital education (European Commission, 2021). Moreover, this crisis is having an impact on the future demand for digital skills among EU citizens, especially learners and the labour force. The digital economy will play a key role in Europe's recovery from the pandemic in the years to come but will require digitally competent citizens and workers. This needs to be addressed, starting with the initial stages of education (European Commission, 2020a).

Digital competences have been among the key competences for lifelong learning since the first European recommendation on that matter in 2006 ([3]). The digital education action plan 2021–2027 (European Commission, 2020b), the European Education Area communication (European Commission, 2020c) and the updated skills agenda (European Commission, 2020d) aim to reinforce cooperation among the Member States in the area of education and training and contribute to the overarching European Commission objectives of a digital and green Europe. Moreover, the EU digital decade presented in March 2021 set the targets of having 20 million ICT specialists (and gender convergence) and minimum 80% of the population with basic digital skills ([4]). These initiatives consider the initial lessons learned from the COVID-19 crisis, especially in relation to 'the digital transformation of education and training systems' ([5]).

The 2021–2027 digital education action plan sets two strategic priorities: promoting the development of a European digital education ecosystem and enhancing digital competences (knowledge, skills and attitudes) of all learners for the digital transformation. The action plan highlights the essential role of informatics education in schools in ensuring that young people 'gain a sound understanding of the digital world. Introducing pupils to computing [also known as informatics or computer science in many countries] from an early age … can help develop skills in problem solving, creativity and collaboration. It can also foster interest in STEM [science, technology, engineering and mathematics] related studies and future careers while tackling gender stereotypes. Actions to promote high quality and inclusive computing education can also impact positively on the number of girls pursuing IT-related studies in higher education and, further on, working in the digital sector or digital jobs in other economic sectors. A solid and scientific understanding of the digital world can build on, and complement, broader digital skills development. It can also help young people to see the potential and limitations of computing for solving societal challenges' (European Commission, 2020b, p. 13).

Some European countries have a long-standing history of teaching informatics at school; for example, in Poland it has been taught since the 1990s (Sysło and Kwiatkowska, 2015; Sysło, 2018) and in Slovakia it has been taught since the early 2000s (Kabátová, Kalaš and Tomcsányiová, 2016).

Many other countries have introduced informatics more recently, especially from primary education. In the United Kingdom, for example, the Royal Society released a report in 2012 advocating educating all students in informatics from primary school. The report pointed out that a better understanding of the digital world would enhance young people's participation in the public debate around digital technologies and contribute to the prosperity of the whole nation (The Royal Society, 2012). In 2014/2015, schools in the United Kingdom started introducing the computing curriculum, and in 2018 the government created the National Centre for Computing Education to improve the teaching of

([3]) European Parliament and Council of the European Union, Recommendation of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning, OJ L 394, 30.12.2006, pp. 10–18.

([4]) Europe's Digital Decade: digital targets for 2030 | European Commission (europa.eu)

([5]) Council of the European Union, Council conclusions of 16 June 2020 on countering the COVID-19 crisis in education and training, OJ C 212, 26.6.2020.

computing and drive participation in computer science, founded with GBP 84 million ([6]). Similarly, in France the Académie des Sciences*,* in its 2013 report on the role of informatics in school education, argued in favour of teaching informatics in schools from primary education (Académie des Sciences, 2013). The report emphasised the importance of preparing all citizens for a digital future, enabling their active participation, through informatics education. It also noted that an understanding of the scientific principles of informatics would better prepare them for any future profession. Subsequently, principles of informatics were included in the curricula of primary and lower secondary schools in 2015, and were part of the reform of the *Lycée* in 2018 ([7]).

Similar trends and developments have taken place worldwide. In the United States, in 2015 the Congress passed the 'every student succeeds' act, which included computer science among the 'well-rounded' educational subjects that should be taught in schools ([8]). In 2016, Israel introduced informatics from grade 4 in primary school up to the end of secondary school (Armoni and Gal-Ezer, 2014a). In addition, Japan reformed its curriculum relating to informatics education, starting with primary school in 2020, followed by middle school in 2021 and upper secondary in 2022 (Oda, Noborimoto and Horita, 2019).

In 2017, the Committee on European Computing Education confirmed a growing awareness across Europe of the importance of offering young students the opportunity to obtain a sound education in informatics. However, it also showed that in several countries/regions in Europe students could complete secondary school without ever being exposed to the basic principles of the discipline.

Terms and methodology

Against this background, this report provides a comprehensive comparative analysis of informatics education in primary and general secondary education (International Standard Classification of Education (ISCED 2011) 1, 24 and 34) in Europe. It complements the 2019 Eurydice report on digital education (European Commission / EACEA / Eurydice, 2019).

Informatics is a scientific discipline, in the same way as mathematics and physics, with a body of knowledge, a set of rigorous techniques and methods, a way of thinking and a stable set of concepts, independent of specific technologies. It can be described as the science underpinning the development of the digital world, and covers the foundations of computational structures, processes, artefacts and systems, and their software designs, applications and impact on society (Committee on European Computing Education, 2017; Caspersen et al., 2018). Informatics comprises areas such as algorithms, data structures, programming, systems architecture, communication and coordination, and design and problem-solving, among others (The Royal Society, 2012).

In Europe, different names are used to refer to the discipline, such as computer science, computing, informatics and information technology. In countries such as France, Italy, Spain, and Germany, the national words for informatics (i.e. *informatique*, *informatica*, *informática*, *Informatik*) denote both the scientific part of the discipline, which corresponds to the term 'computer science' in the United Kingdom and the United States, and the technological part of the discipline, which is usually referred to as information technology in those countries. The term 'informatics' encompasses 'the science and technology of processing information' (Académie des Sciences, 2013, p. 8). The term 'computing' has a similar meaning in the United Kingdom and the United States. However, as most European

([6]) https://www.gov.uk/government/news/tech-experts-to-provide-national-centre-for-computing-education

([7]) https://www.education.gouv.fr/bac-2021-un-tremplin-vers-la-reussite-1019

([8]) US Government Publishing Office, Every student succeeds act, Public Law No 114-95, 114th Congress, 10 December 2015.

countries use ‘informatics’, this term is used throughout this report (see Chapter 1 and Annex 1 for further details and names of the subjects in national languages).

This report examines informatics in school education as a distinct discipline, either taught as a separate subject or integrated into other subjects. However, the report does not include cross-curricular approaches to teaching digital key competences. The analysis builds on how the curricula cover the most common areas of informatics, drawing from several widely used competence and curricular frameworks (see Annex 2) ([9]):

1. Data and information	6. People–system interface
2. Algorithms	7. Design and development
3. Programming	8. Modelling and simulation
4. Computing systems	9. Awareness and empowerment
5. Networks	10. Safety and security

The operationalisation of these 10 core areas in relevant learning outcomes as defined in the different frameworks has provided a common reference for the analysis of school curricula across Europe.

Content of the report

The report is organised in three chapters.

The **first chapter** explains the curricular approaches to teaching informatics, notably in relation to its status as a separate subject or integrated into other subjects and as a compulsory or optional subject, and the age or point of the educational process at which it is introduced. It then shows how and when the different education systems include informatics in the curricula of primary and general secondary education. For upper secondary education, it provides the annual instruction time allocated to teaching informatics subjects. The chapter also takes stock of policy reforms being implemented or in development. Annex 1 provides a list of the informatics subjects and their status in school curricula by country.

The **second chapter** examines the content of informatics education at school through analysing learning outcomes. First, it describes 10 common content areas covered by existing competence frameworks and how those are expressed in school curricula across Europe. Second, it shows the general coverage of those 10 informatics areas from the empirical evidence gathered through the Eurydice network. It also analyses the comprehensiveness and progression of learning outcomes at each education level from primary to general upper secondary education. The final section of the chapter gives a glimpse into the discussion on how to obtain more balanced participation of men and women in higher education degrees in informatics and the informatics workforce, starting with increasing girls’ participation in and engagement with informatics education at school. Annex 2 briefly presents the sources and existing competence frameworks with learning outcome examples.

The **third chapter** focuses on teachers. It first analyses the professional profiles of those teaching informatics at school. It then addresses the existence of professional development programmes for becoming a specialist informatics teacher across Europe (i.e. initial teacher education, alternative pathways and retraining opportunities). The chapter also looks at the main measures available to support in-service informatics teachers to successfully implement the curricula. Finally, it provides country examples of policy reforms and initiatives that cover professional development and support

([9]) The national curriculum in England for computing (UK Department of Education, 2013), K–12 computer science framework (2016), Massachusetts curriculum framework for digital literacy and computer science (2016), computational thinking construct in the International Computer and Information Literacy Study (2018), computational thinking framework (Raspberry Pi Foundation, 2020), Microsoft computer science framework and informatics reference framework for school (Informatics for All coalition, 2022).

measures for teachers. Annex 3 outlines the professional profiles of teachers, other than specialist informatics teachers, who can teach informatics at different education levels, and Annex 4 provides a short description of alternative pathways and retraining programmes.

Scope of the report and sources of information

The report covers all members of the Eurydice network (i.e. the 27 EU Member States plus Albania, Bosnia and Herzegovina, Switzerland, Iceland, Liechtenstein, Montenegro, North Macedonia, Norway, Serbia and Turkey). In most cases, only public schools are included (except for Belgium, Ireland and the Netherlands, where government-dependent private schools are taken into account).

Information generally refers to the 2020/2021 school year but the report also includes more recent policy developments.

The information was collected through a questionnaire completed by representatives and experts of the Eurydice network in the countries concerned. The primary sources of information and the analysis in the report are regulations/legislation, curricula and other official steering documents issued by top-level education authorities, unless otherwise stated. The report was drafted and produced by Unit A6 – Platforms, Studies and Analysis of the European Education and Culture Executive Agency. All contributors are acknowledged at the end of the report.

CHAPTER 1: INFORMATICS IN THE CURRICULUM

Educating students in informatics at school is essential to equip every citizen with the basic knowledge required to participate, influence and contribute to the development of the digital world. Learning informatics allows students to navigate the internet more safely and critically and enables them to contribute to a fast-expanding infosphere consisting more and more of algorithms that may be biased or information that may be flawed or incomplete. Informatics education helps students understand how digital technologies work and empowers them to be active creators, not merely passive consumers (Caspersen et al. 2018).

These are not the only benefits of learning informatics at school. Although not exclusive to this discipline, studying and practising informatics develops key thinking skills such as logical reasoning and abstraction. A unique aspect of informatics is that students learn to build executable models of many kinds of phenomena, which improves their understanding of these phenomena and provides them with opportunities to test their knowledge (Nardelli, 2019, p. 35).

Learning informatics is also important because of the essential role it plays in other sciences. It underpins any kind of data-processing activity, be that in biology, physics or applied sciences, such as meteorology, epidemiology, automotive and aeronautics. Moreover, teaching students informatics from early on in their education can boost their motivation to pursue related studies after general education, which could contribute to raising the availability of skilled personnel. Every industry needs this to continue its progress and to fully realise its potential (Code.org, 2016).

However, enhancing informatics education in schools is a challenging endeavour, and the time factor makes it even more daunting. One of the main challenges to introducing informatics as a separate subject into the curriculum is fitting the new subject into the school timetable, which may require reducing the time allocated to other subjects. Another important challenge is the need to make enough teachers with the adequate preparation and qualification available to teach the discipline (see Chapter 3).

There are also additional challenges in the development of the curricular content in terms of progression over grades and the balance between theory and practice. With regard to the former, it is essential to develop a curriculum appropriate to the various levels of education. While there is a lot of experience in teaching informatics in tertiary education, and, to a certain extent, in upper secondary education, the amount of knowledge developed in teaching in lower secondary and primary education is much more limited. Although there is ongoing research analysing the specific content that should be taught and how it should be taught, more research is sorely needed (Caspersen et al., 2018).

Another key factor for successful informatics education is maintaining a good balance between the theoretical and abstract aspects and the technological and practical aspects. Putting too much emphasis on abstraction aspects too early could make the subject interesting only to the more mathematically inclined students. However, overemphasising the technological components could deprive students of the fundamental principles, useful whatever their future profession is and indispensable for adapting to rapid, continuous technological change (Académie des Sciences, 2013). A strong focus on the use of computers underestimates a scientific discipline where abstraction plays an essential role. It is important to avoid putting excessive emphasis on the use of technology and integrate ‘unplugged’ activities into the educational process (Rodriguez et al., 2017). Generally, unplugged activities involve problem-solving to achieve a goal without using computers, and in the process dealing with fundamental concepts from computer science (Bell et al., 2009).

The introduction of informatics into the curriculum also requires the availability of learning materials and pedagogical practices that teachers can choose from, depending on their students’ needs and characteristics. In particular, it is important that teaching methods and content are appropriate to the various levels of education and are delivered in a way that engages students, given the varying learning modes across their progression through school (Lister, 2016). It is challenging to find a fun way to teach the subject that does not deter students from understanding the real science behind it, to prepare reference standards for the various levels of education and concepts inventories to support curricula implementation, and to define diagnostic assessment methods for evaluating learning difficulties to ensure that slower learners can progress (Vahrenhold, 2012). These overall challenges are even more difficult in the early years of education and considering the need to identify effective and evidence-based pedagogies (Beetham and Sharpe, 2013; Bird, Caldwell and Mayne, 2014; Beauchamp, 2016; Manches and Plowman, 2017).

Despite the challenges, this chapter shows the growing tendency to enhance informatics education in European countries. The first section explains the different approaches to including informatics in curricula regarding its status (as a separate subject or integrated into other subjects), its outreach (compulsory or optional) and the age or point of the educational process at which it is introduced. The following sections describe the curricular approach followed in the education systems covered by this report, primary, general lower and upper secondary education, in the 2020/2021 school year. The last section takes stock of the most recent policy reforms. A full list of informatics subjects taught by country is available in Annex 1.

1.1. Curricular approaches to teaching informatics

This chapter looks into three main aspects of the curricular approach to teaching informatics: the status of the discipline as a separate subject or integrated into other subjects, the age or point of the educational process at which the subject is introduced, and the outreach in terms of the number of students taking the subject. This section briefly explains the different approaches.

A separate subject or integrated into other subjects

As is the case for other disciplines, informatics can be taught as a separate subject or as part of other subjects. A third possibility is that informatics-related learning outcomes are addressed across all the school subjects (a cross-curricular approach).

Providing informatics in the curriculum as a separate subject has two main advantages. Firstly, the educational goals are clearer, and it is easier to develop and manage the curriculum. Secondly, the subject has a more important status, which facilitates its uptake in the education systems and its alignment with other science, technology, engineering and mathematics subjects, providing an opportunity to develop synergies with them. The main drawback of this approach is the difficulty in finding a place in the timetable for the new subject. There is also a risk that informatics is perceived as a specialised, advanced area of study suitable only for a minority with a special aptitude for it, which could potentially contribute to reinforcing gender stereotypes around school subjects (McGarr and Johnston, 2020).

Integrating informatics learning outcomes into the curriculum of other subjects could make it easier to find a place for the new content in the existing timetable, but more difficult to manage the subject's curriculum and informatics teachers' careers. Moreover, it could hinder the perception of informatics as a scientific discipline. Even when integrated into other subjects, it is important to provide informatics as a distinct discipline. Otherwise, there is a risk of losing its relevance (Académie des Sciences, 2013). This is particularly relevant when integrating informatics into technology. Informatics is both a science and a technique. Although part of it is a technique for building objects, these objects have an abstract nature, while technology is oriented towards material objects.

The cross-curricular approach has a number of disadvantages in relation to the development of the curricular content and teachers' careers. Combining informatics activities and experiences with all the school subjects requires a high level of organisation and planning, changes to curricula and the professional development of all teachers (McGarr and Johnston, 2020). Moreover, there is a risk of focusing on the technological part of the discipline and incentivising the perception of informatics as a tool for teaching other subjects rather than as an individual scientific subject. However, this cross-curricular approach can allow other subjects to benefit from the important role of informatics in so many aspects of life and work by reflecting this in their knowledge areas (McGarr and Johnston, 2020). Teaching informatics as a separate subject and teaching and applying its concepts across other subjects can have significant educational benefits (Caspersen et al., 2018). However, such an approach would require not only the availability of specialised teachers but also that teachers of the other subjects have basic skills in informatics.

Starting age

The introduction of informatics in schools has traditionally taken place at upper secondary level, either to prepare students interested in pursuing academic studies in the area or for students of vocational schools looking for a faster way into an expanding labour market sector. More recently, owing to the motivations discussed previously, some countries have started to discuss and introduce informatics in lower secondary and primary education (Oda, Noborimoto and Horita, 2021).

There is a growing consensus that starting to teach informatics in primary education is not only possible but also beneficial for learning and boosting self-esteem and motivation (Webb et al., 2017). Even though abstraction capabilities are not yet developed at this education level (Armoni and Gal-Ezer, 2014b; Piaget and Inhelder, 1969), the emphasis can be on concreteness and operational exploration (Académie des Sciences, 2013; Manches and Plowman, 2017; Forlizzi et al., 2018). Other disciplines focus on concrete examples and basic operations in primary education, leaving the learning of its more complex mechanisms and abstract principles to later stages.

Duncan, Bell and Tanimoto (2014) underlined a number of factors to consider regarding the best age to start learning computer programming, which is one of the main learning areas in informatics (see Chapter 2). These factors can be cultural (such as the role of information technology (IT) professionals and teachers' perceptions of subjects for boys and girls), environmental (such as teachers' self-confidence and skills and training opportunities), social (the image of the discipline and stereotypes), personal (students' attitudes and backgrounds) or instrumental (the availability of attractive and effective learning tools).

According to Scherer, Siddiq and Sánchez Viveros (2019), there is a variety of empirical evidence confirming that some exposure to programming before 12 years old is both worthwhile and feasible. Their meta-analysis of 105 studies showed the positive overall effect of learning computer programming on other cognitive skills, such as creative thinking, mathematical skills, metacognition and reasoning. Furthermore, exposing girls to computer programming before middle school, where young people tend to become influenced by the stereotypical classifications of 'subjects for boys' and 'subject for girls', could contribute to getting them interested in the subject.

Prat et al. (2020) related differences in children's ability to learn programming language to differences in their natural ability to learn foreign languages, suggesting that language aptitude could be more relevant than numeracy to predicting programming ability. As a programming language, although restricted and formal, is still a language, it may be useful to leverage children's aptitude to learn foreign languages when they are still very young.

Compulsory for all or some students, or optional

A third consideration regarding the status of informatics in the curriculum is whether to provide instruction in the subject to all students or only to some students, depending on their interests, abilities and choices.

Introducing informatics as a compulsory subject for all students can contribute to increasing their interest in the discipline (and, therefore, the number of future graduates in the subject), to promoting their active participation in digital society, allowing them to take informed positions on critical issues and discussions, and to enhancing their thinking and problem-solving skills (McGarr and Johnston, 2020).

George Forsythe argued back in 1968 that ‘the most valuable acquisition in a scientific or technical education are the general-purpose mental tools which remain serviceable for a lifetime’, rating ‘natural language and mathematics as the most important of these tools, and computer science as a third’ (Forsythe, 1968, p. 456). Seymour Papert underlined the central role that programming may have in children’s learning processes, as it allows self-controlled and almost unconstrained exploration of subjects, enriching their learning skills (Papert, 1980).

A risk of making informatics a compulsory subject for all students is that, if schools do not have teachers knowledgeable in the discipline, they may substitute it for whichever technological subject is available (e.g. teaching students to use software packages for document production, number manipulation, presentation or graphics illustration). The implementation review 3 years after the introduction of the mandatory computing curriculum in the United Kingdom in 2014/2015 pointed out this risk (The Royal Society, 2017). It may be even riskier to tackle the situation with teachers who are thought to be ready but are not well prepared in all the aspects of the discipline because they will pass down bad habits or incorrect concepts to students (Fincher, 2015).

At primary and lower secondary levels, school subjects are usually compulsory for all students and there is generally less diversification than at upper secondary level, where students more often have the opportunity to choose between different specialisations, subject clusters or subjects. Providing informatics as an optional subject in upper secondary education when students have acquired a basic knowledge of the science behind the discipline in the previous years (an incremental approach) can equip them with further specific skills and knowledge and better prepare them to pursue related university studies or enter the labour market. However, providing informatics only for some students at the upper level of education but not before (a one-off approach) may compromise the many benefits that learning informatics can yield.

Informatics as a distinct discipline

The focus of this report is on the education systems that include informatics as a distinct discipline in their school curricula, either as a separate subject or as part of other subjects. The consideration of whether it is a distinct discipline is based on how the curriculum addresses the 10 core learning areas: data and information, algorithms, programming, computing systems, networks, the people–system interface, design and development, modelling and simulation, awareness and empowerment, and safety and security (see Chapter 2). This study does not cover instances where some informatics-related content is provided in a cross-curricular area, as informatics cannot be considered a distinct discipline.

The distinction between a separate subject and an integrated approach is based not on the name of the subject but on its specific content and learning outcomes. When the focus of the subject is on the aforementioned informatics learning areas, it is considered a separate subject. When the subject includes some learning outcomes on informatics but the focus is on another discipline or on digital literacy, informatics is considered integrated into another subject. For instance, the subject information and communications technology (ICT) is considered a separate informatics subject at primary level in Greece, at secondary level in Malta and Romania and at upper secondary level in Spain, but not in Czechia (at primary and lower secondary levels), Portugal (at lower secondary level), Slovenia (at upper secondary level) or Albania (at upper secondary level). In these cases, ICT includes some learning outcomes on informatics but its focus is on digital literacy.

In some European countries, informatics is taught as a separate subject throughout primary and secondary education (Bulgaria, Greece, Croatia, Hungary, Poland, Slovakia, Bosnia and Herzegovina, Switzerland, Liechtenstein, Montenegro, North Macedonia and Serbia). In other countries, such as Malta and Romania, it is taught as a separate subject starting in lower secondary education. In countries such as Spain, France, Italy, Luxembourg, Austria, Portugal, Sweden and Norway the approach to integrate some informatics learning outcomes in other subjects is more common. Next sections show the curricular approach to teaching informatics in primary, general lower and upper secondary education across Europe.

1.2. Informatics in primary education

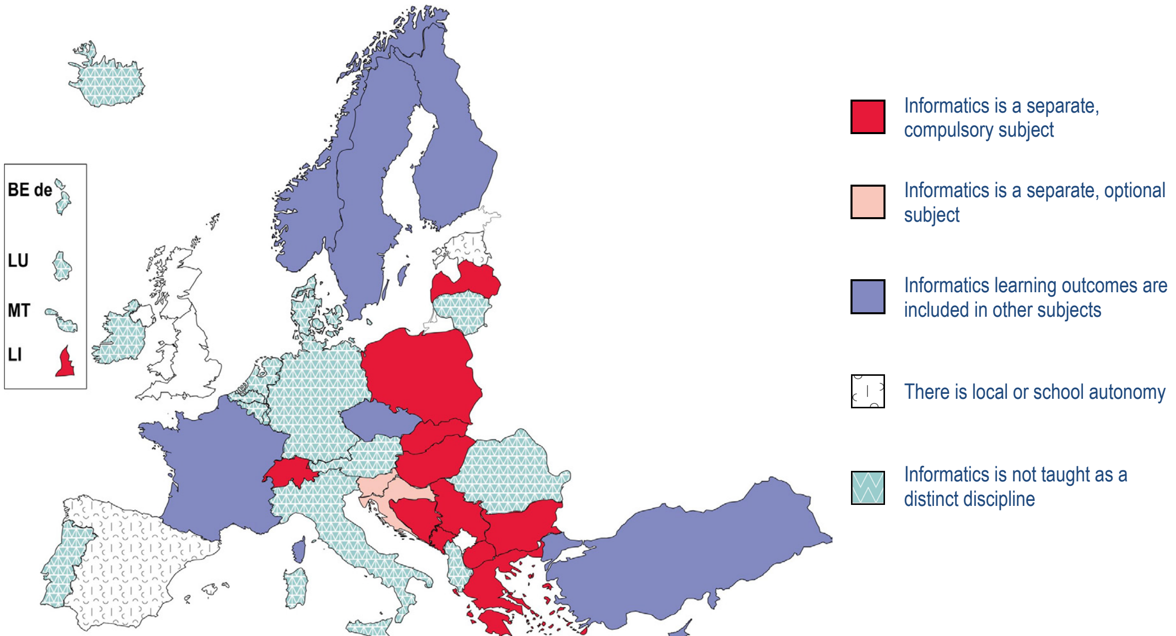
Figure 1.1 shows the European countries where informatics was taught as a distinct discipline in primary education (International Standard Classification of Education (ISCED) 1) in 2020/2021, either as a separate subject or integrated into other subjects. Informatics is taught as a separate subject throughout the whole of primary education in only a few countries, but more and more education systems are including the subject in their curricula at least in the highest grades. At this education level, it is also common to teach some content on informatics in other subjects.

In Greece only, informatics is a separate, compulsory subject from grade 1 throughout the whole of primary education. A few other countries are implementing reforms in this direction. In Lithuania, the curriculum was updated to introduce the new subject informatics from grade 1 at primary level in 2020/2021, but its implementation will be mandatory only from 2023. In Bosnia and Herzegovina, some cantons of the Federation of Bosnia and Herzegovina started to teach the subject informatics in 2019/2020, while Republika Srpska started to teach the subject digital world in 2021/2022. In Serbia, digital world is being gradually introduced in grades 1–4, although only children in grade 1 took this subject in 2020/2021.

Another 3 education systems provide for teaching informatics throughout the whole of primary education but not necessarily as a separate subject in the early grades. In Poland, informatics education is a compulsory learning area in grades 1–3, where there are no subjects and teachers decide how to organise their teaching. However, schools may assign an informatics teacher to provide this content as a separate subject for 1 hour per week. In grade 4, informatics is a separate, compulsory subject. In Latvia, the curricular reform that started to be phased in in 2020/2021 includes the new separate subject computing in grades 4–6, while in grades 1–3 local and school authorities decide how to provide the related learning outcomes. In Liechtenstein, media and informatics is integrated into other subjects in grades 1–3 and is a separate subject in grades 4–5.

In another 6 countries, informatics is a separate, compulsory subject in the upper grades of primary education. In Slovakia, it is compulsory from grade 3 but schools can also offer it to students in grades 1 and 2 as an optional subject. In Bulgaria, North Macedonia and Hungary (with the implementation of the new curriculum), informatics is also a compulsory subject from grade 3. In Switzerland, the 21 German-speaking cantons already provided the new subject media and informatics in 2020/2021 (usually starting from grade 5). The French-speaking cantons started to gradually introduce the new subject digital education the following year. In Montenegro, 5th grade children study the subject informatics with technology.

Figure 1.1: Informatics in the curriculum of primary education (ISCED 1), 2020/2021



Source: Eurydice.

(*)	BE fr	BE de	BE nl	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	AL	BA	CH	IS	LI	ME	MK	NO	RS	TR
1	–	–	–	–	◊α	–	–	α	–	●	α	◊	○	–	–	α	–	–	–	–	–	–	α	–	–	–	α	◊α	◊	–	●	–	–	◊	–	–	–	●	◊
2	–	–	–	–	◊α	–	–	α	–	●	α	◊	○	–	–	α	–	–	–	–	–	–	α	–	–	–	α	◊α	◊	–	●	–	–	◊	–	–	–	●	◊
3	–	–	–	●	◊α	–	–	α	–	●	α	◊	○	–	–	α	–	–	–	–	–	–	α	–	–	–	●	◊α	◊	–	●	–	–	◊	–	●	–	●	◊
4	–	–	–	●	◊α	–	–	α	–	●	α	◊	○	–	◊	●	–	–	●	–	–	–	●	–	–	○	●	◊α	◊	–	●	–	–	●	–	●	–	●	◊
5	–	–	–		◊α	–		α	–	●	α	◊		–	◊	●		–		–	–				–	○		◊α	◊	–	●	●	–	●	●	●	◊		
6	–	–	–			–			–	●	α				◊	●		–		–	–					○		◊α	◊	–		●	–				◊		
7						–			–												–												–				◊		

(*) Grade

● Separate, compulsory subject ○ Separate, optional subject ◊ Integrated into other subjects α Local/school autonomy ▭ Not ISCED 1

Explanatory notes

The map in this figure shows the education systems that have informatics as a separate (compulsory or optional) subject in one or more grades of primary education, and the education systems where informatics-related learning outcomes are included in other, compulsory subjects. The table provides the breakdown by grade.

Country-specific notes

Czechia: The national curriculum provides for the minimum instruction time for the subject ICT for the whole of primary education. Schools decide on the allocation of this time across grades, including the starting grade (which is often grade 4).
Denmark: Primary education covers grades 0–6, which correspond to grades 1–7 in the figure.
Spain: Informatics is not included in the national curriculum of primary education. However, the *Comunidades Autónomas* (autonomous communities) have the power to allocate some instruction time to subjects of their choice, which can include informatics. They can also give schools this prerogative.
Latvia: Learning outcomes for informatics come under the learning area 'technology', which includes the separate subject computing in grades 4–6 at primary level. In grades 1–3, schools can teach computing as a separate subject or as part of other subjects.
Lithuania: Informatics was a cross-curricular subject in primary education in 2020/2021. However, around 10% of the schools had already introduced the new, separate subject informatics in grades 1–4. From September 2023, all schools must teach the new subject.
Luxembourg: Pattern recognition, generalisation, decomposition, abstraction, algorithmic thinking, iteration, debugging and evaluation are computational thinking skills taught across all subjects in primary education. They are evaluated in the final grade.
Poland: In stage I (grades 1–3) there are no subjects. Instead, there are learning outcomes relating to different disciplines, including informatics education. Teachers decide how to organise their teaching and provide the content relating to the different disciplines. However, schools may assign an informatics specialist teacher to provide informatics as a separate subject for 1 hour per week. From grade 4, teaching is organised into subjects and informatics is a separate subject.

Romania: Primary education covers grades 0 to 5, which correspond to grades 1–6 in the figure.
Slovakia: In grades 1 and 2, schools may offer informatics as an optional subject.
Finland: In the national curriculum, the subjects mathematics and crafts and the transversal competence ICT include learning outcomes on informatics. Local and school authorities can include additional content in subjects of their respective curricula and use the weekly lesson assigned for optional studies.
Bosnia and Herzegovina: Informatics was introduced in 2019/2020 in some cantons of the Federation of Bosnia and Herzegovina, and in the following years in the rest of the country.
Switzerland: Information in the figure refers to the German-speaking cantons. The other cantons had not introduced informatics as a separate subject in 2020/2021.
Serbia: In 2020/2021, the new subject digital world was in place only in grade 1.

Informatics is rarely an optional subject at primary level, with the only exceptions of Croatia (grades 1–4) and Slovenia (grades 4–6). In Slovenia, the subject computer science was offered by around 65% of schools and was chosen by approximately 18% of the students in 2020/2021.

A common approach at primary level is to cover some content on informatics in other compulsory subjects. In France and Sweden, learning outcomes covering most of the core informatics learning areas are included in mathematics and technology throughout the whole of primary education (see Chapter 2, Section 2.1). In a less comprehensive manner, some learning outcomes on informatics are included in the subject IT and software in Turkey, and, in the final grades of primary education, in design and technology in Cyprus and in mathematics in Norway. In Czechia, schools decide in which grades to teach the subject ICT, which includes some learning outcomes on informatics. In Finland, the subjects mathematics and crafts and the transversal competence ICT, taught across all school subjects, include learning outcomes on informatics.

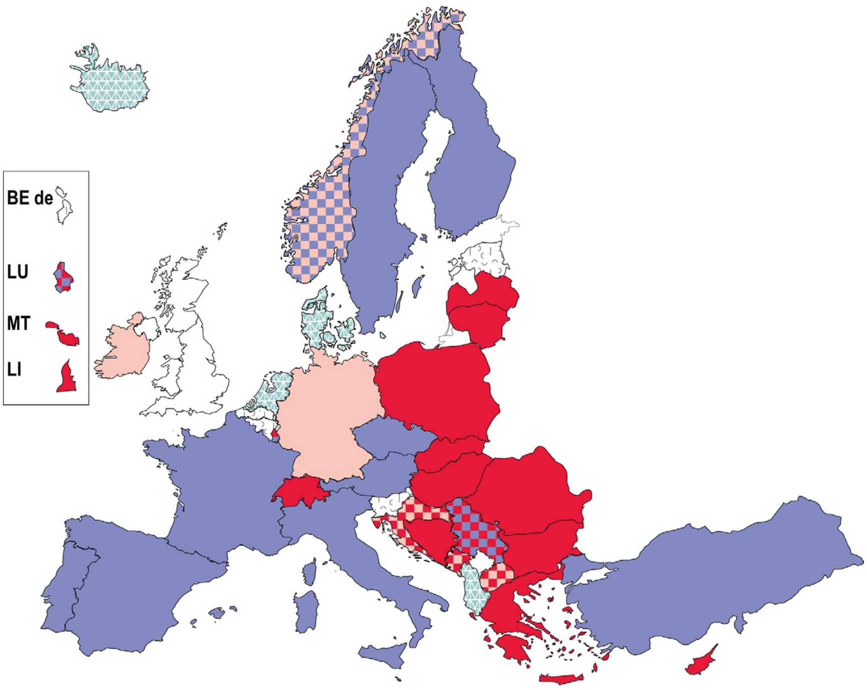
In Estonia, the central government has specified the content of the subject informatics and developed the relevant learning materials, and schools decide when and how they use them. In Spain, although informatics is not included as a distinct discipline in the national curriculum of primary education, some *Comunidades Autónomas* (autonomous communities, CAs) include it in their curricula. For instance, the subject technology and digital resources to improve learning in Madrid (grades 1–6) and the subject mathematics in Andalucía (grades 5–6) include informatics-related learning outcomes. The CAs can also give schools the power to allocate part of the officially recommended instruction time to subjects of their choice, including informatics. This is the case, for instance, in Valencia, Murcia and Galicia.

In the remaining 16 education systems, informatics is not taught as a distinct discipline in primary education, although digital competences are usually covered in the curriculum. ICT is a cross-curricular learning area in Portugal and a separate subject in Iceland, but is primarily focused on digital skills at this education level.

1.3. Informatics in general lower secondary education

The number of education systems that provide informatics education is higher at lower secondary level than at primary level. As shown in Figure 1.2, informatics is in the curriculum of general lower secondary education (ISCED 24), either as a separate subject or integrated into other subjects, in all but 4 countries. However, in some of them it is optional or not offered in all schools.

Figure 1.2: Informatics in the curriculum of general lower secondary education (ISCED 24), 2020/2021



Source: Eurydice.

(*)	BE fr	BE de	BE nl	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	AL	BA	CH	IS	LI	ME	MK	NO	RS	TR
5				●			○						●				●		●			◊	●	◊			●											●◊	◊
6				●	◊α		○	α				◊	●	◊			●		●			◊	●	◊	●		●				●			●	●	●		●◊	◊
7	α	α	α	●	◊α		○	α		●	◊	◊	○	◊	●	●	●	α◊	●	●		◊	●	◊	●	–	●	◊α	◊	–	●	●		●	●○	●		●◊	◊
8	α	α	α		◊α	–	○	α	○	●	◊	◊	○	◊	●	●	●	α◊	●	●	–	◊	●	◊	●	α	●	◊α	◊	–	●	●	–	●	●○	○	◊○	●◊	◊
9					◊α	–	○	α	○	●	◊	◊			●	●	●	●◊		●	–			◊	●	α	α	◊α	◊	–	●	●	–	●	○	○	◊○		
10						–			○								●																–				◊○		

(*) Grade.

● Separate, compulsory subject ○ Separate, optional subject ◊ Integrated into other subjects α Local/school autonomy ▢ Not ISCED 24

Explanatory notes

The map in this figure shows the education systems that have informatics as a separate (compulsory or optional) subject in one or more grades of general lower secondary education, and the education systems where informatics-related learning outcomes are included in other, compulsory subjects. The table provides the breakdown by grade.

Country-specific notes

Czechia: The national curriculum provides for the minimum instruction time for the subject ICT for the whole of general lower secondary education. Schools decide on the allocation of this time across grades. Some schools may not provide the subject in one or more grades.
Denmark: Lower secondary education covers grades 7–9, which correspond to grades 8–10 in the figure.
Germany: Informatics is an elective subject in the *Gymnasium* and other lower secondary schools in most *Länder*, but not necessarily in all grades. In some *Länder*, it is a compulsory subject in one or more grades.
Spain: In the national curriculum, the subject technology includes some learning outcomes on informatics. The CAs decide whether to teach this subject in one or more grades at lower secondary level. They also have the power to allocate some instruction time to subjects of their choice, including informatics as a separate subject, or give schools this prerogative.
Luxembourg: Informatics is a compulsory subject in grade 9 in the *Enseignement Secondaire Général*, in which approximately two thirds of the students are enrolled. Some schools offer it as an optional subject in grades 7 and 8.
Romania: Lower secondary education covers grades 5–8, which correspond to grades 6–9 in the figure.
Slovenia: Schools may offer the optional subjects robotics and technology in grades 8 and 9 (which is offered in around 17% of schools) and computer science in grades 7–9 (which is focused on digital literacy).
Slovakia: In grade 9, schools may offer informatics as an optional subject.
Finland: In the national curriculum, the subjects mathematics and crafts and the transversal competence ICT include learning outcomes on informatics. Local and school authorities can include additional content in subjects of their respective curricula and use the weekly lesson assigned for optional studies.
Switzerland: Information in the figure refers to the German-speaking cantons.

In 13 education systems, informatics is a separate, compulsory subject throughout the whole of general lower secondary education. In most of them (Bulgaria, Greece, Latvia, Hungary, Poland, Slovakia, Bosnia and Herzegovina, Liechtenstein and Serbia), informatics is also a compulsory subject in primary education. In Serbia, the subject technics and technology also covers some areas of informatics. In Cyprus, Malta and Romania, informatics is a separate, compulsory subject in lower secondary (but not primary) education. In Lithuania, informatics is a separate, compulsory subject at lower secondary level and is being introduced at primary level.

In a second group of countries, informatics is a compulsory or optional subject depending on grade. In Croatia, it is compulsory in grades 5 and 6 and optional in grades 7 and 8. In Luxembourg, informatics is a compulsory subject in grade 9 of the *Enseignement Secondaire Général* and schools can offer it as an optional subject in the other grades. In addition, some informatics-related learning outcomes are included in mathematics and science. In Montenegro, informatics with technology (grades 6–8) is a compulsory subject, while creating graphics and image and photography processing (grades 7–9), and introduction to programming (grades 8 and 9) are optional. In North Macedonia, informatics is a compulsory subject for all students in grades 6 and 7, and programming is an optional subject in grades 8 and 9.

Other education systems include the informatics-related learning outcomes in other subjects. These learning outcomes largely cover the core learning areas (see Chapter 2, Section 2.2) in France (mathematics, technology, and media and information literacy), Portugal (ICT), Austria (digital basic education) and Sweden (mathematics and technology), and a few learning areas in Czechia (ICT), Italy (technology), Norway (mathematics) and Turkey (IT and software). In Norway, students can also take the optional subject programming. In Finland, the subjects mathematics and crafts and the transversal competence ICT, taught across all school subjects, include learning outcomes on informatics.

In Ireland, coding is an optional subject in the junior cycle, and the optional short course on digital media literacy also covers some areas of informatics.

In countries where powers over education are shared with subnational authorities, there are usually differences in the curricular approach to teaching informatics. In most *Länder* in Germany, informatics is an optional subject in the *Gymnasium* (and in the other lower secondary schools), but the subject is compulsory in one or more grades in some *Länder*. In Spain, some learning outcomes on informatics are included in technology in the national curriculum, but some CAs have a separate subject in their curricula. For instance, in Madrid the subject technology, programming and robotics is compulsory in all grades at lower secondary level, and in Andalucía computing and robotics is an optional subject. In Switzerland, the 21 German-speaking cantons provided the new subject media and informatics in 2020/2021, but it was still a cross-curricular subject in the Italian- and French-speaking cantons.

In 5 education systems, there is local or school autonomy. In the French Community of Belgium, introduction to computers is among the subjects that schools may choose to offer at lower secondary level. In the German-speaking community, schools may offer informatics as an optional subject. In the Flemish Community, schools have the power to decide the curricular approach to achieving the learning outcomes relating to the recently introduced digital competence and media literacy. In Estonia, the central government has defined the content of the subject informatics and has developed the relevant learning materials, and schools have the power to decide when and how to use them. In Slovenia, schools may offer the optional subjects robotics and technology and computer science (but the focus of this subject is on digital literacy).

Informatics is not a distinct discipline at lower secondary level in only 4 countries. ICT is a cross-curricular area with a focus on digital literacy in Denmark, and a compulsory subject also with a focus on digital literacy in Albania and Iceland. In the Netherlands, the national curriculum does not include specific learning outcomes on informatics, although it is under revision (see Section 1.5.2) and some schools may provide the subject.

1.4. Informatics in general upper secondary education

In general upper secondary education, almost all education systems include informatics in the curriculum. However, the subject is often optional or compulsory only for some students. The first part of this section examines the curricular approach to teaching informatics at upper secondary level across Europe, while the second shows the instruction time allocated to informatics subjects in the different countries.

1.4.1. Curricular approach at general upper secondary level

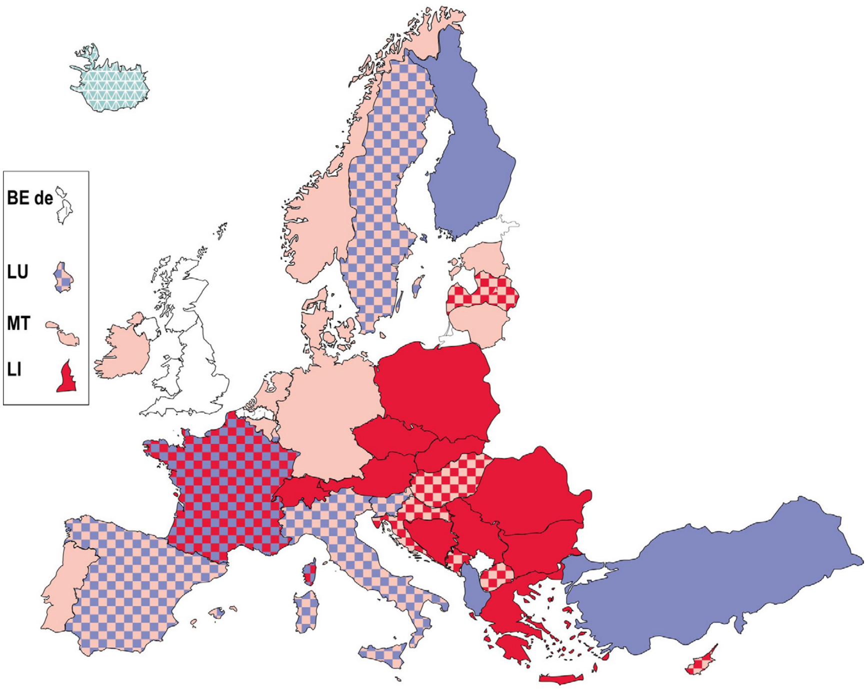
All the education systems except Iceland teach informatics as a distinct discipline in general upper secondary education, either as a separate subject or integrated into other subjects. There is a stronger tendency to teach informatics as a separate subject at this education level than at primary and lower secondary levels. However, it is more often not compulsory for all students.

As shown in Figure 1.3, informatics is a compulsory subject for all students in all grades in general upper secondary education (ISCED 34) only in Romania, Bosnia Herzegovina, and Serbia. In Romania, all upper secondary students (in general programmes) must take ICT and pass a digital competence examination in the last grade, while students in the mathematics / computer science and natural science programmes must also take the subject informatics.

In Czechia and Slovakia, schools decide on the allocation of the recommended minimum instruction time for informatics across grades.

In 5 other countries, informatics is compulsory for all the students at least in two grades. In Bulgaria, all students in grades 8–10 must take the subject IT. In addition, students in the mathematics, software and hardware sciences, economic development or natural science profiles with intensive foreign language must study informatics in grade 8, and informatics and IT in grades 11 and 12. In Greece, all students must take the subject IT applications in grade 10 and introduction to the principles of computer science in grade 11. In grade 12, informatics is compulsory only for students in the subject cluster economics and informatics. Informatics is compulsory in the first two grades of general upper secondary education in Hungary, whereas it was optional in the other two grades in 2020/2021. However, the new subject digital culture will be compulsory in grades 9–11. In Poland, informatics is compulsory for all students in grades 9–11, and for students in specialisations with advanced informatics in grades 9–12. In most Swiss cantons and schools, informatics is compulsory in two grades at upper secondary level (although it can be compulsory in one or the three grades depending on the canton and the school).

Figure 1.3: Informatics in the curriculum of general upper secondary education (ISCED 34), 2020/2021



Informatics is a separate, compulsory subject

Informatics is a separate, optional subject

Informatics learning outcomes are included in other subjects

There is local or school autonomy

Informatics is not taught as a distinct discipline

Source: Eurydice.

(*)	BE fr	BE de	BE nl	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	AL	BA	CH	IS	LI	ME	MK	NO	RS	TR
8				●																																			
9	○	α	α	●									●○	⦿◊					●			●	●⦿															●	◊
10	○	α	α	●	●α		○	○		●	○◊	●◊	●○	⦿◊	●	●		⦿◊	●	○	○	α	●⦿	–	●	◊	●α	◊α	○◊	◊	●	●α		●	●	●		●	◊
11	○	α	α	⦿	●α	⦿○	○	○	○	●	○	⦿◊	⦿○	⦿	○	○	○	⦿◊	○	○	○	α	●⦿	–	●	○	●α	◊α	○◊	◊	●	●α	–	–	○	○	–	●	◊
12	○	α	α	⦿	●α	○	○	○	○	⦿	○	⦿◊	⦿○	⦿	○	○	○	⦿◊	○		○	α	⦿	○	●	○	●α	◊α	○◊	◊	●	●α	–	–	○	○	○	●	◊
13					●α	○	○							⦿				⦿◊							●	○	●α				●		–		○	○	○		

(*) Grade

● Separate, compulsory subject ⦿ Separate, compulsory subject for some students ○ Separate, optional subject ◊ Integrated into other subjects α Local/school autonomy ▢ Not ISCED 34

Explanatory notes

The map in this figure shows the education systems that have informatics as a separate (compulsory or optional) subject in one or more grades of general upper secondary education, and the education systems where informatics-related learning outcomes are included in other subjects (which may or may not be compulsory). The education systems where informatics is a separate, compulsory subject only for some students are included in the category 'informatics is a separate, optional subject' on the map. The table provides the breakdown by grade and specifies when informatics subjects are compulsory for all or only some students. Annex 1 provides further information on the subjects.

Country-specific notes

Belgium (BE fr): Informatics is an optional subject in the *Enseignement Technique de Transition*. Around 13% of general upper secondary students are enrolled in this pathway.
Czechia: The national curriculum provides for the minimum instruction time for the subject informatics and ICT for the whole of general upper secondary education. Schools decide on the allocation of this time across grades.
Denmark: General upper secondary education covers grades 10–12, which correspond to grades 11–13 in the figure.
Germany: Informatics is an elective subject in the *Gymnasium* in most *Länder*, but not necessarily in all grades. In some *Länder*, it is compulsory. The same applies to the general programmes in technical schools.
Estonia: The new informatics syllabus for upper secondary schools, which started to be implemented in 2020/2021, consists of five elective courses and a digital solution development project.
Spain: ICT is an optional subject in all the general upper secondary programmes and grades in the national curriculum. In grade 10, the subject technology, which includes learning outcomes on informatics, is compulsory for students in applied studies and optional for students in academic studies in high schools that offer this subject. The CAs may include other informatics subjects in their curricula.
Italy: Informatics is compulsory for students in the applied sciences section of the *Liceo Scientifico*, and it is integrated into mathematics in grades 9 and 10 in all the sections.
Latvia: In the 1st grade of general upper secondary education, schools can offer computing, programming I or design and technology as compulsory subjects. In the upper grades, they can offer the advanced optional subject programming II.
Luxembourg: Informatics is compulsory in some sections of the *Enseignement Secondaire Géneral*.

Malta: In 2020/2021, the subject ICT was compulsory for all students in grades 10 and 11 but its focus was on digital literacy and the use of software. The new compulsory subject ICT C3 was introduced in grade 10 in 2021/2022 and will be introduced in grade 11 in 2022/2023. Data in the figure is for the optional subject computing.
Poland: Informatics is compulsory for all students in grades 9–11, and for students in specialisations with advanced informatics (offered in some schools) in grades 9–12.
Romania: General upper secondary education covers grades 9–12, which correspond to grades 10–13 in the figure.
Slovenia: The focus of the compulsory subject informatics in grade 10 is on digital literacy, although it covers some learning outcomes on informatics.
Slovakia: Schools decide on the allocation of the recommended minimum instruction time across grades.
Finland: In the national curriculum, the subject mathematics and the transversal competence ICT include learning outcomes on informatics. Local and school authorities can include additional content in subjects of their respective curricula, provide informatics as a separate, optional subject or offer optional courses.
Switzerland: All cantons had introduced the subject informatics by August 2022, although a few had not yet done so in the 2020/2021 school year. Cantons and schools decide on the grades at which the subject is offered.
North Macedonia: In *Gymnasium*, informatics is compulsory in grade 10 and optional in grades 11–13. The new mathematics / informatics *Gymnasium*, which includes several compulsory informatics subjects, was implemented in grade 10 in 2020/2021.

In another 8 countries, informatics is a separate subject compulsory for all the students in one grade of general upper secondary education, and, in most of them, it is optional or compulsory for some students in the other grades. In France, digital science and technology is compulsory for all the students in grade 10 in the *Lycée général et technologique*, while in grades 11 and 12 digital technology and computer science is compulsory only for students specialising in informatics. However, mathematics (grade 10) and science (grades 11 and 12), which are compulsory for all students, include some learning outcomes on informatics. In the *Baccalauréat technologique*, all students learn informatics either in mathematics or as a separate subject depending on the section.

In Croatia, informatics is compulsory in the 1st and/or 2nd grades and optional in the other grades in all the grammar schools except the mathematics and natural science grammar schools, where it is compulsory in all four grades. In Latvia, schools may offer computing, programming I or design and technology in the 1st grade, and the advanced optional subject programming II in the upper grades. In Austria, informatics is compulsory in grade 9 and schools decide whether and how to teach the discipline in the other grades. In Cyprus, Liechtenstein, Montenegro and North Macedonia, informatics is compulsory in the 1st grade and, except in Liechtenstein, optional in the other grades.

Informatics is compulsory only for students in certain programmes or sections in 3 other countries. In Denmark, it is compulsory in the 1st grade of the Higher Commercial Examination Programme and optional in the other grades and programmes. In Italy, students in the applied sciences section in the *Liceo Scientifico* must study informatics in grades 9–13. In addition, informatics-related learning outcomes are integrated into mathematics in all the sections in grades 9 and 10. In Luxembourg, in the *Enseignement Secondaire Général* informatics is taught in mathematics and technology and is a compulsory subject in the Engineering section (*Division technique générale*) in grades 10–13. The informatics section offers a wide range of other informatics subjects in grades 12 and 13.

In another 12 education systems, informatics is an optional subject and it may also be integrated into other subjects. In the French Community of Belgium, informatics is an optional subject in the *Enseignement Technique de Transition*. In Germany, informatics is an optional subject in most *Länder*, although in some it is a compulsory subject in one or more grades. In Estonia, upper secondary schools are gradually introducing the new informatics syllabus, consisting of five elective courses that can be provided by schools in different ways. Schools may also offer other subjects, such as robotics and mechatronics, 3D modelling, geoinformatics, the use of computers in research and cybersecurity.

The Leaving Certificate Computer Science is an optional subject in grades 11 and 12 in Ireland. In Spain, ICT is an optional subject in the three grades of general upper secondary education in the national curriculum. The CAs may include other informatics subjects in their curricula, as is the case in Madrid and Andalucía. In grade 10 (grade 4 of compulsory secondary education), the subject technology, which includes some learning outcomes on informatics, is compulsory for students in applied studies and optional for students in academic studies in high schools that offer it.

Informatics is also an optional subject in Lithuania, Malta and the Netherlands, and in the last grade of general upper secondary education in Portugal. In Slovenia, the focus of the compulsory subject informatics in the 1st grade is on digital literacy, although it includes some learning outcomes on informatics; in higher grades, it is an optional subject with a focus on informatics as a science. In Sweden, both mathematics and technology include informatics-related learning outcomes. The subjects computing, programming and web development are optional for students in several programmes and compulsory for some students in the technology programme. In Norway, programming and IT are optional subjects in the general studies programme.

Finally, in Albania informatics is taught as part of the subject ICT and in Turkey it is taught as part of IT and software. In Finland, the subject mathematics and the transversal competence ICT include learning outcomes on informatics. Local and school authorities can include additional content in subjects of their respective curricula. In the German-speaking and Flemish Communities, schools may offer informatics as an optional subject.

1.4.2. Minimum recommended instruction time for informatics as a separate subject at upper secondary level

Unlike in primary and lower secondary education, where the instruction time in informatics is generally compulsory for all students, most of the instruction time allocated to teaching informatics at upper secondary level is optional or compulsory only for some students. Figure 1.4 shows the instruction time recommended for informatics subjects that are compulsory for all general upper secondary students and for informatics subjects that are either optional or compulsory for students in certain programmes, specialisations or subject clusters.

In 5 education systems, all general upper secondary students receive more than 100 hours of instruction in informatics. In Bosnia and Herzegovina, they receive at least 240 hours throughout the four grades of upper secondary education, 280 hours in the mathematics / natural science programme and 432 hours in the computer science programme. In Serbia, all students receive 163.45 hours of instruction in informatics over the four grades, except in the natural science programme, where students receive 188.25 hours. In Romania, the instruction time for the subject ICT, which is compulsory for all students, is 35 hours per grade (140 hours in total). In addition, students in the mathematics / natural science programmes must take at least 350 additional hours of instruction in informatics, which can go up to 770 hours in the mathematics / computer science section. In Czechia, schools decide how to allocate the 117 hours of instruction time recommended for the subject informatics and ICT, which is compulsory for all students, across grades. In Greece, all students must study informatics for 52.5 hours in their first year and 52.5 hours in their second year. In the third and last years of upper secondary education, students in the economics and informatics subject cluster must take 157.5 additional hours of instruction in informatics.

Another 12 education systems provide for less than 100 hours of instruction for compulsory informatics subjects but often offer more time for instruction in subjects that are optional or compulsory in some programmes or sections. In Poland, all general upper secondary students study informatics for 85.5 hours, and students in specialisations with advanced informatics must take a minimum of 171 additional hours. In Hungary, the subjects digital culture (53.4 hours in the 1st grade) and informatics (27 hours in the 2nd grade) are compulsory for all students. Furthermore, students can choose to take informatics (27 hours) in the 3rd and 4th grades. In Slovakia, the compulsory instruction time is around 75 hours but it can be more if schools provide other informatics subjects. In

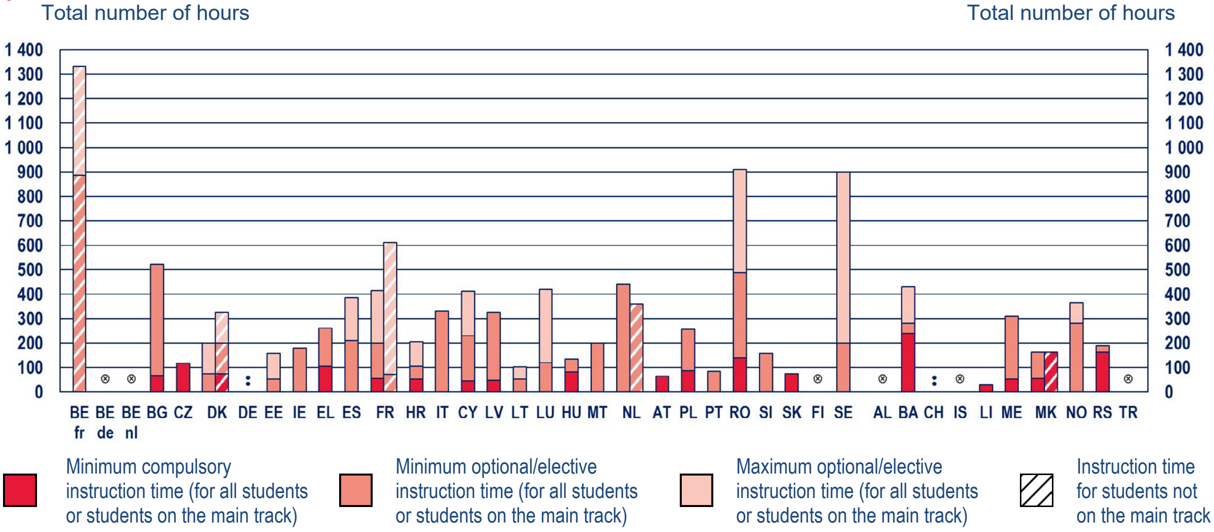
Bulgaria, all students must take the subject IT in the first three grades (27 hours in the 1st and 2nd grades and 13.5 hours in the 3rd grade). In addition, students in the mathematics, software and hardware sciences, economic development or natural sciences profiles with intensive foreign language also have 54 hours of instruction in informatics in the 1st grade, 201 hours of instruction in IT and 201 hours of instruction in informatics over the last two grades.

In Austria, the instruction time for the compulsory subject informatics in the 1st grade of general upper secondary education is 65 hours. In France, the instruction time for the compulsory subject digital science and technology in the 1st grade of the *Lycée général et technologique* is 54 hours. In the 2nd and 3rd years, for the optional subject digital technology and computer science (*Baccalauréat général*), students receive 144 hours and 216 hours of instruction, respectively. In the *Baccalauréat technologique,* students may receive between 72 and 612 hours of instruction in informatics subjects depending on the programme. In North Macedonia, the compulsory instruction time is also 54 hours. Students can also take 108 additional hours in optional subjects. In addition, the 1st grade of the new mathematics / informatics *Gymnasium* commenced in 2020/2021, with 81 hours of instruction in informatics and 81 hours of instruction in programming.

In Croatia, students must take 52.5 hours of informatics in the 1st grade in general grammar schools, in the 2nd grade in language and classical grammar schools and in both grades in natural science grammar schools. In the other grades, the subject is optional. In the mathematics and natural science grammar schools, the subject is compulsory in the four grades (205.5 hours of instruction in total). In Montenegro, 52.5 hours of instruction are compulsory for all students in the 1st grade of upper secondary education, and students can take up to 255.75 hours in optional subjects in the other grades. In Latvia, 47 hours of instruction in informatics are compulsory for all students and 280 hours in programming are optional.

In Cyprus, all students in the 1st grade of general upper secondary education must study informatics for 46.5 hours. Over the 2nd and 3rd grades, they can take 183 additional hours of the subject and another 183 hours of computer networks. In Liechtenstein, all general upper secondary students receive 29.5 hours of instruction in informatics.

Figure 1.4: Instruction time for informatics as a separate subject in general upper secondary education, (ISCED 34), 2020/2021



Source: Eurydice.

Explanatory notes

This figure shows the recommended instruction time (for the whole of general upper secondary education) for all the informatics subjects that are compulsory for all the students and for informatics subjects that are optional or compulsory for students choosing a specific programme, specialisation or subject cluster. For the optional and elective subjects, the figure shows the minimum and maximum instruction times. The first column corresponds to the only track or to the main track when there is more than one track, and the second column refers to other tracks where applicable.

Country-specific notes

Belgium (BE fr): Informatics is an optional subject in the *Enseignement Technique de Transition*. Around 13% of general upper secondary students are enrolled in this pathway.
Czechia: Instruction in the figure is for the compulsory subject informatics and ICT. Schools can provide additional instruction time in informatics.
Denmark: Data for 'students not on the main track' refers to the Higher Commercial Examination Programme.
Spain: Data refers to the minimum and maximum instruction time nationally recommended for the optional subject ICT. The CAs may include additional instruction time on other informatics subjects in their curriculums. For instance, Madrid allocates 70 hours in the fourth year of compulsory secondary education to the subject technology, programming and robotics: technological projects, and Andalucía allocates 70 hours in the first year of the *Bachillerato* to the subject digital creation and computational thinking, and 70 hours in the second year to programming and computing.
France: Minimum compulsory instruction time for all students refers to grade 10 in the *Lycée général et technologique* and data for optional/elective instruction time refers to grades 11 and 12 in the *Baccalauréat général* (on the main track) and in the *Baccalauréat technologique* (not on the main track).
Italy: Data in the figure refers to the applied sciences section in the *Liceo Scientifico*, which enrols around 15% of the general upper secondary students.
Luxembourg: Data in the figure refers to the engineering and informatics sections of the *Enseignement Secondaire Géneral*.
Malta: The new compulsory subject ICT C3 was introduced in grade 10 in 2021/2022 and will be introduced in grade 11 in 2022/2023. The minimum annual instruction time for this subject (45 hours per grade) is not reflected in the figure.
Netherlands: Top-level regulations provide for the total instruction time that local and school authorities must allocate across subjects and grades. This figure shows the instruction time necessary to achieve the learning outcomes corresponding to the subject informatics in pre-university education (on the main track) and senior general secondary education (not on the main track).
Poland: The minimum optional/elective instruction time refers to specialisations with advanced informatics offered in some schools. This instruction time is compulsory for students taking these studies.
Slovakia: Instruction time in the figure is for the compulsory subject informatics. Schools can provide other informatics subjects.
Switzerland: Cantons and schools are free to decide how to allocate the instruction time across grades as long as the instruction time allocated to informatics, mathematics and natural sciences altogether accounts for 27–37% of the total instruction time of upper secondary education.
North Macedonia: The compulsory instruction time on the main track is for grade 10 in *Gymnasium*, and the additional optional instruction time is for grades 11–13. Data for students not on the main track includes the subjects informatics and programming, delivered in grade 10 of the new mathematics / informatics *Gymnasium*. Informatics subjects in the other grades had not yet been implemented in 2020/2021.

In 14 education systems, all the instruction time provided for informatics subjects is optional or compulsory only for some students.

In the French Community of Belgium, the recommended instruction time for the optional subject informatics in the *Enseignement Technique de Transition* can be from 222 to 333 hours per year (depending on the school) in grades 9–12. Around 2% of all the students in general upper secondary education took the subject in 2019/2020.

In Denmark, students can choose to take 75 hours of instruction in informatics C, and may complement it with another 125 hours in informatics B. They may also take only informatics B (200 hours in total). Students in the Higher Commercial Examination Programme must take at least 75 hours of instruction in informatics C, and may complement it with 125 hours in informatics B or 250 hours in IT-A. They can also take only informatics B (200 hours) or IT-A (325 hours).

In Estonia, the new informatics syllabus for upper secondary schools consists of five elective courses (26.25 hours each) and a digital solution development project (26.25 hours). In Ireland, the optional subject computer science has 180 hours of instruction over a 2-year cycle, but fewer than 2% of all the general upper secondary students took it in 2020/2021. In Spain, the CAs must offer from 70 to 105 hours of instruction in informatics as an optional subject in grade 10 (fourth year of compulsory secondary education) and from 70 to 140 hours in grades 11 and 12 (*Bachillerato*).

In Italy, the applied sciences section of the *Liceo Scientifico*, in which around 15% of the general upper secondary students are enrolled, provides for 330 hours of instruction in informatics over five years. In Lithuania, around one quarter of the students take the optional subject IT, which has 52.5 hours of instruction over two grades for the basic course and 104 hours for the advanced course. In Luxembourg, the minimum instruction time in the engineering section of the *Enseignement Secondaire Général* is 120 hours for the four grades. In the last two grades, there are other optional informatics subjects amounting to 300 additional hours of instruction.

Malta provides for 104 hours of instruction in the 1st grade and 95 hours in the 2nd grade for the optional subject computing, taken by around 15% of the students. In the Netherlands, top-level regulations only provide for the total instruction time that local and school authorities must allocate across subjects and grades. In the preparatory scientific education track, it is estimated that students need around 150 hours in the 1st and 2nd grades and 140 hours in the 3rd grade in order to achieve the learning outcomes for the subject informatics. In the senior general secondary education track, they need around 180 hours in each of the two grades. In both cases, the subject is offered at the discretion of schools, and is optional for students. In the last year of upper secondary education, Portugal provides for 85 hours of instruction in the optional subject informatics applications, chosen by around one quarter of students. In Slovenia, the optional subject informatics, taken by around 3% of students, has 157.5 hours of instruction over three grades.

In Sweden, upper secondary students have at least 200 points (200 hours) of optional courses, which include one or more courses on informatics depending on the programme (see Annex 1). In the technology programme, students have up to 900 points (900 hours) of optional courses and, for some of the students, some informatics subjects are compulsory. In Norway, the optional subject IT has 140 hours of instruction in the 2nd grade and 140 in the 3rd grade of the general studies programme. Around 9% and 5% of the students, respectively, chose it in 2020/2021. Students can also take 84 additional hours in programming and modelling.

1.5. Curricular reforms

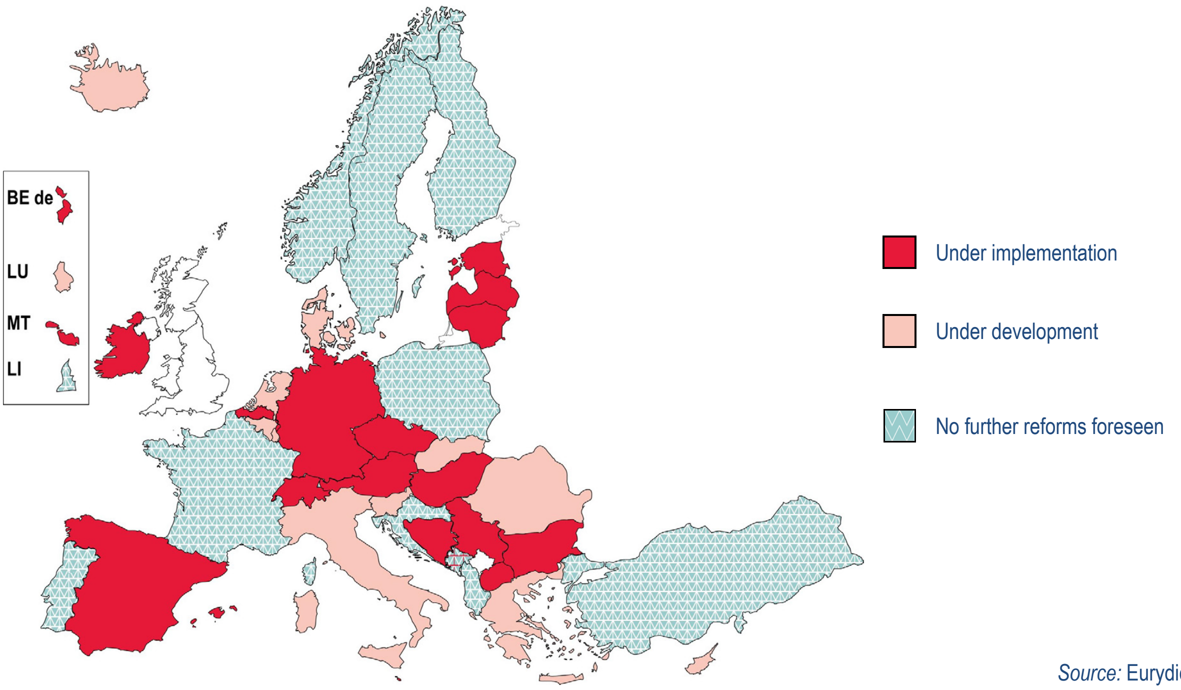
Informatics in school education has undergone important reforms in recent years. The informatics curriculum in 2020/2021, as described in previous sections, was in some countries, such as Croatia, France, Montenegro, Norway, Poland and Sweden, the result of reforms that had been recently implemented. This section gives an account of other curricular reforms not yet fully implemented in 2020/2021 or still under development, which were taking place in 28 other education systems. Some countries have included them in the recovery and resilience plans (RRPs) developed in response to the COVID-19 pandemic, which are financially supported by the Recovery and Resilience Facility ([10]).

1.5.1. Curricular reforms under implementation

As shown in Figure 1.5, 17 education systems were in the process of implementing curricular reforms on informatics education. These often include the introduction of an informatics subject at one or more education levels. In most cases, the reforms include measures related to teachers (see Chapter 3, Section 4).

([10]) The Recovery and Resilience Facility is a temporary recovery instrument that allows the European Commission to raise funds to help Member States implement reforms and investments to mitigate the economic and social impact of the COVID-19 pandemic and become more sustainable, resilient and better prepared for the green and digital transitions. For this purpose, Member States submitted RRPs including the reforms and investments that they planned to undertake. See the Commission's web page for the Recovery and Resilience Facility (https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en).

Figure 1.5: Foreseen curricular reforms for informatics in school education (ISCED 1, 24 and 34), 2020/2021



Source: Eurydice.

In 2021, the German-speaking Community of Belgium added a sixth competence area, problem-solving and computer modelling, to the information and media literacy guidelines. This area covers basic computer literacy and IT education, strategies for problem-solving, basic skills in programming, and the impact of algorithms and the automation of processes on the digital world ([11]).

As of 2021/2022, the Flemish Community of Belgium has been gradually introducing the key competence digital and media literacy at general upper secondary level ([12]). The government is also planning, as part of its RRP, to create a knowledge and advisory centre to support schools in implementing recent curricular changes.

Bulgarian education authorities passed a reform in August 2020 introducing the subject computer modelling and IT in grades 5–7 from 2021/2022. This new subject includes learning outcomes on modelling and more instruction time than the old subject IT ([13]). Bulgaria's RRP provides for further reforms in school education aiming to improve computer literacy.

The new informatics curriculum in Czechia will be fully implemented by 2023 at primary level and by 2024 at lower secondary level, although some schools are already providing it. While the previous subject ICT focused on developing students' ability to use computers and information and digital literacy, the subject new informatics focuses on developing computational thinking and understanding the principles of how digital technologies work. New Informatics is based on an active approach in which students use informatics procedures and concepts such as algorithms, coding and modelling, and become aware of how digital technologies work to promote their effective, safe and ethical use. The instruction time for the new subject is also greater ([14]). At upper secondary level, the subject

([11]) http://www.ostbelgienbildung.be/desktopdefault.aspx/tabid-3969/7117_read-41353/

([12]) https://www.kwalificatiesencurriculum.be/sites/default/files/atoms/files/Sleutelcomptentie%20Digitale%20competenties.pdf

([13]) Ministry of Education and Science, Amendment to Ordinance 4/2015 on the curriculum of the Minister of Education and Science, 28 August 2020 (https://dv.parliament.bg/DVWeb/showMaterialDV.jsp;jsessionid=E9F15C615920159C617F339EB5174CDC?idMat=150995).

([14]) Ministry of Education, Youth and Sports, *Framework Education Programme for Basic Education 2021*, Prague, 2021 (https://revize.edu.cz/files/rvp-zv-2021-s-vyznacenymi-zmenami.pdf).

informatics will replace ICT and informatics by September 2025, introducing updates and additional content to align the subject with the new curriculum at primary and lower secondary levels ([15]). Czechia's RRP is contributing to financing the implementation of the curricular reform.

Some German *Länder*, such as Schleswig-Holstein and Lower Saxony, are gradually introducing informatics as a separate subject at lower secondary level ([16]).

Estonian education authorities have developed new informatics curricula for grades 1–3, 4–6 and 7–9. The revised curricula include the courses digital art, coding and digital safety in grades 1–3; digital media, programming and digital hygiene in grades 4–6; and cybersecurity, software projects, web design and animation in grades 7–9. In 2020, a new syllabus for informatics, including five elective courses and a digital solution development project, was completed and piloted in 40 (25%) upper secondary schools ([17]).

The Irish government's action plan for education 2017 accelerated the digital agenda in schools ([18]), including through the gradual introduction (from 2014 to 2021) of the junior cycle short course in coding at lower secondary level ([19]). This subject aims to develop students' ability to solve problems logically; and to design, write and test code through developing programs, apps, games, animations and websites. From 2018, schools in Ireland started to introduce, at upper secondary level, the Leaving Certificate Computer Science, which covers programming, computational thinking and the impact of computing technology on our world ([20]).

In Spain, a comprehensive revision of the informatics curriculum has taken place following the entry into force of Organic Law 3/2020. The changes will be implemented in 2022/2023 and 2023/2024. In primary education, some learning outcomes on informatics will be integrated into the subject natural, social and cultural environment in grades 1–6. In lower secondary education, the new subject technology and digitalisation will be compulsory for all students at least in one grade. In general upper secondary education, technology and engineering will be one of the four elective subjects for students in the science and technology programme ([21]).

In Latvia, the education authorities have developed a new syllabus and new learning materials for the subjects design and technology and computing (grades 1–10) and programming (grades 10–12). Implementation started in grades 1, 4, 7 and 10 in 2020/2021; in grades 2, 5, 8 and 11 in 2021/2022; and in grades 3, 6, 9 and 12 in 2022/2023.

The implementation of the new informatics curriculum for primary education started in some Lithuanian schools in 2021 and the new curriculum will be mandatory for all from 2023 ([22]). The

([15]) Ministry of Education, Youth and Sports, *Framework Education Programme* for Secondary General *Education*, Prague, 2022 (https://revize.edu.cz/files/001-rvp-gym-vyznacene-zmeny.pdf).

([16]) https://www.mk.niedersachsen.de/startseite/aktuelles/presseinformationen/informatik-wird-ab-dem-schuljahr-2023-2024-pflichtfach-weitere-qualifizierungskurse-fur-lehrkrafte-starten-184807.html; https://www.schleswig-holstein.de/DE/Landesregierung/III/Presse/PI/2021/Mai_2021/III_Informatik.html

([17]) https://courses.cs.ut.ee/t/digiopik/; https://www.hitsa.ee/ikt-haridus/progetiiger/gumnaasiumi-informaatika-ainekava

([18]) Government of Ireland, *Action Plan for Education 2017*, Department of Education and Skills, Dublin, 2017 (https://www.gov.ie/en/collection/005664-action-plan-for-education-2017/).

([19]) https://www.curriculumonline.ie/Junior-cycle/Short-Courses/Coding/

([20]) https://www.curriculumonline.ie/Senior-cycle/Senior-Cycle-Subjects/Computer-Science

([21]) Organic Law 3/2020 of 29 December modifying Organic Law 2/2006 of 3 May on Education (https://www.boe.es/buscar/act.php?id=BOE-A-2020-17264#df-5); Royal Decree 157/2022 of 1 March establishing the organisation and minimum teachings of primary education (https://www.boe.es/buscar/pdf/2022/BOE-A-2022-3296-consolidado.pdf), p. 26; Royal Decree 217/2022 of 29 March establishing the organisation and minimum teachings of compulsory secondary education (https://www.boe.es/boe/dias/2022/03/30/pdfs/BOE-A-2022-4975.pdf), p. 189; Royal Decree 243/2022 of 5 April establishing the organisation and minimum teachings of the *Bachillerato* (https://www.boe.es/eli/es/rd/2022/04/05/243/dof/spa/pdf), p. 346.

([22]) https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/e1e6cca00a4211eaa727fba41f42a7e9/asr

Lithuanian education authorities have also approved a new curriculum for informatics at secondary level, which will be implemented from September 2023. This curriculum comprises six areas of achievement (digital content creation, algorithms and programming, data mining and information, technological problem-solving, virtual communication and collaboration, and safe behaviour). Informatics education is part of Lithuania's RRP.

In Hungary, the implementation of the new informatics curriculum started in 2020/2021 in grades 1, 5 and 9, and has continued gradually in the years since. The name of the subject changed to digital culture, and the content was modernised to include new fields such as robotics and the use of mobile applications ([23]).

The introduction of the new subject ICT C3 in Malta started in 2018/2019 in grade 7, and continued over the following years, finishing in 2022/2023 in grade 11. The new subject includes the topics of coding, digital ethics, block chain and digital safety, among others ([24]).

Austria updated the curricula for primary, general lower and upper secondary education in 2018, changing from content-oriented to competence-oriented teaching and having a stronger focus on interdisciplinary topics. The reform is still being phased in ([25]).

In 2021/2022, Republika Srpska, in Bosnia and Herzegovina, started to introduce the subject digital world from grade 2 in primary education, with the aim of enhancing students' basic digital skills, increasing their awareness of digital safety and developing their algorithmic thinking ([26]).

The French-speaking cantons in Switzerland have updated the curriculum of the subject media, images and ICT, which is now called digital education, at primary and lower secondary levels, reinforcing the informatics dimension. Changes started to be phased in in 2021/2022 ([27]).

From 2020/2021, students in the 1st grade of upper secondary education in North Macedonia had the opportunity to enrol in the new mathematics / informatics *Gymnasium*. The other grades will follow suit on a year-by-year basis ([28]).

In Serbia, the implementation of the new compulsory subject digital world started in 2020/2021 in the 1st grade, and has continued for the other grades over the following years. The new subject covers topics of computer science, IT, digital society and safety, digital communication, networking and cooperation ([29]).

1.5.2. Curricular reforms under development

In 11 other education systems, the education authorities are planning the development of curricular reforms on informatics education.

In the French Community of Belgium, the new digital strategy is expected to be implemented from 2023/2024. The strategy provides for the inclusion of digital skills in the curriculum from grade 3 in primary education to the end of secondary education.

([23]) https://magyarkozlony.hu/dokumentumok/3288b6548a740b9c8daf918a399a0bed1985db0f/letoltes

([24]) https://curriculum.gov.mt/en/Curriculum/Year-9-to-11/Pages/default.aspx

([25]) https://www.bmbwf.gv.at/Themen/schule/zrp/pp.html

([26]) https://www.rpz-rs.org/sajt/doc/file/web_portal/05/5.2/Nastavni_plan_za_osnovno%20obrazovanje/Nastavni_plan_za_osnovno_vaspitanje_i_obrazovanje_2021.pdf

([27]) https://www.ciip.ch/files/2/Comm_presse_CIIP_PER-EdNum_2021-04.pdf

([28]) https://www.bro.gov.mk/wp-content/uploads/2018/02/Nastaven_plan-Gimnazisko-1.pdf

([29]) https://www.pravno-informacioni-sistem.rs/SlGlasnikPortal/viewdoc?uuid=35c16014-db79-4f8a-bdf3-c2c7d27e27a0

In Denmark, the national exploration project Technology Comprehension (ISCED 1 and 24) has two objectives: (a) to gather knowledge and experiences about whether and how technological comprehension can be taught in primary and lower secondary schools, and (b) to start building the necessary capacity and competences in the educational sector. In the first stage of the project, an expert working group defined the main objectives of the subject area technology comprehension, covering digital empowerment, digital design and design processes, computational thinking, and technological knowledge and skills. In a second stage, 46 schools implemented the objectives, half of them as a separate subject and the other half as part of other subjects. The results were released in October 2021. As part of the project, Danish university colleges and four universities investigated how to develop the necessary competencies to teach technology comprehension. Political discussions will follow on whether and how to include it in the curriculum.

In Greece, the project 'Updating of curricula and creation of educational material in primary and secondary education' was piloted in model and experimental schools in 2020/2021 ([30]). In Luxembourg a number of lower secondary schools piloted the new subject digital sciences in 2021/2022. From the 2022/2023 school year onwards, digital sciences will be integrated into the national curriculum as a new subject (1 hour/week) in all secondary schools. At primary level, education authorities are in the process of updating the *Medienkompass* based on the European digital competence framework for citizens (DigComp) to include artificial intelligence literacy and data literacy.

Fresh legislation in Italy provides for the introduction of computer programming (as a subject and integrated into other subjects) and the further development of digital skills in primary and secondary education ([31]). Reforms on informatics education are part of the Italian RRP ([32]). Cyprus's RRP foresees changes to the curricula and the development of educational material for enhancing digital and science, technology, engineering and mathematics skills. The replacement of Pascal with the Phyton programming language at lower secondary level is also planned for 2022/2023. Slovenia's RRP envisages the revision of the school curricula to include digital skills and cover basic informatics content in different subjects at primary and secondary levels ([33]). Slovakian education authorities are also preparing a curricular reform for all subjects and levels of general education as a part of their RRP ([34]).

In the Netherlands, different proposals to enhance informatics education in primary and secondary education are being investigated. Romania is planning to update the whole curriculum of general upper secondary education, including the area of informatics. Iceland is also in the process of revising the overall curricula for primary and secondary education, but concrete proposals for the area of informatics have not yet been developed.

([30]) http://www.iep.edu.gr/el/espa-2014-2020/14-anabathmisi-programmaton-spoudon-dimiourgia-ekpaideytikou-ylikou-mis-5035542; http://www.iep.edu.gr/el/espa-2014-2020/15-epimorfosi-ekpaideutikon-sta-programmata-spoudon-mis-5035543

([31]) Law No 233/2021 of 29 December 2021 (https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:2021-12-29;233).

([32]) *Piano Nazionale di Ripresa e Resilienza*, 2021 (https://www.governo.it/sites/governo.it/files/PNRR.pdf), p. 187.

([33]) https://www.gov.si/en/registries/projects/the-recovery-and-resilience-plan/about-the-recovery-and-resilience-plan/smart-sustainable-and-inclusive-growth/strengthening-competences-especially-digital-and-those-required-by-new-occupations-and-the-green-transition/

([34]) https://www.planobnovy.sk/site/assets/files/1046/komponent_07_vzdelavanie-21-storocie_1.pdf; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX %3A52021PC0339&qid=1624628625594

CHAPTER 2: LEARNING OUTCOMES

Informatics is still a relatively new discipline in school education. While some European countries have a long-standing history of teaching it, others have only recently introduced this subject, especially in primary and lower secondary education (see Chapter 1). In addition, some have been revising and updating related curricula in recent years. Moreover, a shared understanding of this discipline in Europe has only recently started to be developed (Caspersen et al. 2022). Besides the many different names for informatics in national languages (see Chapter 1 and Annex 1), a range of terms is used in this area with different meanings. This lack of consistent language gives rise to considerable confusion and makes communication and discussion between stakeholders even more difficult (The Royal Society, 2012; Committee on European Computing Education, 2017). It is therefore essential to look beyond the existence and names of subjects and learning modules relating to informatics and examine their content. Analysing the learning outcomes included in curricula is a useful proxy for this.

Regarding the content of the subject over time, it is noticeable that some areas that were considered highly important and formative in terms of academic education when the first higher education degrees were launched and when core technologies (such as logic circuits and operating systems) were in the initial phases of development are now less relevant. However, other areas (such as human–computer interactions and information systems security) are becoming more relevant (Hemmendinger, 2007).

In more recent years, with the ubiquity of the internet and digitised data, the role of empirical analysis and social issues has become more and more relevant in the study of this discipline. Moreover, informatics has moved from being a discipline studied almost exclusively in tertiary education to a subject worthy of being taught at school. This has driven additional changes to its content, including a greater emphasis on the human and social aspects of the discipline itself (K–12 Computer Science Framework, 2016; Connolly, 2020; Nardelli, 2021; Caspersen et al., 2022).

In the beginning informatics was perceived as a discipline mainly allowing the quick manipulation of numbers (in line with the initial meaning of the term ‘computer’), predominantly for military or scientific uses. This perception shifted when informatics was found to also allow the manipulation of symbols, resulting in a rapid increase in its use in business for the manipulation of data. With the spreading of the internet, its application also extended to include supporting personal and public communication. Some authors conclude that currently its social impact is becoming more and more relevant, and that the societal aspects of the discipline are receiving more attention in the educational process (Tedre and Denning (2015).

In the 1990s, with the large-scale distribution of personal computers across many European households, most authorities responsible for education in Europe started discussing what was needed in terms of education to address the challenges of the ‘information society’, as it was called then. The focus was on the operational skills for using computers and their software, and digital literacy for managing information both locally and online. The design of the European Computer Driving Licence certification programme started in 1995, received support through the European Social Fund (Leahy and Dolan, 2010), and was eventually recommended in 2001 by the High Level Group on the Employment and Social Dimension of the Information Society as a Europe-wide certification scheme ([35]). While those skills are certainly important, very little attention was paid to the underlying scientific principles. The trend focusing on skills continued with the establishment of the European e-Skills Forum in 2003 and the 2007 communication on e-skills for the 21st century (European Commission, 2007). At the same time, the United States considered a more comprehensive approach, that is ‘fluency in information technology’. This approach went beyond skills (how to use computer

([35]) https://web.archive.org/web/20080627232227/http://ec.europa.eu/information_society/eeurope/2002/action_plan/eworking/eu/targets_2001_2002/index_en.htm applications) to also consider the basic principles and ideas of the discipline and intellectual capabilities (problem-solving ability), integrating them all in a unified approach (Committee on Information Technology Literacy, 1999).

A decade later, the widely circulated report *Running on Empty* was published (Wilson et al., 2010), clearly arguing in favour of the importance of students having a deeper understanding of fundamentals of informatics to be well-educated citizens in the digital world. Moreover, the report found that educational activities focused almost exclusively on skills-based aspects of informatics. Since then, the scientific nature of informatics has received much more attention in educational discourses in the United States.

The current trend is now shifting away from the traditional information technology content, focusing on using digital tools, to a more scientific approach. This is happening in many countries worldwide: the United States (ACM et al., 2016), the United Kingdom (Royal Society, 2012), France (Académie des Sciences, 2013; Baron et al., 2014), Italy (Bellettini et al., 2014), India (Raman et al., 2015), Israel (Armoni and Gal-Ezer, 2014a; Gal-Ezer and Stephenson, 2014), New Zealand (Bell, Andreae and Robins, 2012; Bell, 2014), Denmark (Caspersen, 2021), Poland (Sysło and Kwiatkowska, 2015), Russia (Khenner and Semakin, 2014), Slovakia (Kabátová, Kalaš and Tomcsányiová, 2016) and Sweden (Rolandsson and Skogh, 2014).

In every country, issues in implementing the informatics curriculum are different in their details but similar at their core (see Chapter 1). Moreover, while digital technology is everywhere, the need to give all students an appropriate education on its underlying scientific principles is not widely recognised and accepted, unlike in the fields of physics and biology (Académie des Sciences, 2013; Committee on European Computing Education, 2017).

For the present analysis, informatics in school education is understood by looking at the content that characterises it as a distinct discipline. This was operationalised through the analysis of relevant learning outcomes defined in the related curricula. The selection of 10 core areas of informatics and the references to possible learning outcome formulations stem from the analysis of a range of widely used existing competence and curricular frameworks (see Annex 2).

This first section briefly introduces each of the 10 content areas relating to informatics used in this analysis and the frameworks that were used to select these. It then describes the content of the areas and how it can be expressed in terms of learning outcomes in school education, including concrete examples from school curricula across European countries.

The second section describes the general coverage of the 10 areas in European education systems, including whether those areas are covered within separate subjects or integrated into other subjects and whether they are compulsory for all students, compulsory for some students only or optional. Some starting points for analysing the proportion of students for which those learning outcomes are within non-compulsory subjects are given in the previous chapter (Section 1.4.2). The section also analyses the comprehensiveness of school curricula in relation to the informatics content and the differences and progression between education levels, looking more in depth at each education level from primary to general upper secondary education.

The last section highlights the discussion around how to make informatics at school, and therefore as a career choice, more attractive to girls, giving some examples of policies and initiatives in European countries.

In this analysis, no differentiation is made between the terms ‘learning objectives’ and ‘learning outcomes’, although the latter is most commonly used throughout this text. The terms can be seen as two sides of the same coin: while learning objectives refer to the content from the perspective of the education authorities, schools and teachers, learning outcomes refer to the same content but from the perspective of the learners. In the context of this report, learning outcomes are defined as statements of what learners know, understand and are able to do on completion of a level or learning module (Harvey, 2004-22).

Learning outcomes give an indication of the content of subjects and of what skills students should develop during school education. Those relating to informatics can be achieved within a separate subject or within modules integrated into other subjects.

Obviously, the content of teaching and learning is not limited to that specified in top-level regulations on curricula. The content is also defined by individual teachers, by teaching materials and finally by the schools themselves through the general framework in terms of overall objectives and training. However, curricula are the central and leading guidelines teachers work with to structure their teaching and learning processes. They are also a robust source that allows for a comparative analysis across the wide range of European education systems. They can give an indication of the extent to which the informatics-related school subjects focus mainly on informatics as a distinct scientific discipline, or on specific areas of informatics, as opposed to emphasising digital literacy or the use of information technology. It is therefore worth looking at their content.

As seen in the previous chapter, there are a variety of situations across Europe regarding informatics education. There is variation not only in the approaches to teaching informatics (as a separate subject or integrated into other subjects), but also in the nature, scope and focus of these specific informatics subjects.

2.1. Informatics-related learning outcomes in 10 content areas

2.1.1. Sources of existing frameworks and methodology

While a lot of work has been done regarding digital competences as a key competence, at present there is not a shared reference framework for the content of informatics subjects in school education. At European level, the reference framework for digital competence is the digital competence framework for citizens (DigComp). Its latest version was published in March 2022 (Vuorikari, Kluzer and Punie, 2022), with the five main areas and 21 skills remaining the same, but with updated examples of knowledge, skills and attitudes that highlight contemporary themes, including emerging digital technologies and practices. However, digital competences, when defined as key competence, while overlapping in certain aspects with informatics as a scientific discipline, do not have the same focus and content. To feed into and support work in European countries that aims to further develop and strengthen informatics education at school, a specific reference framework was recently developed by the Informatics for All coalition ([36]). The current analysis draws from seven computer science/informatics frameworks existing at the time of data collection, summarised in a selection of 10 areas (see Figure 2.1 and Annex 2).

Comparing these frameworks allows the identification of recurrent core areas and examples of learning outcomes that define informatics as an independent scientific discipline (irrespective of whether it is taught as a separate subject or it is integrated into other subjects) in primary and general secondary school education curricula. The purpose is to provide a better understanding of the subject, its concepts and content and to frame the description of related curricula across Europe. Therefore,

([36]) https://www.informaticsforall.org/wp-content/uploads/2022/03/Informatics-Reference-Framework-for-School-release-February-2022.pdf the descriptions and learning outcome examples are neither prescriptive nor exhaustive. Rather, they intend to guide and enable a shared understanding and discussion.

Figure 2.1: Selection of 10 areas related to informatics in European education systems, 2020/2021

1	Data and information	6	People–system interface
2	Algorithms	7	Design and development
3	Programming	8	Modelling and simulation
4	Computing systems	9	Awareness and empowerment
5	Networks	10	Safety and security

Source: Eurydice.

Explanatory notes

The areas were selected through the analysis of existing informatics/computer science frameworks in Europe and beyond to capture the recurrent content. However, this list is neither exhaustive nor prescriptive. For details, refer to Annex 2.

The selection of areas draws from the analysis of the following existing sources and frameworks, covering different proficiency levels from primary to general upper secondary education:

- National curriculum for computing from the Department for Education (United Kingdom, Department for Education, 2013) ([37]),
- K–12 computer science framework (2016) ([38]),
- Massachusetts curriculum framework for digital literacy and computer science (2016) ([39]),
- Computational thinking construct in the International Computer and Information Literacy Study (ICILS, 2018) ([40]),
- Computational thinking framework from the Raspberry Pi Foundation (2020) ([41]),
- Microsoft computer science framework ([42]),
- Informatics reference framework for school (Caspersen et al., 2022) ([43]).

2.1.2. Main areas of informatics education in terms of learning outcomes

This section provides a short description of each area illustrated by several exemplary learning outcomes, concrete examples from school curricula across Europe and general observations regarding their place within informatics education.

The following 10 areas aim to capture the recurrent content in existing competence frameworks and therefore to give a general understanding of the possible content of informatics subjects. For most of the areas, the definitions stem from the K–12 computer science framework, as it is very comprehensive and widely used in the United States but also in Europe, offering examples of progression from primary education to upper secondary. However, the mapping of learning outcomes in school curricula across Europe was further guided by examples from all seven sources and frameworks mentioned in Figure 2.1 (see Annex 2 for more details). This section gives an initial

([37]) https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study

([38]) www.k12cs.org

([39]) http://masscan.edc.org/documents/publications/DLCS_MA_Curriculum_Framework-June_2016.pdf

([40]) https://education.ec.europa.eu/document/the-2018-international-computer-and-information-literacy-study-icils-main-findings-and-implications-for-education-policies-in-europe

([41]) https://www.raspberrypi.org/app/uploads/2020/09/Raspberry_Pi_Foundation_Computational_Thinking_Framework_v1.pdf

([42]) https://edudownloads.azureedge.net/msdownloads/Microsoft-Computer-Science-Framework.pdf

([43]) https://www.informaticsforall.org/wp-content/uploads/2022/03/Informatics-Reference-Framework-for-School-release-February-2022.pdf overview of the number of education systems that explicitly cover the different areas in terms of learning outcomes.

Data and information

Digital computing systems ([44]), referred to in the following section simply as 'computing systems', process data represented in digital form, that is as a finite set of signs/characters taken from a finite alphabet (almost universally an alphabet of just two symbols / binary code is used) ([45]). As the amount of digital data generated is rapidly expanding, effective data processing is becoming increasingly important.

> *Data is collected and stored so that it can be analysed to better understand the world and make more accurate predictions. … Core functions of computers are storing, retrieving, and processing data. In early grades, students learn how data is stored on computers. As they progress, students learn how to evaluate different storage and processing methods, including the trade-offs associated with those methods. … Transmitting information securely across networks requires appropriate protection. In early grades, students learn how to protect their personal information. As they progress, students learn increasingly complex ways to protect information sent across networks* (K–12 Computer Science Framework, 2016, pp. 89–90).

The following examples illustrate how learning outcomes for this area are formulated in school curricula in Europe, addressing the scientific principles but also covering information and data literacy.

In **Czechia**, this area is addressed within the aims of the information and communications technology (ICT) educational content, which include, at primary level, 'understanding the flow of information from its generation, storage on a medium, transfer, processing, retrieval by search and practical use' ([46]), therefore overlapping with information and data literacy.

In **Slovenia**, at the same level the learning outcomes are more theoretical: 'pupils should understand binary system for representing data. And know that the data can be compressed lossless and with loss of information' ([47]). Similarly, in **Ireland** in lower secondary education, 'students should be able to explain how computers represent data using 1s and 0s' (junior cycle short course in coding) ([48]).

The **Swiss** curriculum also includes learning outcomes related to the area of data and information that clearly go beyond basic data literacy and are characteristic of informatics as a discipline: in primary education, 'pupils can represent structure and evaluate data from their environment'. In addition, 'pupils can encrypt data using secret scripts they have developed themselves'. In lower secondary education, 'pupils can distinguish and apply methods for data replication (backup, synchronisation, versioning)' ([49]). In upper secondary education, students can 'understand the relationships and differences between signs, data and information' ([50]).

([44]) This report only deals with 'digital computing systems', that is systems that process data represented in digital form. The term 'computing systems' is used as a shorthand for 'digital computing systems'. Indeed, 'analogue computing systems', based on the representation of values to be manipulated by means of continuous physical quantities (e.g. voltage or current), were generally phased out during the late 1970s (see https://dl.acm.org/doi/10.5555/1074100.1074123).

([45]) See definition in *Encyclopaedia Britannica* (https://www.britannica.com/technology/digital-computer).

([46]) Ministry of Education, Youth and Sports, Framework Education Programme for Basic Education, 2021 (https://www.edu.cz/rvp-ramcove-vzdelavaci-programy/ramcovy-vzdelavacici-program-pro-zakladni-vzdelavani-rvp-zv/), p. 38.

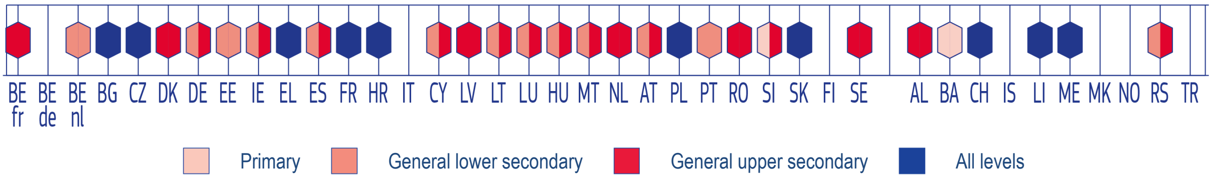
([47]) Ministry of Education, Science and Sport, *Računalništvo* (https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/Osnovna-sola/Ucni-nacrti/izbirni/Neobvezni/Racunalnistvo_izbirni_neobvezni.pdf), p. 6.

([48]) The computer science/informatics curriculum specification, known as the junior cycle short course in coding, is available on the website of the National Council for Curriculum and Assessment (https://www.curriculumonline.ie/Junior-cycle/Short-Courses/Coding/Expectations-for-Students-Learning-outcomes/).

([49]) https://v-fe.lehrplan.ch/index.php?code=a|10|0|2|0|1

([50]) Swiss Conference of Cantonal Ministers of Education: *Rahmenlehrplan für die Maturitätsschulen: Informatik* (https://edudoc.ch/record/131917/files/rlp_inf_2017_d.pdf), p. 4.

Area 1: Data and information



While the majority of education systems address data and information at secondary level, 10 education systems already define learning outcomes relating to this area from primary education level to upper secondary education level (Bulgaria, Czechia, Greece, France, Croatia, Poland, Slovakia, Switzerland, Liechtenstein and Montenegro).

Algorithms

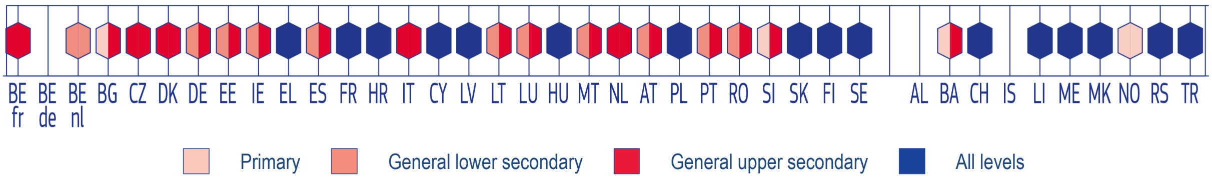
Informally speaking, 'an algorithm is a sequence of steps designed to accomplish a specific task. Algorithms are translated into programs, or code, to provide instructions for computing devices. … In early grades, students usually learn about age-appropriate algorithms from the real world. As they progress, students learn about the development, combination, and decomposition of algorithms, as well as the evaluation of competing algorithms' (K–12 Computer Science Framework, 2016, p. 91).

The possible progression of learning outcomes relating to algorithms is clearly visible in the following examples from the Croatian and Hungarian informatics curricula.

In **Croatia**, the curricula of the informatics subject, which is optional in some grades and compulsory in other grades (see Chapter 1, Section 1.2-1.4), show how complexity can increase progressively. In primary education, the student 'follows and presents a sequence of steps required for solving a simple task' and 'solves more complex logical tasks with or without [a] computer (unplugged computing)'. In lower secondary education, the student 'creates an algorithm for solving a simple task, checks if the algorithm is correct, [and] discovers and fixes errors'. Finally, in upper secondary education, the student 'analyses basic algorithms with simple data types and basic programme structures and applies them while solving new problems' and 'analyses traditional cryptographic algorithms and describes the basic idea of modern cryptographic systems' ([51]).

Similarly, **Hungary** offers the subject informatics / digital culture from primary to upper secondary education, and the learning outcomes linked to the area of algorithms show a clear progression. In primary education, students learn to 'recognise, act out, [and] implement some of the elementary steps experienced in everyday activities, actions to be performed in a given sequence', and to 'break down a given algorithm from everyday life into elementary steps, interpret the sequence of steps, [and] formulate the expected outcome of the algorithm'. Then, in lower secondary education, students have to 'interpret the relationship between the data needed to execute the algorithm and the results', and 'analyse and construct simple algorithms'. Finally, in upper secondary education the students must 'understand the basic building blocks of an algorithm description tool and understand the possible use of types of algorithms' ([52]).

Area 2: Algorithms



More than half of the countries already have learning outcomes relating to algorithms in primary education. In nearly half of the countries, this area is explicitly covered at all three education levels.

([51]) Ministry of Science and Education, *Curriculum of the subject informatics for primary schools and gymnasiums* (https://mzo.gov.hr/UserDocsImages/dokumenti/Publikacije/Predmetni/Kurikulum %20nastavnog %20predmeta %20Informatika %20za %20osnovne %20skole %20i %20gimnazije.pdf), pp. 12–33.

([52]) National curriculum 2012 (https://ofi.oh.gov.hu/sites/default/files/attachments/mk_nat_20121.pdf); National curriculum 2020 (https://magyarkozlony.hu/dokumentumok/3288b6548a740b9c8daf918a399a0bed1985db0f/letoltes), pp. 430, 432 and 433.

Algorithms is an area that appears regularly as part of mathematics teaching, such as in Finland (in an optional module called algorithm and number theory at upper secondary level) and Norway.

Programming

Programs implementing algorithms:

> *control all computing systems, empowering people to communicate with the world in new ways and solve compelling problems. The development process to create meaningful and efficient programs involves choosing which information to use and how to process and store it, breaking apart large problems into smaller ones, recombining existing solutions, and analysing different solutions. … Programs are developed through a design process that is often repeated until the programmer is satisfied with the solution. In early grades, students learn how and why people develop programs. As they progress, students learn about the trade-offs in program design associated with complex decisions involving user constraints, efficiency, ethics, and testing. … Modularity involves breaking down tasks into simpler tasks and combining simple tasks to create something more complex. In early grades, students learn that algorithms and programs can be designed by breaking tasks into smaller parts and recombining existing solutions. As they progress, students learn about recognizing patterns to make use of general, reusable solutions for commonly occurring scenarios and clearly describing tasks in ways that are widely usable* (K–12 Computer Science Framework, 2016, p. 91).

It is important to underline that this area is closely connected to the previous area, algorithms, and that some curricula will treat these two as one area. Where this is the case, it can be difficult to distinguish between both areas in terms of learning outcomes (e.g. in Estonia and Slovakia).

> In the **Slovak** curriculum of informatics, for example, there is no special part focusing on programming. However, related learning outcomes are integrated into those relating to algorithms. They are divided into the following categories: algorithmic problem-solving – problem analysis, using a programming language, sequences of commands, cycles (loops), branches, variables, tools for interaction and the interpretation of a programme. The school or teachers themselves choose the programming language ([53]).

In general, curricula do not mention specific programming languages. Instead, they focus on basic principles, and the schools and the individual teachers choose the programming language. Indeed, a peculiar challenge of informatics is that the practical part of the curricula is essential to get a good grasp of the subject but risks rapidly becoming obsolete, given the high pace of change in technology. This problem can be seen clearly in the area of programming languages used in software development, where new languages are regularly designed and released to support technological advances. However, the foundations of programming languages are by now stable, and anybody who has grasped their principles will be able to use the latest language by only updating the specific vocabulary. Some European school curricula mention block programming, or visual programming, and only very rarely specific programmes such as Scratch (e.g. in the informatics curriculum for grade 7 in North Macedonia).

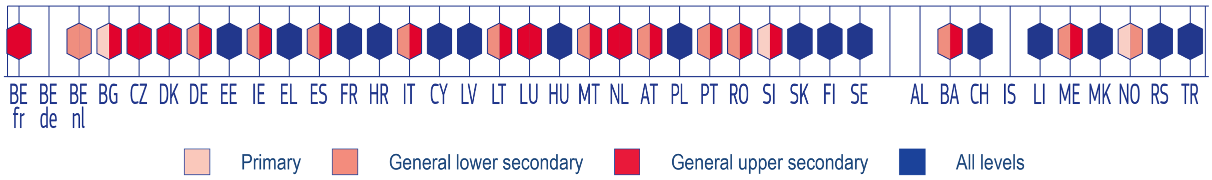
The Polish informatics curriculum illustrates the progression in the area of programming, with increasing complexity.

> In **Poland**, the subject informatics is offered to all students at all three education levels. Learning outcomes are therefore incremental. Related to programming, the primary education student 'designs, creates and writes in a visual programming language:

([53]) National Institute for Education, *Informatics – Primary education*, 2014 (https://www.statpedu.sk/files/articles/dokumenty/inovovany-statny-vzdelavaci-program/informatika_pv_2014.pdf), pp. 3–10; National Institute for Education, *Informatics – Lower secondary education*, 2014 (https://www.statpedu.sk/files/articles/dokumenty/inovovany-statny-vzdelavaci-program/informatika_nsv_2014.pdf), pp. 3–31; National Institute for Education, *Informatics – Grammar school with 4-year and 5-year educational programme* (https://www.statpedu.sk/files/articles/dokumenty/inovovany-statny-vzdelavaci-program/informatika_g_4_5_r.pdf), pp. 3–18.

story ideas and problem solutions, including simple algorithms using sequential, conditional and iterative commands and events. The learner designs, creates and writes in visual programming language: a simple programme that controls a robot or other object on a computer screen.' In lower secondary education, 'the learner designs, develops and tests programmes in the process of problem solving. In programmes he/she uses: input/output instructions, arithmetic and logical expressions, conditional instructions, iterative instructions, functions and variables and arrays. In particular, the learner programs basic algorithms (on natural numbers and search and order).' In upper secondary education, 'the student programs algorithms' ([54]).

Area 3: Programming



Learning objectives linked to programming, such as for the area of algorithms, are already quite common in school curricula across Europe. In nearly half of the countries, these are included from primary education up to upper secondary education.

Computing systems

People interact with a wide variety of computing devices that collect, store, analyse, and act upon data in ways that can affect human capabilities both positively and negatively. The physical components (hardware) and instructions (software) that make up a computing system communicate and process data in digital form. An understanding of hardware and software is useful when troubleshooting a computing system that does not work as intended. […] Computing systems use hardware and software to process and communicate data in digital form. In early grades, students learn how systems use both hardware and software to represent and process information. As they progress, students gain a deeper understanding of the interaction between hardware and software at multiple levels within computing systems (K–12 Computer Science Framework, 2016, p. 89) ([55]).

The following examples show how European school curricula formulate learning outcomes in this area.

In **Bulgaria**, at lower secondary level the 5th grade curriculum describes the concepts of software, hardware and computer systems and indicates the relationship between hardware and software ([56]). In **Germany**, at the same education level, 'pupils explain the principle of input, processing and output of data (EVA principle) as a basic working principle of computer science systems' ([57]).

In **Czechia**, at upper secondary level, the 'pupil will utilise his/her theoretical as well as practical knowledge of the functions of individual components of both hardware and software to solve problems creatively and effectively' (in the subject information science

([54]) For ISCED 1 and 24, see Ministry of National Education, Regulation of the Ministry of National Education of 14 February 2017 on the core curriculum for preschool education and the core curriculum for general education for primary schools, including students with moderate or severe intellectual disabilities, general education for the 1st degree industry school, general education for special schools preparing for work and general education for post-secondary schools (http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20170000356), pp. 176–178; For ISCED 34, see Ministry of National Education, Regulation of the Ministry of National Education of 30 January 2018 on the core curriculum for general education for general secondary schools, technical secondary schools and second-cycle industry schools (https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180000467), p. 298.

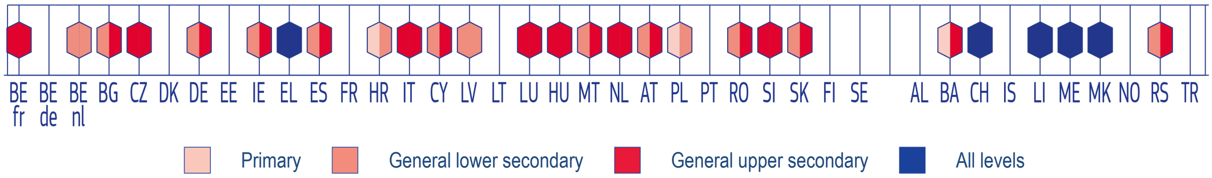
([55]) For definitions of hardware and software, see the 2016 Massachusetts digital literacy and computer science curriculum framework (http://masscan.edc.org/documents/publications/DLCS_MA_Curriculum_Framework-June_2016.pdf).

([56]) Ministry of Education and Science, *Information Technologies Curriculum for 5th Grade* (https://www.mon.bg/upload/13484/UP_V_IT.pdf), theme 1.1, p. 3.

([57]) German Informatics Society, Principles and Standards for Computer Science at School – Educational standards in computer science for secondary level I: Recommendations of the German Informatics Society (GI) e.V., 2008 (https://informatikstandards.de/fileadmin/GI/Projekte/Informatikstandards/Dokumente/bildungsstandards_2008.pdf), p. 16.

and ICT) (58). In the **Netherlands**, at the same level, 'the candidate is able to explain the structure and functioning of digital artefacts in terms of architectural elements, i.e. in terms of the physical, logical and applications level layers, and in terms of the components in these layers and their mutual interaction' (59).

Area 4: Computing systems



It is rather rare across Europe to address this area from primary education (only Greece, Croatia, Poland, Bosnia and Herzegovina, Switzerland, Liechtenstein, Montenegro and North Macedonia). Furthermore, only 5 of these countries have learning outcomes relating to computing systems at all three education levels. However, more than half of the countries explicitly include this area in their informatics curricula from lower secondary education.

Networks

Computing devices typically do not operate in isolation. Networks connect computing devices to share information and resources and are an increasingly integral part of computing. Networks and communication systems provide greater connectivity in the computing world by providing fast, secure communication and facilitating innovation. … Computing devices communicate with each other across networks to share information. In early grades, students learn that computers connect them to other people, places, and things around the world. As they progress, students gain a deeper understanding of how information is sent and received across different types of networks (K–12 Computer Science Framework, 2016, p. 89).

The Irish curriculum for lower secondary education and the Latvian curricula for all three education levels provide clear examples of learning outcomes related to networks.

In **Ireland**, lower secondary students taking the optional junior cycle short course in coding 'should be able to discuss the basic concepts underlying the internet, [and] describe how data is transported on the internet and how computers communicate and cooperate through protocols' (60).

The **Latvian** computer science curricula in primary and lower secondary education (where it is a compulsory subject), shows what progression can look like in this area. In primary education, the student 'explains that software-controlled devices can be connected to a variety of computer networks, which can have different usage conditions'. Then, in lower secondary education, the student 'explains the basic principles of a simple computer network structure (including the client–server architecture) and classifies the most frequently connected devices to computer networks and describes the possibilities of their use by modelling examples of the most frequently used computer networks'. Finally, for those students who chose the subject programming in upper secondary education, the objective is to 'compare different types of computer networks, their structure, security solutions and usage possibilities according to the target audience' (61).

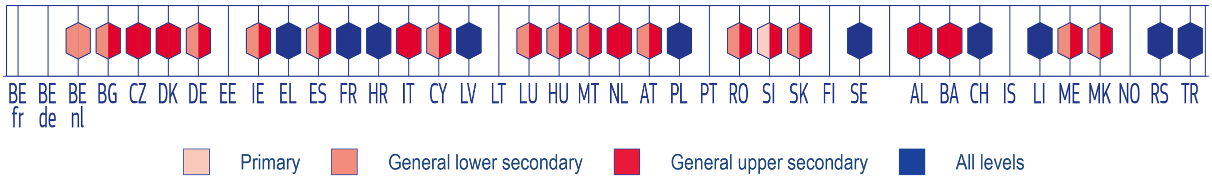
(58) Framework Education Programme for General Upper Secondary Education (https://www.edu.cz/rvp-ramcove-vzdelavaci-programy/ramcove-vzdelavaci-programy-pro-gymnazia-rvp-g/).

(59) Examenblad.nl, *Examination Programme HAVO/VWO* (https://www.examenblad.nl/examenstof/informatica-havo-en-vwo-3/2022/f=/examenprogramma_Informatica_havo-vwo.pdf), p. 3.

(60) The computer science/informatics curriculum specification, known as the junior cycle short course in coding, is available on the website of the National Council for Curriculum and Assessment (https://www.curriculumonline.ie/Junior-cycle/Short-Courses/Coding/Expectations-for-Students-Learning-outcomes/).

(61) https://likumi.lv/ta/id/309597-noteikumi-par-valsts-visparejas-videjas-izglitibas-standartu-un-visparejas-videjas-izglitibas-programmu-paraugiem; Republic of Latvia, Regulations regarding the State basic education standard and model basic education programmes (https://likumi.lv/ta/id/303768-noteikumi-par-valsts-pamatizglitibas-standartu-un-pamatizglitibas-programmu-paraugiem), pp. 55–62.

Area 5: Networks



Nearly a dozen countries already address the area of networks in primary education. In upper secondary education, three quarters of European education systems include explicit learning outcomes relating to this area in their curricula. A total of 10 countries have learning outcomes relating to networks at all three education levels (Greece, France, Croatia, Latvia, Poland, Sweden, Switzerland, Liechtenstein, Serbia and Turkey).

People–system interface

The people–system interface area, also called human–machine interaction, aims to develop an understanding of the requirements for interaction between people and computing artefacts (Caspersen et al., 2022). 'Developing effective and accessible user interfaces involves the integration of technical knowledge and social sciences and encompasses both designer and user perspectives' (K–12 Computer Science Framework, 2016, p. 88). In early grades, students learn how to consider diverse user and community needs in the design of digital artefacts. As they progress, students study the people–system interface to test and improve the design of digital artefacts, considering usability, security and accessibility, among other things.

Specific learning outcomes for the people–system interface area are rarer in European school curricula, but the following examples show how it is possible to address the consideration of (end-) user needs and thus of the interaction between people and computing artefacts.

> The informatics / digital culture curriculum in **Hungary**, for example, aims to enable primary education students to 'explain, with a few examples, how the use of a given tool makes the user's work easier'. At lower secondary level, students 'understand the importance of end-users' needs', and at upper secondary level students 'consider the specific needs of users of systems and software' ([62]).
>
> In **Latvia**, the lower secondary education curriculum for the subject computer science includes the following learning outcome: 'when testing the [design] solution, the opinion of users is obtained and appropriate improvements are made' ([63]).
>
> In **Denmark**, upper secondary students taking the subject informatics B 'analyse and evaluate how IT [information technology] systems affect and influence human activities and apply user-oriented techniques for the construction of IT systems' ([64]). In **Estonia**, at the same education level students choosing the subject digital services 'justify the technological choices and steps made in the created project from the point of view of system[s], technology, equipment, etc. [, and] security as well as practicality; describe the target group of the digital solution and its needs, [and] formulate the goals and results of the project (development requirements); and analyse existing digital solutions in the chosen field' ([65]). In **Sweden**, the subject computers and ICT in upper secondary education includes the human–machine interface, 'from [the] use of software for visualising data in real-time to safe and user friendly interfaces' ([66]).

([62]) National curriculum 2012 (https://ofi.oh.gov.hu/sites/default/files/attachments/mk_nat_20121.pdf); national curriculum 2020 (https://magyarkozlony.hu/dokumentumok/3288b6548a740b9c8daf918a399a0bed1985db0f/letoltes), pp. 430, 431 and 432.

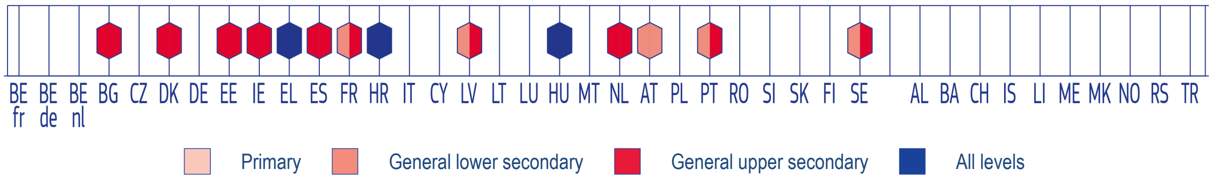
([63]) Skola 2030, *Computers Grades 1–9 –Sample of the subject programme* (https://mape.skola2030.lv/resources/327), grade 9, p. 56.

([64]) Ministry of Children and Education, *Læreplan Informatik B – hhx, htx 2017* (https://www.uvm.dk/gymnasiale-uddannelser/fag-og-laereplaner/laereplaner-2017/htx-laereplaner-2017) (Scroll down to locate 'Informatik'), p. 2.

([65]) Teachers' guide for the new informatics syllabus for upper secondary school (https://web.htk.tlu.ee/digitaru/digiteenused/front-matter/introduction/).

([66]) Skolverket, *Curriculum for the compulsory school, preschool class and school-age educare*, 2018 (https://www.skolverket.se/download/18.4fc05a3f164131a74181051/1535372296811/Computers-and-ICT-swedish-school.pdf), p. 16.

Area 6: People–system interface



This area is less developed in European school curricula in terms of learning outcomes. Only 3 countries (Greece, Croatia and Hungary) already include explicit learning outcomes relating to the people–system interface in primary education and only slightly more than a dozen countries have learning outcomes relating to this area in upper secondary education.

Design and development

The area of design and development involves planning and creating digital artefacts through an iterative and incremental process, taking into account stakeholders' viewpoints and critically evaluating alternatives and their outcomes, as well as modelling suitable representations of information and behaviour (Caspersen et al., 2022). 'This process … includes understanding the development life cycle, such as testing, usability, documentation, and release' (Massachusetts Department of Elementary and Secondary Education, 2016, p. 16).

In early grades, students learn how and why people develop digital artefacts. As they progress, students learn about the trade-offs in the design and development process, associated with complex decisions involving user constraints, efficiency, ethics and testing (K–12 Computer Science Framework, 2016, p. 91).

In this context, a literature review focusing on identifying informatics learning objectives that experts deemed important to teach led to the identification of a category of learning objectives with the highest discrepancy between what is predicated to be achieved and what is actually achieved. This category is dealing with the high-level planning of computational solutions, that is beginning to find a computational solution to a real-world problem (Rich, Strickland and Franklin, 2017). This is clearly related to the area of design and development but also to the area of modelling and simulation, both indeed currently less present in European informatics curricula than other areas.

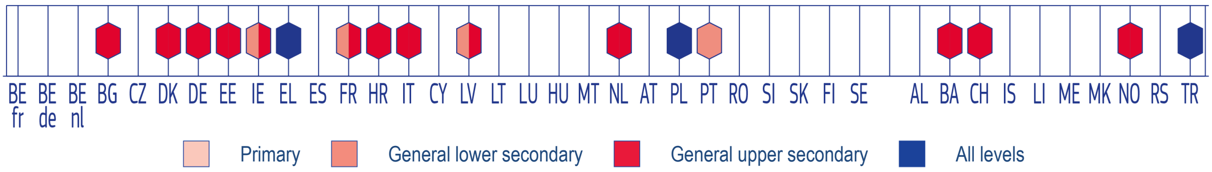
The learning outcome examples from the Irish and Dutch upper secondary curricula give an idea of how design and development is currently included in European school curricula.

> The **Irish** upper secondary leaving certificate in computer science addresses this area very clearly: 'students should be able to identify features of both staged and iterative design and development processes, [and] Students should be able to compare two different user interfaces and identify different design decisions that shape the user experience' ([67]).
>
> Similarly, the **Netherlands** has very explicit learning outcomes relating to this area in its (optional) informatics subject at upper secondary level. The curriculum states that 'the candidate can: see opportunities in a context for the use of digital artefacts; translate these capabilities into a design and development objective, taking into account technical, environmental and human factors; specify wishes and requirements and test them for feasibility; design a digital artefact; weigh choices in the design of a digital artefact through research and experimentation; implement a digital artefact; evaluate the quality of digital artefacts, and use these skills together to develop digital artefacts' ([68]).

([67]) The computer science/informatics curriculum specification, known as the leaving certificate in computer science, is available on the website of the National Council for Curriculum and Assessment (https://www.curriculumonline.ie/Senior-cycle/Senior-Cycle-Subjects/Computer-Science/Strands-and-learning-outcomes/).

([68]) Examenblad.nl, *Examination Programme HAVO/VWO* (https://www.examenblad.nl/examenstof/informatica-havo-en-vwo-3/2022/f=/examenprogramma_Informatica_havo-vwo.pdf), p. 3.

Area 7: Design and development



Like the previous area, the area of design and development does not seem to be very explicitly included in European school curricula. Only 3 countries (Greece, Poland and Turkey) have learning outcomes relating to this area at all three education levels. Another 3 countries (Ireland, France and Latvia) address this area both in lower secondary education and in upper secondary education. This area is mostly present in upper secondary education, where it is included in more than a third of European countries.

Modelling and simulation

> *Computational modelling and simulation help people to represent and understand complex processes and phenomena. Computational models and simulations are used, modified, and created to analyse, identify patterns, and answer questions of real phenomena and hypothetical scenarios* (Massachusetts Department of Elementary and Secondary Education, 2016, p. 16).
>
> *Data science is one example where informatics serves many fields. [With informatics methods and techniques, one can] use data to make inferences, test theories, or formulate predictions based on the data collected from users or simulations. In early grades, students [usually] learn about the use of data to make simple predictions. As they progress, students learn how models and simulations can be used to examine theories and understand systems and how predictions and inferences are affected by more complex and larger data sets* (K–12 Computer Science Framework, 2016, p. 90).

The following examples from European school curricula illustrate how learning outcomes relating to modelling and simulation are formulated from primary education.

In **Greece**, at primary education level the ICT curriculum includes the 'use of a simulation tool to understand the behaviour of a real-world system' and the 'use [of] a simulation tool to make predictions of future scenarios based on given data' ([69]).

In **Ireland**, upper secondary students taking the leaving certificate in computer science 'should be able to develop a model that will allow different scenarios to be tested' ([70]). Moreover, 'modelling and simulation' is one of the applied learning tasks, in which 'students will engage with a problem that is difficult to solve analytically, but that is amenable to a solution using simulation or modelling. Students will develop a computer system that simulates or models the problem. Engaging with a problem in this way will heighten students' awareness and understanding of how algorithms can be used across a wide range of disciplines and subjects.'

Again at upper secondary level, in the **Netherlands**, 'the candidate can model aspects of another scientific discipline in computational terms. The candidate is able to construct and use models and simulations to investigate phenomena in that other science' (this is part of the optional subject informatics) ([71]).

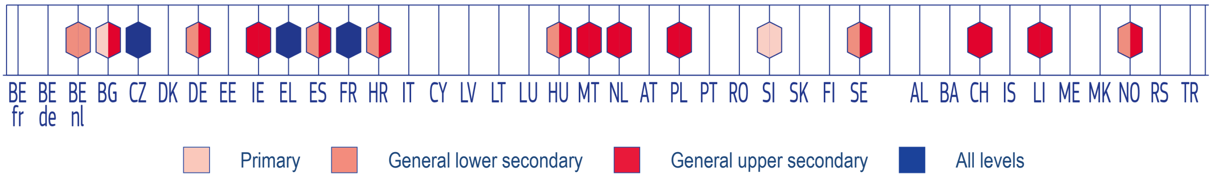
([69]) Ministry of Education and Religious Affairs, *ICT Guidelines for Primary School* (http://www.iep.edu.gr/images/IEP/EPISTIMONIKI_YPIRESIA/Epist_Grafeia/Graf_Ereynas_B/2020/ΤΠΕ-ΦΥΣΙΚΗ_ΑΓΩΓΗ-2020-21.zip), part 1, pp. 6 and 77.

([70]) The computer science/informatics curriculum specification, known as the leaving certificate in computer science, is available on the website of the National Council for Curriculum and Assessment (https://www.curriculumonline.ie/Senior-cycle/Senior-Cycle-Subjects/Computer-Science/Strands-and-learning-outcomes/).

([71]) Examenblad.nl, *Examination Programme HAVO/VWO* (https://www.examenblad.nl/examenstof/informatica-havo-en-vwo-3/2022/f=/examenprogramma_Informatica_havo-vwo.pdf), p. 6.

In **France**, related learning outcomes are included at all three education levels. In primary education, the subjects science and technology include 'modelling reality (mock-up, geometric and digital models) and representation in computer-aided design'. In lower secondary education (in the subject technology), students 'digitally simulate the structure and/or behaviour of an object'. Finally, upper secondary students in the subject digital science and technology 'write and develop programmes to respond to problems and model physical, economic and social phenomena' ([72]).

Area 8: Modelling and simulation



Modelling and simulation is yet another area that informatics school curricula do not often address. Only 5 countries have explicit learning outcomes for this area in primary education (Bulgaria, Czechia, Greece, France and Slovenia), and only 3 out of these address this at all three education levels (Czechia, Greece and France). A bit more than a third of European education systems include this area in upper secondary education.

Awareness and empowerment

Computing affects many aspects of the world in both positive and negative ways at local, national, and global levels. Individuals and communities influence computing through their behaviours and cultural and social interactions, and in turn, computing influences new cultural practices. An informed and responsible person should understand the social implications of the digital world, including equity and access to computing. Computing influences culture – including belief systems, language, relationships, technology, and institutions – and culture shapes how people engage with and access computing. In early grades, students learn how computing can be helpful and harmful. As they progress, students learn about trade-offs associated with computing and potential future impacts of computing on global societies (K–12 Computer Science Framework, 2016, p. 92).

Data is collected with both computational and non-computational tools and processes. In early grades, students learn how data about themselves and their world is collected and used. As they progress, students learn the effects of collecting data with computational and automated tools (K–12 Computer Science Framework, 2016, p. 90).

This area, although an essential part of informatics, can often be addressed in other parts of the curriculum, for example in social sciences. It can also be taught across all subjects, as it is linked to transversal competences such as critical thinking and responsibility.

The Estonian curriculum illustrates that awareness and empowerment can be specifically addressed in an informatics subject as well as being taught as part of the development of digital competence, while the Polish curriculum shows how learning outcomes for this area can progress incrementally and the Portuguese and Cypriot curricula provide more examples of learning outcomes in this area in secondary education.

([72]) Ministry of National Education, Youth and Sports, *Programme Cycle 3* (https://cache.media.eduscol.education.fr/file/A-Scolarite_obligatoire/37/5/Programme2020_cycle_3_comparatif_1313375.pdf), pp. 86–87;
Ministry of National Education, Youth and Sports, *Programme Cycle 4* (https://cache.media.eduscol.education.fr/file/A-Scolarite_obligatoire/37/7/Programme2020_cycle_4_comparatif_1313377.pdf), pp. 122–126;
Ministry of National Education and Youth, *Programme SNT* (https://eduscol.education.fr/sti/sites/eduscol.education.fr.sti/files/textes/2nde-generale-et-technologique/2nde-generale-et-technologique-sciences-numeriques-et-technologie-snt/11576-programme-denseignement-en-snt.pdf), p. 3.

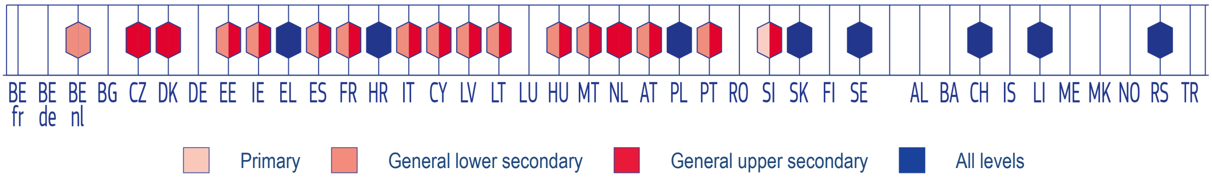
In the **Estonian** curriculum, the more general learning outcomes relate to the development of digital competence while the subject informatics focuses more on its technical and practical implementation, rather than discussing societal impact or cultural practices.

The **Polish** curriculum for informatics, taught from grade 1 of primary education to grade 11 of upper secondary education, illustrates what progression across levels can look like. In primary education (grades 1 to 4), 'the learner lists the risks associated with widespread access to technology and to information and describes ways of avoiding them. The learner recognises and respects the right to privacy of data and information and the right to intellectual property.' In lower secondary education, 'the learner describes ethical issues related to the use of computers and computer networks, such as security, digital identity, privacy, intellectual property, equal access to information and [the] sharing of information. The learner acts ethically when working with information.' Finally, in upper secondary education, 'The learner gives examples of the impact of computing and computer technology on the most important spheres of personal and professional life; uses selected e-services; [and] presents the impact of technology on the welfare of societies and social communication. The learner presents trends in the historical development of computing and technology and their impact on the development of societies' ([73]).

In **Portugal**, the lower secondary education curriculum for ICT emphasises emerging technologies. Students need 'to be aware of the Information and Communication Technologies impact in society and everyday life' and 'to be aware of the impact of emerging technologies (e.g. virtual reality, augmented reality and artificial intelligence) on society and everyday life' ([74]).

In **Cyprus**, within the subject informatics in upper secondary education the main learning outcome related to the area of awareness and empowerment is 'to identify and mitigate ethical, social and legal issues that occur from the increased application of informatics in private and professional life' ([75]).

Area 9: Awareness and empowerment



This area is widely addressed in informatics curricula across Europe. A quarter of European countries already have explicit learning outcomes relating to this area in primary education, and more than half of the countries address this area in lower and upper secondary education.

The present analysis of European school curricula confirms that an awareness of the importance of the social impact elements in informatics education is emerging. It aims to develop students' ability to understand the technology of informatics not only in itself but also in its effects on people and society (DIGHUM, 2019). The development of this capability requires first of all an awareness that the way digital artefacts are designed, implemented and deployed is far from unique. Subsequently, it requires an understanding that their overall realisation process interacts with and influences behavioural and relational patterns in the context where they are deployed. The interaction and influence need to be critically examined and constructively explored to ensure that the design of initial choices and subsequent revisions through iterations do not clash with the existing system of relations and accompany its evolution along the desired path (Caspersen, 2021).

([73]) For ISCED 1 and 24, see Ministry of National Education, Regulation of the Ministry of National Education of 14 February 2017 on the core curriculum for preschool education and the core curriculum for general education for primary schools, including students with moderate or severe intellectual disabilities, general education for the 1st degree industry school, general education for special schools preparing for work and general education for post-secondary schools (http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20170000356), pp. 177 and 179; for ISCED 34, see Ministry of National Education, Regulation of the Ministry of National Education of 30 January 2018 on the core curriculum for general education for general secondary schools, technical secondary schools and second-cycle industry schools (https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180000467), pp. 302–303.

([74]) Government of Portugal, *Aprendizagens Essenciais – Tecnologias da Informação e Comunicação: 5.º Ano*, 2018 (https://www.dge.mec.pt/sites/default/files/Curriculo/Aprendizagens_Essenciais/2_ciclo/5_tic.pdf), p. 6; Government of Portugal, *Aprendizagens Essenciais – Tecnologias da Informação e Comunicação: 9.º Ano*, 2018 (https://www.dge.mec.pt/sites/default/files/Curriculo/Aprendizagens_Essenciais/3_ciclo/tic_3c_9a_ff.pdf), p. 6.

([75]) Ministry of Education, Culture, Sport and Youth national curricula (http://www.moec.gov.cy/analytika_programmata/programmata_spoudon.html); Ministry of Education, Culture, Sport and Youth, 'Course: information technologies' (http://archeia.moec.gov.cy/sm/110/ap_deiktes_eparkeias_epitychias.zip), folder *Lykeio,* file DEIKTES_EpityxiasEparkeias_BLykEfarmoges20210402.pdf, B1.2, pp. 1–2.

Some even say that, considering the close link between digital technology and people and their social interactions, informatics is nowadays inherently social and no social aspects can be meaningfully separated from it (Connolly, 2020). Students needs to integrate the traditional science and engineering skills with new ones from the social sciences, to be able to create informatics systems well adapted to the continuous flow of interaction with people and between people (Frauenberger and Purgathofer, 2019). It is therefore important in the educational process to deal with the social aspects of informatics and to set up curricula with multidisciplinary (i.e. merging more disciplines) and interdisciplinary (i.e. multiple disciplines interacting) educational components (Connolly, 2020).

Safety and security

Various ways of using computing devices may affect the safety and security of individuals. 'Security refers to the safeguards surrounding information systems and includes protection from theft or damage to hardware, software, and the information in the systems' (K–12 Computer Science Framework, 2016, p. 88). 'In early grades, students learn the fundamentals of digital citizenship and appropriate use of digital media. As they progress, students learn about the legal, social and ethical issues that shape computing practices' (K–12 Computer Science Framework, 2016, p. 92). Digital data need to be kept secure both when stored and when transmitted across networks. 'In early grades, students learn how to protect their personal information. As they progress, students learn increasingly complex ways to protect information sent across networks' (K–12 Computer Science Framework, 2016, p. 89). This area involves understanding the risks when using technology and learning how to protect individuals and systems.

As for the first area of data and information, safety and security is also closely linked to digital literacy. Safety is also one of the five competence areas in the European digital competence framework for citizens (DigComp) (Carretero, Vuorikari and Punie, 2017; Vuorikari, Kluzer and Punie, 2022).

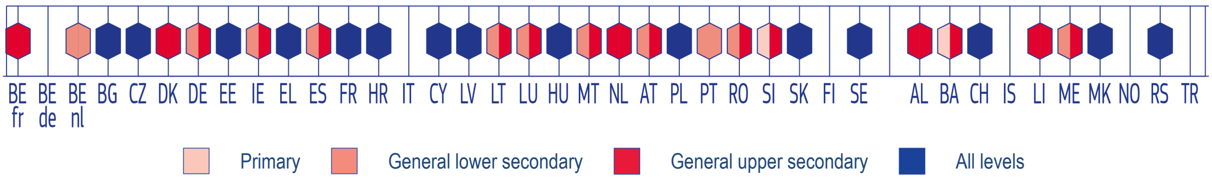
In **Ireland**, for example, this area is covered within digital media literacy (in the junior cycle short course in digital media literacy).

Still, taking a closer look at the learning outcomes, it is possible to notice differences between safety aspects addressed in terms of the safe use of digital technologies, which is associated with digital key competence, and more specific informatics content related to safety and security, also involving technical means to prevent and mitigate security threats.

In **Cyprus**, for example, the informatics curriculum in lower secondary education prepares students 'to identify main threats that may affect an individual when using networks and the Internet (e.g. spam, phishing, access to inappropriate content, misinformation, cyberbullying, intellectual property theft) and on ways to protect against, prevent and mitigate [threats]' ([76]).

Similarly, in the **Netherlands** the curriculum for informatics (an optional subject) in upper secondary education states in specific terms that 'the candidate is able to identify and relate some security threats and commonly used technical measures to architectural elements' and that 'the candidate can identify some security threats and commonly used socio-technical measures and relate them to social and human factors' ([77]).

Area 10: Safety and security



([76]) Ministry of Education, Culture, Sport and Youth national curricula (http://www.moec.gov.cy/analytika_programmata/programmata_spoudon.html); Ministry of Education, Culture, Sport and Youth, 'Course: information technologies' (http://archeia.moec.gov.cy/sm/110/ap_deiktes_eparkeias_epitychias.zip), folder *Gymnasio,* file DEIKTES_EpityxiasEparkeias_AGymn20210620.pdf, A5.4, pp. 21.

([77]) Examenblad.nl, *Examination Programme HAVO/VWO* (https://www.examenblad.nl/examenstof/informatica-havo-en-vwo-3/2022/f=/examenprogramma_Informatica_havo-vwo.pdf), p. 3.

Given the relevance of safety and security in terms of digital key competence, related learning outcomes are rather common in school curricula across Europe. Nearly half of the education systems already address this area in primary education, while three quarters do so in secondary education. In more than a third of the countries, curricula at all three education levels include learning outcomes relating to safety and security.

Other areas

As explained in Section 2.1.1, the 10 areas analysed in this context serve as a working framework for the comparative analysis of informatics education. It is not a prescriptive or comprehensive framework. At country level, informatics can be defined in different and specific ways. While the proposed 10 areas to analyse informatics education cover a major part of informatics-related learning outcomes in European countries, there are many, sometimes slight, differences in the content and formulation of informatics education curricula. Some countries indicate other areas to which they give particular importance in their informatics curricula, namely robotics, innovative IT systems, software analysis and testing, environmental protection, the foundation of informatics and the focus on specific applications in the use of technology.

Some countries mention robotics as an important area of informatics education (Spain, Latvia, Hungary, Poland, Serbia), while other countries address robotics in relation to programming, for example.

Denmark highlights the analysis of innovative IT systems as another important area, meaning that students are taught to 'explain and analyse different types of innovative IT systems in conjunction with their own developed IT systems' ([78]).

Estonia has a new informatics syllabus for upper secondary schools, taking a hands-on approach and including the systemic preparation of students for real life and real-life simulation, including software analysis and testing. Other countries have mentioned this in the areas of programming, computing systems or design and development. Related learning outcomes in Estonia include the ability of students to 'analyse the advantages and disadvantages of existing software solutions and to plan the software project testing process and the roles of the participants' ([79]). Indeed, since 2017 the syllabi of informatics have been continuously updated within the framework of the national programme Progetiiger to bring the syllabus in line with developments in informatics and real needs in terms of digital skills. School are increasingly using the textbooks and guides for teachers developed on the basis of these developments and needs.

France stresses the topic of environmental protection and climate change as very present in French school curricula since the Paris Agreement was adopted in 2015. Examples of related learning outcomes are the 'relationship between the use of digital tools, their energy consumption and the health hazards of their intensive use' (primary education); and the 'environmental impact related to data storage and flow and information network' (lower secondary education) ([80]). Similar learning outcomes have also been quoted by some countries for the area of awareness and empowerment.

While these skills are intrinsically part of the informatics curricula in general, some countries put a special focus on digital skills in the use of technologies (e.g. communication and collaboration in Croatia) or specific applications, such as computer publishing, website development and electronic publishing, database development and management (Cyprus and Lithuania) and text processing (Austria).

([78]) Ministry of Children and Education, *Læreplan Informatik C – hhx, htx, stx 2017* (https://www.uvm.dk/gymnasiale-uddannelser/fag-og-laereplaner/laereplaner-2017/htx-laereplaner-2017) (Scroll down to locate 'Informatik'), p. 2.

([79]) Teachers' guide for the new informatics syllabus for upper secondary school (https://web.htk.tlu.ee/digitaru/testimine/front-matter/introduction/).

([80]) Ministry of National Education, Youth and Sports, *Programme Cycle 3* (https://cache.media.eduscol.education.fr/file/A-Scolarite_obligatoire/37/5/Programme2020_cycle_3_comparatif_1313375.pdf), pp. 86–87;
Ministry of National Education, Youth and Sports, *Programme Cycle 4* (https://cache.media.eduscol.education.fr/file/A-Scolarite_obligatoire/37/7/Programme2020_cycle_4_comparatif_1313377.pdf), pp. 119–121.

2.2. Comprehensiveness and progression across education levels

Much of the research on informatics education has been carried out in the higher education area. Hence, issues have mostly been studied in this context. However, pedagogical approaches cannot be transferred to students of different age groups without testing their relevance and appropriateness for the primary and secondary levels of education (Hansen et al., 2016). There are no established learning progression pathways for informatics in general compulsory education, as happens in any other science area studied at school (Gudzial and Morrison, 2016).

It is widely acknowledged in the educational research literature that students progress during their learning process through various stages of development of increasing sophistication. This is true of any subject – for example, consider how the learning of mathematics develops from primary through lower secondary to upper secondary levels – including informatics. Clearly, within each discipline the actual details for each stage are specific to the subject itself (Lister, 2016). Generally speaking, during school years there is a progression from exploration to formalisation, passing through a phase of conceptualisation of increasing complexity (Meerbaum-Salant, Armoni and Ben-Ari, 2013).

Forlizzi et al. (2018) distinguish the three stages of exploring, discovering, growing in autonomy, and mastering the concepts. Exploration is the dominant approach in primary education. Through increasing conceptualisation and abstraction students grow in autonomy in lower secondary education and arrive, also by means of an increasing formalisation, to master the basis in upper secondary education. It is therefore reasonable to say that a 'discovery-oriented' way of learning should dominate in kindergarten and at the primary level, as should an 'autonomy acquisition' approach in lower secondary education and an 'in-depth study' mode in upper secondary school and higher education (Académie des Sciences, 2013).

In the discovery-oriented stage, students should be encouraged to ask questions while exploring some basic ideas of informatics by experimenting with concrete devices in their everyday lives and through unplugged activities, that is, activities not using digital technologies. They should be instructed to search for answers, including through collective discussions and through finding inspiration from similar concepts in other fields (e.g. algorithms versus instructions to perform an activity and the internet versus their networks of friends).

In the autonomy acquisition stage, while learning more about organising data, algorithms and programming, they develop a knowledge of how to design and implement digital artefacts. They also develop their abstract thinking skills and investigate the cross-disciplinary role of informatics as a helpful mental tool for describing and understanding other disciplines. Thus, they move beyond the role of users towards that of creators.

In the in-depth study stage, students deepen their knowledge and skills around fundamental concepts of informatics, refine their abstraction capabilities, and recognise the importance of accuracy and organisation, which are essential elements of the informatics approach to problem-solving. This also helps them to improve in their critical thinking skills and complexity-mastering capabilities and to understand key cultural achievements of informatics that have had large impacts on society (global networks, very large databases, efficient algorithms, etc.)

In addition to these common development stages, there is another fundamental feature of informatics: it is both a science and a technique. The knowledge component of informatics allows the building of machines, which have an intrinsic abstract and immaterial nature, ultimately boiling down to configurations of 0s and 1s. These 'digital machines', born as pure mathematical objects, capable of computing any function a person can compute, are then made concrete by physically representing them, whether that be as an electric circuit or a mechanical system with levers and gears (Nardelli, 2021). In this respect, informatics is in itself the only discipline whose models can be easily 'brought to life' (Wing, 2017). It is capable of hugely boosting the comprehension of any other discipline, by allowing the building of virtual representations, through computer-based animation, of models that would be otherwise impossible to build in a school setting.

For informatics, it is therefore critical not to separate the science and technique parts. More so than for any other traditional scientific subject, the practical work is as important as the theory behind it. Moreover, working on practical projects, above all when selected according to students' aspirations and desires, allows them to develop a sense of ownership that is important in fostering their interest in the subject (Repenning et al., 2015).

The many digital devices that are currently widely available can be effectively used to guide students to discover informatics concepts. Teachers can lead students through a learning process based on questions around how these devices work. These devices store 'actionable knowledge', that is knowledge that can be readily put into action (Nardelli, 2018). Therefore, they replicate processes that were done by human beings. Hence, students can be challenged to figure out how the same processes could be executed automatically and mechanically. Students will then gradually understand that informatics is about problem-solving using a machine, while mathematics is about problem-solving by humans (Nardelli, 2019), discovering throughout this process the concepts of representation, algorithm, programming language and automata, among others (Académie des Sciences, 2013).

Informatics includes scientific, fundamental, abstract and technological principles. Again, a key factor for successful informatics education in schools is maintaining a good balance between the theoretical and abstract aspects and the technological and practical aspects (Académie des Sciences, 2013).

For example, the curriculum of the **Flemish Community of Belgium** reflects this well when distinguishing the conceptual knowledge (e.g. in data and information – building blocks of a digital system, input processing output, binary, etc.; in programming – principles of programming languages, sequence, repetition structure, choice structure; and in safety and security – security risks and privacy aspects specific to the age group), procedural knowledge (e.g. in safety and security – security and privacy rules specific to the age group) and standard functionalities (e.g. in data and information – applying standard functionalities of digital infrastructure and applications to create and share content, and applying standard data management methods) ([81]).

Italy specifies the theoretical and practical dimensions of informatics in the informatics curriculum for general upper secondary education: 'Computer science teaching must have several objectives: understanding the main theoretical foundations of information sciences, acquire the mastery of information technology tools, use these tools for solving significant problems in general, but in particular related to the study of other disciplines, acquire the awareness of advantages and limitations of the use of IT tools and methods and the consequences social and cultural use of such use' ([82]).

Progressively, from primary to lower secondary education, students will increase their capability to realise informatics objects on their own, initially through a use–modify–create approach and subsequently by growing in their planning and design capabilities (Lee et al., 2011). The goal is not to train programmers, but to help students understand how programmes are made and better understand the digital world they live in, thus enabling them to transition from spectators to actors.

Once this autonomy has been acquired, students in upper secondary school can start to acquire a deeper understanding of the real world of informatics, by studying and getting to know how the most relevant building blocks of informatics (e.g. database systems, cryptographic protocols, machine-learning-based systems, operating systems and programming languages) work and are designed and organised (Académie des Sciences, 2013).

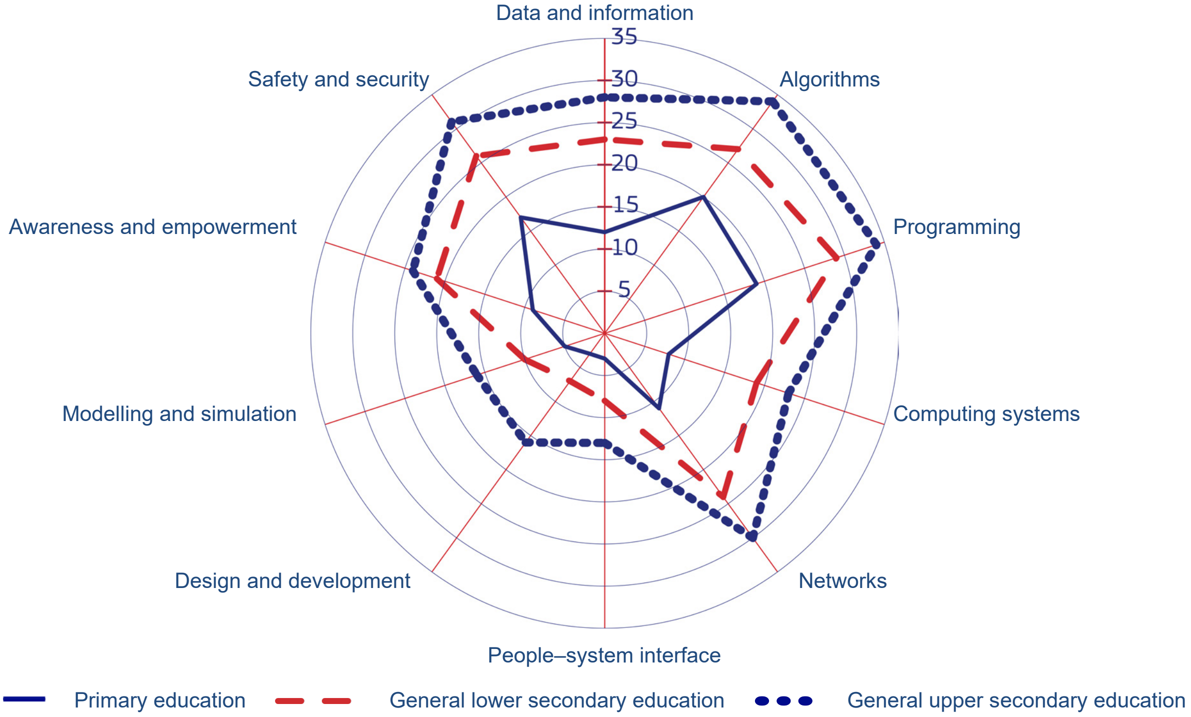
([81]) www.onderwijsdoelen.be; https://www.ejustice.just.fgov.be/mopdf/2019/04/26_1.pdf, pp. 65–69.

([82]) https://www.indire.it/lucabas/lkmw_file/licei2010/indicazioni_nuovo_impaginato/_decreto_indicazioni_nazionali.pdf, p. 369.

Progression between education levels could also be reflected in the timing of the introduction of specific concepts and in the relative weight of different informatics content areas at each education level. A more recent survey (Oda et al., 2021) analysed the situation of 10 countries worldwide that have introduced informatics education in school starting at the primary level. They found that most of them start the curriculum at primary level, beginning with the concepts of algorithms and programming, developing the first computational artefacts and considering the social impact of the discipline. Other concepts, such as computing systems and networks/communication, are introduced in higher grades. Another common finding was that subconcepts (e.g. control structures in programming) are introduced and further developed in subsequent grades. In addition, social impact issues and practical work are gradually introduced starting from the first years of school.

Before moving on to the analysis by education level, this section will conclude with an analysis of the aggregated data of European education systems. Figure 2.2 clearly shows that the number of education systems defining learning outcomes relating to informatics increases from primary to upper secondary education.

Figure 2.2: Coverage of informatics-related areas by European education systems in primary and general secondary education (ISCED 1 to ISCED 34), 2020/2021



Source: Eurydice.

Explanatory note

The figure shows the number of education systems covering each area in their explicit learning outcomes, regardless of whether these are within compulsory or optional subjects, with one line for each education level.

Moreover, a wider array of areas is covered as students progress through the education levels. The figure also shows the areas that are most common in European informatics curricula and the areas that are less common, and the differences at each education level. The details, including of the proportion of students concerned (compulsory subjects for all students or for some students, optional subjects) are analysed in the following sections by level.

2.2.1. Informatics learning outcomes in primary education

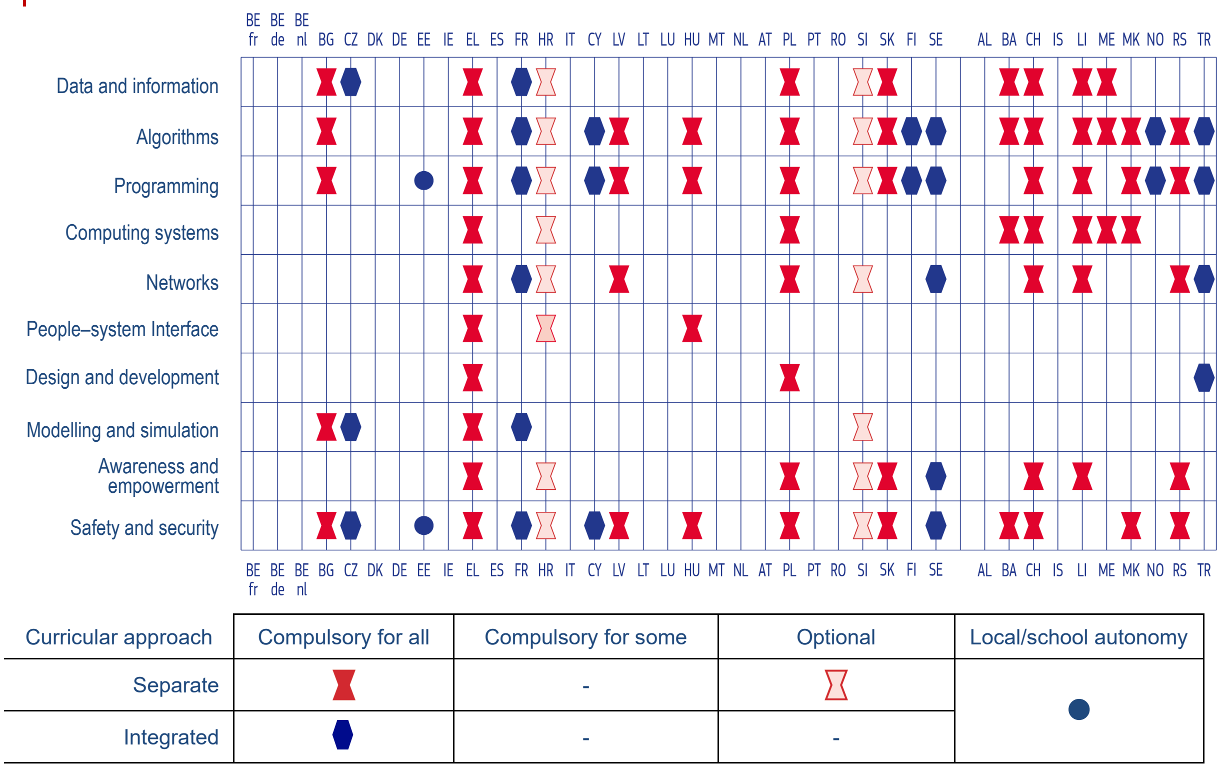
As seen in Chapter 1 (Section 1.2), teaching informatics as a distinct discipline from primary education is not very common. Nevertheless, more than half of the countries start teaching informatics at that education level, and this is clear from the learning outcomes already present in primary school curricula (see Figure 2.3).

In primary education, the most common areas covered in European school curricula are algorithms, programming, and safety and security. Less than a third of the European education systems explicitly include learning outcomes relating to data and information, networks, and awareness and empowerment in their curricula. Only a few include learning outcomes relating to computing systems, modelling and simulation, people–system interface, and design and development.

As for other disciplines, students in primary education are mostly new to the subject and will be introduced to the basics of informatics. This could explain why in the majority of education systems some areas are not yet covered in the learning outcomes.

Still, some countries seem to already include a broad and comprehensive range of objectives relating to informatics in primary education (see Figure 2.3).

Figure 2.3: Existence of learning outcomes related to 10 areas of informatics in primary education (ISCED 1), 2020/2021



Source: Eurydice.

Explanatory notes

The figure shows the areas relating to informatics explicitly addressed by learning outcomes in curricula. It also shows whether those learning outcomes belong to curricula of informatics subjects (separate) or to other subjects including informatics contents (integrated). Finally, it shows if the subject to which the learning outcomes belong is compulsory for all students, compulsory for some students or optional.

Country-specific notes

Estonia: Schools are autonomous and design their own curricula based on the national curriculum. They choose different ways to teach informatics: as a separate subject, integrated with other subjects or both.

Spain: While no learning outcomes are defined at national level, some *Comunidades Autónomas* (autonomous communities) develop some of these within different subjects. Madrid for example does so within the subject 'Technology and digital resources to improve learning' (programming) and Andalucía in the subject 'Culture and digital practice' (safety and security).
Latvia: Some learning outcomes relating to the areas programming, awareness and empowerment, and safety and security are formulated for the learning area technology, which is then split into the subjects computing, design and technology, and engineering. Schools decide how to provide them.
Lithuania: In 2020/2021, the new curriculum for informatics was implemented in around 10% of the primary schools, including learning outcomes relating to data and information, algorithms, programming and safety and security.
Finland: The objectives of the national core curricula are very general and will be specified at local level (curricula of education providers i.e. municipalities and individual schools). In 2020, the Ministry of Education and Culture launched a new literacy development programme, which helps the local level to develop their own curricula in order to strengthen students' media literacy, ICT skills and programming skills in early childhood, pre-primary and basic education as transversal competences. It includes descriptions for ICT-competence ([83])), programming competence ([84]) and multiliteracy and addresses the areas data and information, algorithms, programming, computing systems, networks, awareness and empowerment, and safety and security. This programme is not part of the national curriculum nor a regulation. Local education providers and schools can also include more informatics-related content in their curricula and use a weekly lesson for optional studies.
Switzerland: Information in the figure refers to the German-speaking cantons. The other cantons had not introduced informatics as a separate subject in 2020/2021.

The curriculum in Greece, for instance, includes a separate, compulsory subject that covers the 10 analysed areas in terms of learning outcomes. Poland also has a separate, compulsory subject that covers most areas, except for 'people–system interface' and 'modelling and simulation'. In a few other countries, informatics subjects include explicit and comprehensive learning outcomes in five or more areas (i.e. seven in Switzerland; six in Liechtenstein; and five in Bulgaria, Slovakia and Serbia).

Primary school curricula in Croatia and Slovenia include learning outcomes relating to most of the areas of informatics; however, the subjects are optional.

Among the countries integrating informatics in other compulsory subjects in primary education, some also address at least half of the areas (e.g. six in France (mainly within technology) and five in Sweden (within technology and mathematics)).

In terms of progression, primary education corresponds to the exploration phase, which involves students asking questions, discussing and discovering. Similar concepts in other fields and everyday activities can serve as an initial approach to introducing informatics concepts. Below are some examples from primary school curricula in Europe, illustrating how learning outcomes relating to the different content areas of informatics can be formulated in age-appropriate ways.

> With regard to the area of programming, for example, the **Greek** curriculum states that 'students use the selection structure in the programming environment to create their own programs, through examples of everyday life first, appropriate for their age' ([85]). In the same area, **Swedish** students learn in mathematics 'how step-by-step instructions can be constructed, described and followed as a basis for programming' ([86]).
>
> In the area of modelling and simulation, the subject computer modelling in primary education in **Bulgaria** includes the aim of 'mastering the initial knowledge, skills and attitudes related to creating computer models of familiar objects, processes and phenomena and experimenting with them. The implementation of computer models in the visual environment is prepared with familiar visual materials and tools and the implementation of algorithms with tools in this environment – albums with blocks and puzzles, easy-to-operate robotic devices, etc.' ([87]). In **Slovenia**, primary school students taking the optional subject computer science 'learn about and develop the ability to model' ([88]).

([83]) https://miro.com/app/board/o9J_lEpYSJk=/?moveToWidget=3074457358638658317&cot=14

([84]) https://docs.google.com/spreadsheets/d/1GEYNAwhRWMtB8FGWJ5LNllSWRrJqvQCy/edit#gid=861610697

([85]) Ministry of Education and Religious Affairs, *ICT Guidelines for Primary School* (http://www.iep.edu.gr/images/IEP/EPISTIMONIKI_YPIRESIA/Epist_Grafeia/Graf_Ereynas_B/2020/ΤΠΕ-ΦΥΣΙΚΗ_ΑΓΩΓΗ-2020-21.zip), part 1, p. 61.

([86]) Skolverket, *Curriculum for the compulsory school, preschool class and school-age educare*, 2018 (https://www.skolverket.se/getFile?file=3984), p. 56.

([87]) Ministry of Education and Science, *Curriculum in Computer Modelling for 3rd Grade* (https://mon.bg/upload/12205/UP_KM_3kl.pdf), p. 1; and Ministry of Education and Science, *Curriculum in Computer Modelling for 4th Grade* (https://mon.bg/upload/13767/UP9_KM_ZP_4kl.pdf).

([88]) Ministry of Education, Science and Sport, *Računalništvo* (https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/Osnovna-sola/Ucni-nacrti/izbirni/Neobvezni/Racunalnistvo_izbirni_neobvezni.pdf), p. 4.

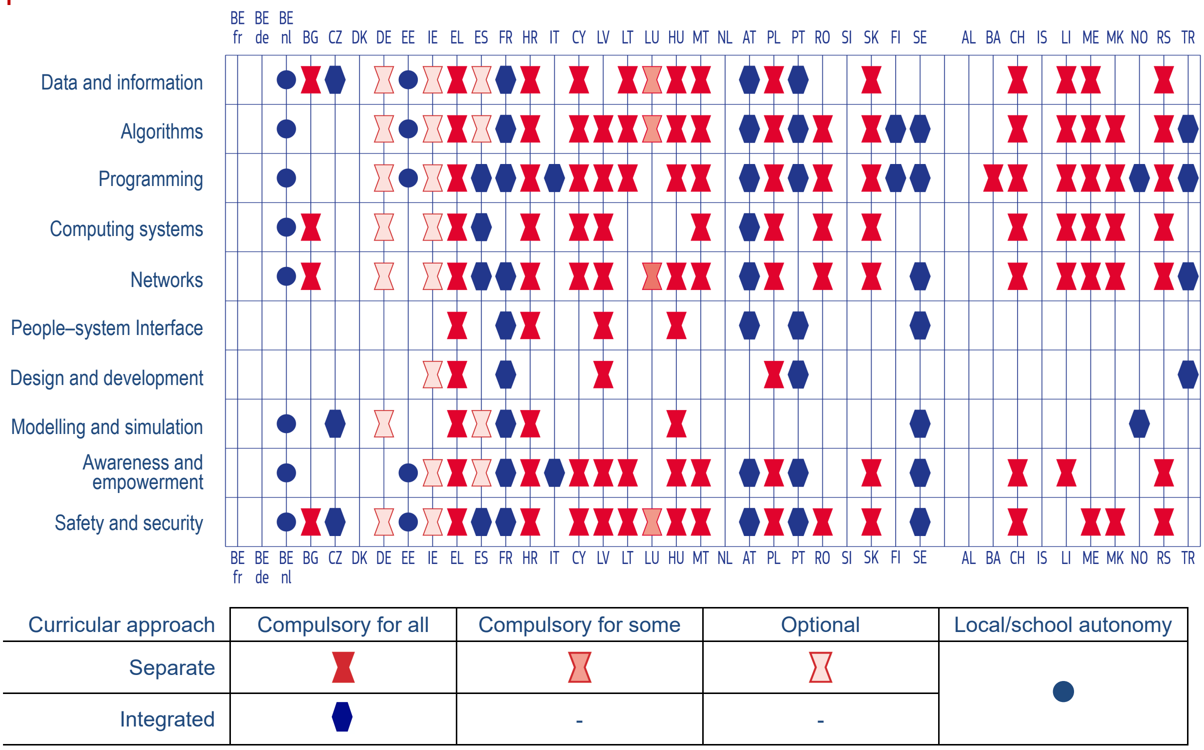
The **Croatian** informatics curriculum for primary education also includes unplugged activities as an initial approach to teaching informatics, for example relating to algorithms, where students are taught to 'follow and present a sequence of steps required for solving a simple task' and to 'solve more complex logical tasks with or without computer[s] (unplugged computing)' ([89]).

2.2.2. Informatics learning outcomes in general lower secondary education

In lower secondary education, the majority of European education systems explicitly address the areas of programming, algorithms, safety and security, networks, data and information, awareness and empowerment, and computing systems in terms of learning outcomes. However, for modelling and simulation, people–system interface, and design and development this is the case in only less than a dozen European education systems (see Figure 2.4).

In general, the teaching of informatics becomes more common from lower secondary education. Figure 2.4 also reflects this, showing a significantly higher number of learning outcomes relating to the different areas of informatics.

Figure 2.4: Existence of learning outcomes related to 10 areas of informatics in general lower secondary education (ISCED 24), 2020/2021



Source: Eurydice.

Explanatory notes

The figure shows which areas of informatics are explicitly addressed in learning outcomes in curricula. It also shows whether those learning outcomes belong to curricula of informatics subjects (separate) or to other subjects including informatics contents (integrated). Finally, it shows if the subject to which the learning outcomes belong is compulsory for all students, compulsory for some students or optional.

Country-specific notes

Belgium (BE nl): In the reformed lower secondary education, attainment targets related to informatics are formulated within the core competency 'digital competence and media literacy' of the basic curriculum and are compulsory for all students. Schools have the autonomy to decide on the curricular approach to achieve these mandatory attainment targets.
Estonia, Finland and **Switzerland**: See note in Figure 2.3.

([89]) Ministry of Science and Education, *Curriculum of the subject informatics for primary schools and gymnasiums* (https://mzo.gov.hr/UserDocsImages/dokumenti/Publikacije/Predmetni/Kurikulum %20nastavnog %20predmeta %20Informatika %20za %20osnovne %20skole %20i %20gimnazije.pdf), pp. 12 and 15.

Many education systems cover a wide range of learning outcomes in their informatics curricula. Greece, as in primary education, includes learning outcomes related to all 10 areas in a separate, compulsory subject. Croatia covers all areas except for design and development. Latvia, Hungary and Poland have a separate, compulsory subject that covers eight of these areas. The Flemish Community of Belgium has defined attainment targets also related to eight areas. Ireland also covers eight areas, but mostly within its optional subject (junior cycle short course in coding). Spain does so either through optional subjects or within the teaching of technology – although in some Autonomous Communities informatics is a separate, compulsory subject. In France, learning outcomes covering all areas except for computing systems are included in the compulsory subjects technology, mathematics, and media and information literacy, while in Austria eight of these areas are included in the compulsory subject digital basic competence.

Another group of countries includes learning outcomes relating to many informatics areas in a separate, compulsory subject (Cyprus, Malta, Slovakia, Switzerland and Serbia), or in the curriculum of another compulsory subject (Sweden).

Similarly to primary education, most lower secondary students take these subjects. Having optional subjects is still quite rare at this level, and specific tracks usually start later in education (see Chapter 1, Section 1.3). Therefore, the learning outcomes relating to informatics concern most students.

As explained in the introduction of the second part of this chapter, lower secondary education, in terms of progression, is the phase of autonomy acquisition. Students can learn how to design and implement digital artefacts and therefore become creators. During this phase, students develop their abstract thinking and experimentation skills. The following are some examples related to the different areas in the learning outcomes for lower secondary students.

In **France**, for example, the curriculum of the subject technology teaches lower secondary students to 'imagine solutions to produce objects and programming elements responding to a need (design innovation and creativity)' ([90]).

In **Cyprus**, the informatics curriculum for this education level and relating to the area of data and information requires students to 'understand and manipulate data in the way they are represented internally by a computer (in digital form, based on the binary system)'. With regard to algorithms, after understanding the notion of an algorithm and its relationship to a computer programme, they 'use dry run to predict the behaviour of an algorithm/computer programme and to detect and correct errors' ([91]).

In **Latvia**, the subject computing includes the objective to 'choose a real problem to solve to meet needs of a target group'. The student 'finds, summarises and researches existing solutions to similar problem situations; documents the user's needs and plans the technical functionality of the solution accordingly; explores various problems and thinks how they can be solved with the help of digital technologies' ([92]).

In **Malta**, in the area of programming, lower secondary students are 'able to work in a team to code a robot that completes a simple task' and 'to use the robotic programming software to programme the robot to perform a specific task' ([93]).

In **Austria**, with regard to the area of safety and security, 'students can understand how digital service providers inform about how personal data is used'. In addition, they 'can use software to encrypt data' ([94]).

([90]) Ministry of National Education, Youth and Sports, *Programme Cycle 4*, 2020 (https://cache.media.eduscol.education.fr/file/A-Scolarite_obligatoire/37/7/Programme2020_cycle_4_comparatif_1313377.pdf), pp. 119–120.

([91]) Ministry of Education, Culture, Sport and Youth national curricula (http://www.moec.gov.cy/analytika_programmata/programmata_spoudon.html); Ministry of Education, Culture, Sport and Youth, 'Course: information technologies', (http://archeia.moec.gov.cy/sm/110/ap_deiktes_eparkeias_epitychias.zip), folder *Gymnasio,* file DEIKTES_EpityxiasEparkeias_GGym20210626.pdf, Γ1.1, Γ7.4.5 and Γ7.4.6, pp. 1 and 25.

([92]) Skola 2030, *Computers Grades 1–9 –Sample of the subject programme* (https://mape.skola2030.lv/resources/327), p. 184.

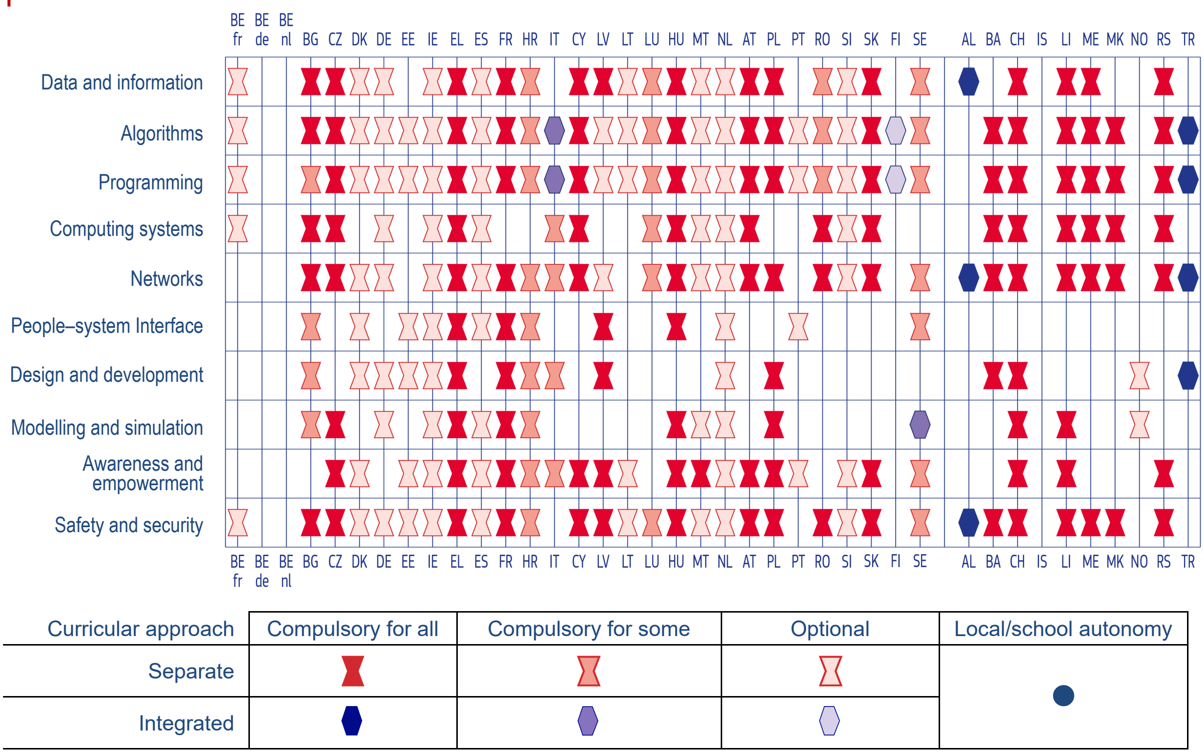
([93]) *Year 7 – Syllabus* (https://curriculum.gov.mt/en/new_syllabi/Documents/Year_07_08/ICT_syllabus_C3_yr07.pdf), pp. 3, 5 and 6.; *Year 8 – Syllabus* (https://curriculum.gov.mt/en/new_syllabi/Documents/Year_07_08/ICT_syllabus_C3_yr08.pdf), pp. 2, 4 and 6; *Year 9 – Syllabus* (https://curriculum.gov.mt/en/Curriculum/Year-9-to-11/Documents/curric_f3_f5/ICT_syllabus_C3_yr09.pdf), pp. 2, 4 and 5.

([94]) Digital Basic Competence Curriculum (ISCED 24) in Rechtsinformationssystem des Bundes, Entire legislation for secondary school curricula (https://www.ris.bka.gv.at/GeltendeFassung/Bundesnormen/20007850/Lehrpl %c3 %a4ne %20der %20Mittelschulen %2c %20Fassung %20vom %2025.04.2022.pdf), p. 113.

2.2.3. Informatics learning outcomes in general upper secondary education

In upper secondary education, the areas of algorithms, programming, and safety and security are explicitly included in more than 30 European education systems. Networks, data and information, awareness and empowerment, and computing system are also addressed in a majority of education systems. The remaining three – design and development, modelling and simulation, and people–system interface – are included in more than a dozen education systems, which is more than at lower levels of education (see Figures 2.3 and 2.4).

Figure 2.5: Existence of learning outcomes related to 10 areas of informatics in general upper secondary education (ISCED 34), 2020/2021



Source: Eurydice.

Explanatory notes

The figure shows which areas related to informatics are explicitly addressed in terms of learning outcomes in curricula. It also shows whether those learning outcomes belong to curricula of informatics subjects (separate) or to other subjects including informatics contents (integrated). Finally, it shows if the subject to which the learning outcomes belong is compulsory for all students, compulsory for some students or optional.

Country-specific notes

Belgium (BE nl): Informatics may be offered by schools as an optional subject in certain fields of study, but learning outcomes are not imposed by the government.
Hungary: The subject informatics / digital culture is compulsory for all students in grades 9–10 but optional in grades 11–12 in the reference year. The new curriculum phasing in makes this subject compulsory in grades 9–11.
Finland: See note in Figure 2.3.

At this education level, students often start to specialise in particular subjects, besides the subjects studied by all. Figure 2.5 shows that nearly half of the education systems addressing informatics-related learning outcomes do so in optional subjects or subjects that are compulsory for some students only. Ireland and the Netherlands have related outcomes in all 10 areas within optional subjects; Spain has related outcomes in all except design and development; and Denmark and Germany have related outcomes in eight areas; while Bulgaria and Croatia cover all areas except one through subjects that are compulsory for some or all students (in Bulgaria five areas are addressed within the subject IT, which is compulsory for all students).

Still, more than a dozen countries cover a very comprehensive range of learning outcomes in compulsory informatics subjects. Greece even covers all 10 areas, while France, Hungary and Switzerland have explicit learning outcomes relating to all areas except one. Several other countries cover a broad range of areas within separate, compulsory subjects: Czechia, Poland and Liechtenstein (eight areas); Cyprus, Austria, Slovakia and Serbia (seven areas); and Bosnia and Herzegovina and Montenegro (six areas).

Compared with lower secondary education, and as analysed in Chapter 1, Section 1.4.1, the approach of a separate subject for informatics becomes clearly dominant over including related learning outcomes in another subject.

At this education level, students can study informatics in depth. They develop their abstraction, critical thinking and complexity-mastering skills, and deepen their understanding of fundamental concepts and key cultural achievements of informatics. The following are some learning outcome examples for the different informatics content areas in upper secondary education.

In **Montenegro**, the informatics curriculum for upper secondary education addresses data and information and the topic of mathematical and logical basics of computer performance. After learning this, a student 'knows the mathematical and logical basics of computer performance, by knowing the working principle of computer memory, understanding the difference between positional and non-positional number system, knowing how text data is presented on a computer [and] knowing how numerical data is presented in a computer' ([95]).

In the area of networks, 9th grade students in **Bulgaria** 'understand the structure, organization and rules of work in the global Internet, … understand the structure, organization and rules of operation of the global Internet, know the protocols used on the Internet, know, understand and use addressing in the Internet environment' ([96]). Meanwhile, in the area of modelling and simulation, 8th grade students in the profile training informatics 'describe the subject and role of computer science for modelling, give examples of objects and phenomena in which it is practically applicable to use the means of object-oriented modelling, compare a mathematical model with a software solution to a problem, implement a model for solving problems, based on real data types, and create a problem-solving model set in the project assignment' ([97]).

With regard to safety and security, **Spanish** upper secondary students taking the optional subject ICT (II) learn how to 'create a block diagram with the physical protection elements against external attacks for a small network considering both the hardware protection elements and the software tools that allow information to be protected'. They also 'classify malicious code according to its propagation capability and describe the features of each one, identifying the elements on which they act' ([98]). The **Maltese** curriculum for computing in upper secondary education also goes in depth regarding safety and security. Students learn to master 'data security and privacy; integrity of data; backups; parity checking; physical security and software safeguards; the provisions and implications of the Malta Data Protection Act for the various sectors and citizens; software piracy and copyright; ethical and legal issues; hardware and software procedures which deter piracy – serial numbers and activation keys, hardware keys (dongles) and software registration' ([99]).

Regarding awareness and empowerment, the **Slovak** informatics curriculum in upper secondary education teaches students to 'assess current trends in digital technologies and their impact on society (limits and risks) and estimate their further development, assess the development of digital technologies and their impact on their learning' ([100]). In relation to the same area, the **Serbian** informatics curriculum indicates that the 'student understands the challenges of using modern technologies in a responsible and safe way; can state the application of informatics and computer science in modern life; [and] is able to explain the impact of artificial intelligence on human life' ([101]).

([95]) Ministry of Education, *Curriculum for Gymnasium*, 2020 (https://zzs.gov.me/ResourceManager/FileDownload.aspx?rId=438077&rType=2), p. 5

([96]) Ministry of Education and Science, *Information Technologies Curriculum for 9th Grade* (https://mon.bg/upload/12234/UP_IT_9kl.pdf), p. 7.

([97]) Ministry of Education and Science, *Informatics Curriculum for 8th Grade* (https://mon.bg/upload/13463/UP_8kl_Informatika_ZP.pdf), pp. 2 and 10–11.

([98]) Royal Decree 1105/2014 of December 26 establishing the basic curriculum of compulsory secondary education and *Bachillerato* (https://www.boe.es/boe/dias/2015/01/03/pdfs/BOE-A-2015-37.pdf), Annex II, p. 534.

([99]) University of Malta, *SEC Syllabus (2021): Computing* (https://www.um.edu.mt/__data/assets/pdf_file/0003/355404/SEC09_2021.pdf, pp. 23–24.

([100]) National Institute for Education, *Informatics* (https://www.statpedu.sk/files/articles/dokumenty/inovovany-statny-vzdelavaci-program/informatika_g_4_5_r.pdf), p. 17.

([101]) Computer Science and Informatics, grades 1–4 (in General Upper Secondary School in general and social science orientations) (https://zuov.gov.rs/wp-content/uploads/2020/08/pravilnik-gimnazija.pdf), pp. 106 (grade 1).

2.3. Increasing girls' engagement in informatics

This last section gives a short glimpse into the discussion on how to obtain a more balanced participation of men and women in higher education degrees in informatics and the informatics workforce, starting with increasing girls' participation in and engagement with informatics education at school. It then highlights some examples of top-level initiatives in European education systems.

The distribution of men and women in the IT workforce is highly unbalanced (Hill, Corbett and Rose, 2010). The latest Eurostat data shows that in 2021 only 19.1% of employed ICT specialists were women (ESTAT isoc_sks_itsps) ([102]). The Women in Digital Scoreboard indicates that in recent years no significant progress has been made in closing this substantial gender gap ([103]). This is an important issue given the increasing presence and impact of IT solutions on society. In fact, IT systems may be designed in many different ways and they will reflect the implicit biases and prejudices of their designers and implementers. The only countermeasure to obtain more balanced systems is to diversify characteristics of people working in the field and, in the European Union, a highly relevant question is the disparity in gender representation ([104]).

Unfortunately, too few girls enter into academic degrees related to informatics (Varma, 2010) and, earlier than that, too few girls are interested in informatics in school (Aguar et al., 2016). According to statistics reported in the Informatics Europe Higher Education Data Portal ([105]) from a sample of 18 European countries ([106])), the percentage of female students enrolled in the first year of informatics bachelor degree programmes was only 18.4% in the 2019–2020 academic year. While comparable statistical data regarding girls' participation in informatics courses in secondary school is scarce, a proxy can be found, at least for the United States, in the percentage of female secondary students taking an advanced placement course before entering university. This percentage was 20% in 2014. However, after the efforts initiated in that same year by Code.org and the Computer Science Teacher Association, with the support of the major IT companies, to spread awareness of the importance of Computer Science education in schools, it increased steadily to reach 31% in 2020 (Code.org, CSTA and ECEP Alliance, 2021).

It is known that well-designed educational programmes can increase the participation of women in informatics at college (Fisher and Margolis, 2002; Klawe, 2013). Research has highlighted the importance of acting at K–12 level (primary to upper secondary school education), where girls risk being discouraged and losing interest in science, technology, engineering and mathematics (STEM) careers (Malcom-Piqueux and Malcom, 2013). This also happens under the influence of the stereotype of informatics students as socially awkward and technology-focused males (Cheryan et al., 2013) and of social and cultural biases, which for adolescents are particular important, and include a sense of belonging and expectation of success (Cohoon and Aspray, 2006; Master, Cheryan and Meltzoff, 2016).

It is therefore necessary to start teaching informatics as early as possible, given that, the longer schools wait to introduce this subject, the lower the chances of getting girls' interest (Nardelli and Corradini, 2019) and the higher the possibility of adhering to gender stereotypes considering informatics a subject not fit for girls (Aivaloglou and Hermans, 2019).

([102]) https://ec.europa.eu/eurostat/databrowser/view/isoc_sks_itsps/default/table?lang=en

([103]) https://digital-strategy.ec.europa.eu/en/news/women-digital-scoreboard-2021

([104]) A 2021 survey of more than 2 200 human resources and business leaders across Europe showed that age and gender are the two most monitored diversity areas in companies (monitored by roughly 50% of them) (https://forms.workday.com/content/dam/web/uk/documents/reports/fm-belonging-and-diversity-report-fy22-emea.pdf).

([105]) https://www.informatics-europe.org/data/higher-education/

([106]) Austria, Bulgaria, Czechia, Estonia, Finland, France, Germany, Ireland, Italy, Latvia, Netherlands, Norway, Portugal, Romania, Spain, Switzerland, Turkey, and the United Kingdom.

By comparing female increasing participation efforts in informatics with those in other disciplines, Zagami et al. (2015) argue that the presence of a compulsory informatics curriculum from an early level of school may be the only measure able to sustain female participation over periods such as adolescence, a stage where students start making critical career choices (Weisgram and Bigler, 2006). The importance of acting from primary school on the improvement of the image of informatics to fight misconceptions and stereotypes and to increase female participation in informatics has also been discussed (Funke et al., 2016). Furthermore, engagement with informatics at an early age can promote self-efficacy, which for girls is significantly related to their interest in pursuing an informatics career and can contrast with the gender stereotype considering informatics a subject for males (Aivaloglou and Hermans, 2019).

In terms of content of teaching and learning informatics, studies have shown that girls are less interested in experimenting with and controlling computers than boys, and are more oriented towards concrete and socially focused goals (Krieger, Allen and Rawn, 2015). In other words, girls are more interested in the purpose and use of the technology than in the technology itself, while boys are more interested in the functions and design of the devices (Hou et al., 2006). Moreover, uses of informatics involving people seems to be more attractive to women than those focusing on things. This element needs to be considered in the organisation of teaching when looking for examples and defining practical activities (Marcher et al., 2021). Similarly, in the wider field of sciences, the science, technology, engineering, arts and mathematics approach has been seeking to make STEM careers more attractive and inclusive for all learners by emphasising the real-world context and empowering them to develop creative solutions.

The following conceptualisation to deal with different approaches to science usually based on gender is particularly interesting (Cheng, 2020). Cheng suggests focusing not on masculine or feminine characteristics, and instead considering two different kinds of behaviour, which she has termed 'ingressive' and 'congressive'. Ingressive behaviours are competitive, adversarial and focused on self over the community; congressive behaviours are collaborative, cooperative and focused on society over self. Traditionally, the former has been associated with males, and the latter with females, but this association does not hold always and it could be wrong to use gender categories in education to deal with the different approaches. She observes that congressive behaviour is better for society, but that our society tends to reward ingressive behaviour. The focus in informatics education could be changed to manage teaching and learning processes with this perspective, giving more importance in the curriculum to activities related to people and society, as this congressive approach – independent of gender – is more beneficial to a larger community.

Across countries, there are many different perspectives on balanced gender participation in informatics education. One of them actually chooses a universal approach (e.g. in Estonia and Austria) instead of a gender-based one focusing on girls. Another addresses girls' engagement in informatics together with the larger field of STEM (e.g. in the Flemish Community of Belgium). In the following paragraphs, some examples of top-level national initiatives relating to the engagement of girls in informatics education at school are analysed.

In the French Community of Belgium, the plan 'women's rights' ([107]), adopted by the government on 17 September 2020, contributes to the implementation of the interfederal and intersectoral plan 'women in digital' through measures that impact school education by addressing gender stereotypes in textbooks and educational resources for initial and in-service teacher training and for school guidance

([107]) Federation Wallonia-Brussels, *Plan Droites des Femmes*, 2020 (https://alteregales.cfwb.be/fileadmin/sites/alter/uploads/Documents/Presentation/Plan_Droits_des_Femmes_2020-2024_FWB.pdf), p. 24.

services. Moreover, the project ‘e-class’ ([108]), which is part of the digital strategy for education (Pact for Excellence in Teaching), is a platform of educational resources for teachers and offers many specific contents related to the gender perspective in the digital world.

In Spain, the Institute of Women in the Ministry of Equality has developed and is managing two related programmes. The programme ‘Diana’ ([109]) aims to stimulate the interest of girls and young women in programming. The programme ‘ADA’ ([110]) aims to promote the interest of girls and young people in the technological branches of study, and through this contribute to a greater presence of women in technological careers in general and in the informatics field in particular.

In France, the inter-ministerial convention for equality between girls and boys (2019–2024) ([111]) includes a component on students’ guidance, including a qualitative indicator, that is a qualitative study on the obstacles to girls choosing the informatics and digital track in upper secondary education. Moreover, the course ‘Equality between girls and boys: for gender balance in the digital trainings and professions’ ([112]) is part of the national training plan, and targets 120 people who will be responsible for taking related initiatives in all *académies*.

In Italy, action 20 of the national plan for digital education – ‘girls in tech and science’ – provides for initiatives aimed at reducing the gender gap in the choice of technical and scientific subjects in secondary schools ([113]). The Womest programme, which is part of the plan, has promoted laboratories and competitions for female students.

In Portugal, the Secretary of State promotes the project ‘Engineers for a Day’ ([114]) for citizenship and equality in partnership with the Portuguese Women in Tech movement. Since its launch in October 2019, its 3rd edition, which includes 41 partner entities (companies, associations and municipalities), 11 universities and 30 schools, has already involved more than 2 000 students of various age groups. The project intends to deconstruct prejudices and gender stereotypes about technological professions, and to raise awareness about the inequality that hinders women’s opportunities in the fields of science and technology. As part of this initiative, six webinars were held, with women in the field of technology talking about their work and professional careers.

In Switzerland, the wider framework of the national initiative for the promotion of mathematics, informatics, natural sciences and technology (MINT) aims, inter alia, to sensitise and motivate children and young people, especially girls, to choose studies and careers in the MINT sector, with an appropriate focus on technology and informatics in order to counteract the shortage of skilled workers. The initiative started in 2013 and is now on its 3rd edition (MINT.III (2021–2024)). The initiative highlights a number of projects promoting MINT, some specifically for girls; for example, the Network of Women in Computer Science organised trial studies for women in informatics at universities ([115]).

([108]) https://www.e-classe.be/

([109]) https://www.inmujeres.gob.es/areasTematicas/SocInfo/Programas/Diana.htm

([110]) https://www.inmujeres.gob.es/areasTematicas/SocInfo/Programas/Ada.htm

([111]) https://www.education.gouv.fr/egalite-entre-les-filles-et-les-garcons-9047

([112]) Ministry of National Education, Youth and Sports (https://cache.media.eduscol.education.fr/file/Formation_continue_enseignants/97/8/Programme_du_PNF_2020-2021_1310978.pdf), p. 8.

([113]) Ministry of Education, *Piano Nazionale Scuola Digitale* (https://www.istruzione.it/scuola_digitale/allegati/Materiali/pnsd-layout-30.10-WEB.pdf), p. 89.

([114]) https://www.cig.gov.pt/2020/04/engenheiras-um-dia-atividades-digitais-70-mulheres-profissoes-tecnologicas-assinalar-girl-in-ict-day/

([115]) https://csnow.inf.ethz.ch

CHAPTER 3: TEACHERS

As for any other school discipline, teaching informatics requires having teachers prepared for this role. A lack of adequately prepared teachers not only compromises the quality of teaching but is also one of the main barriers to introducing informatics into the curriculum (Bocconi et al., 2022). The recent experience of the United Kingdom (England), which introduced a mandatory curriculum on computing in the 2014/2015 school year, is one example confirming this risk. Indeed, the intermediate implementation review points out the links between students' poor results and teachers' lack of preparedness (Royal Society, 2017). Therefore, having knowledgeable, confident and fully trained teachers with access to the adequate resources is the key to successfully introducing informatics into school curricula (Fluck et al., 2016).

It is widely acknowledged that, to provide good-quality teaching, teachers need to be equipped with both extensive knowledge of the discipline and appropriate pedagogical skills. Training teachers in the conceptual or theoretical aspects is more complex to manage when preparing teachers to teach informatics than for other disciplines. This is because, generally speaking, informatics is a subject most prospective or in-service teachers never studied during their school years or in their academic studies (Hewner, 2013).

The ideal scenario would be to set up initial training to equip all informatics teachers with the necessary theoretical and pedagogical knowledge before integrating informatics into the curriculum. However, this requires additional financial investment and would not increase the number of qualified teachers for 4 or 5 years. During this transitional phase, retraining existing teachers could be a viable solution, particularly if they have a scientific background. In any case, it is important not to sacrifice either formal requirements or methodological training in the organisation of such fast-track training (Caspersen et al., 2018).

Another challenge is the need to carry out research in the field to identify and validate best practices and methods for teaching for the different school levels (Caspersen et al., 2018). Most research in the area of informatics education has been done in higher education and, to a lesser degree, in upper secondary education. Much less is known about lower secondary and primary levels. Without evidence-based outcomes, there is the risk of educating students based on uncertain didactic assumptions (Hansen et al., 2016).

Besides the abovementioned constraints, the difficulty in attracting specialist informatics teachers to the profession and retaining them seems to be a challenge shared by countries that are introducing informatics into their curriculum and those that have been providing it for a long time. One of the main reasons for informatics teacher shortages is that relatively few students obtain an academic degree in informatics compared with the number the labour market requires. Almost all the European Union Member States are facing a shortage of digitally competent graduates, with 53% of companies experimenting difficulties in 2019 in recruiting the digital specialists they require (Informatics Europe, 2020). Therefore, the initial pool from which teachers are taken is small, even more so than usual considering the low percentage of women among graduating students. According to Eurostat ([116]), in 2019 21% of information and communications technology (ICT) graduates (International Standard Classification of Education (ISCED 2011) levels 5–8) in Europe ([117]) were female. Another important cause of teacher shortages is that salaries and careers in industry are much more attractive, making teaching appealing only to those who consider it their life's mission. The salary disparities between

([116]) Eurostat, Graduates by education level, programme orientation, sex and field of education [educ_uoe_grad02]. Data was extracted on 2 April 2022.

([117]) This includes 27 EU Member States plus Bosnia and Herzegovina, Iceland, Norway, Switzerland, North Macedonia, Serbia and Turkey. Eurostat data is not available for Liechtenstein and Montenegro.

industry and the education sector are visible in universities, where in any case salaries are higher than in schools (Sherin, 2019), and the disparities are even worse in schools.

This chapter focuses on teachers who provide informatics education in schools across Europe, and is divided into four main sections. The first section analyses the professional profiles of teachers teaching informatics in primary, lower and upper secondary education, looking into the responsibilities of generalist and specialist teachers in the delivery of informatics programmes. Annex 3 provides details of specialist teachers who are not initially qualified as informatics teachers but can go on to teach this discipline in schools. The second section gives an overview of professional development programmes set up by top-level education authorities to prepare informatics teachers. It covers initial teacher education (ITE), alternative pathways and retraining possibilities. Annex 4 complements this section by providing short descriptions of alternative routes and retraining programmes. The third section looks at the main measures available to support in-service informatics teachers to successfully implement informatics curricula. The final section provides the country examples of policy reforms and initiatives that encompass professional development activities and support measures for teachers.

3.1. Professional profiles of teachers teaching informatics

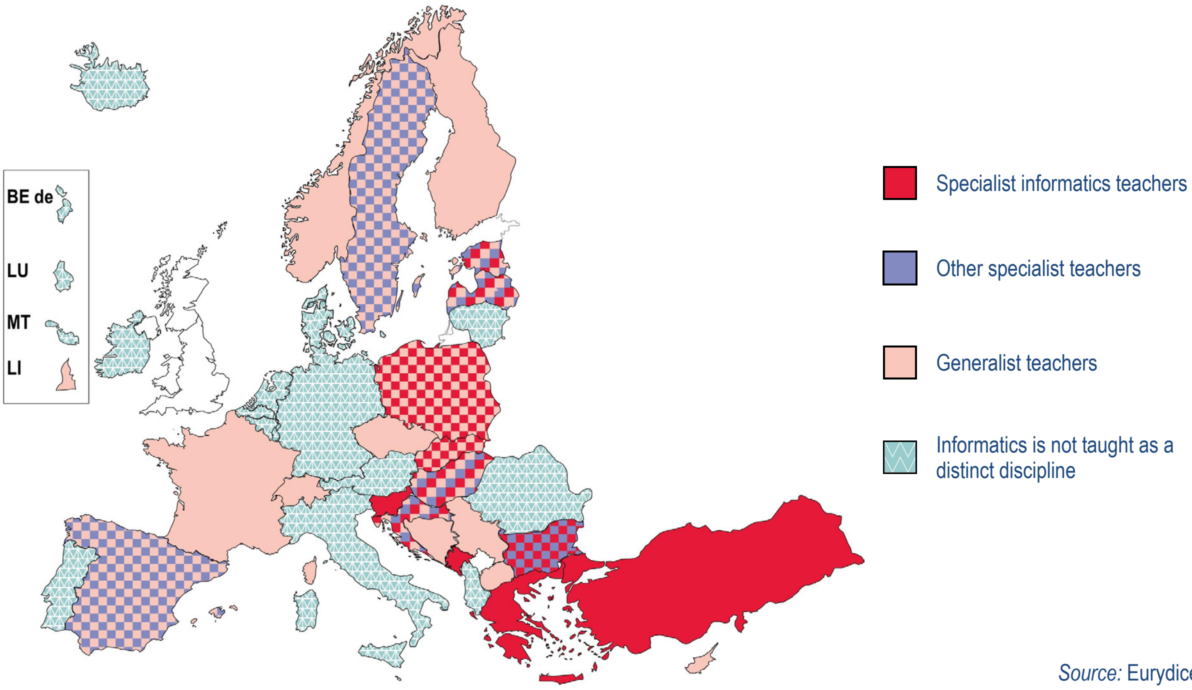
Schoolteachers in Europe are trained as generalists or specialists. Generalist teachers are typically qualified to teach all or most of the subjects prescribed in the curriculum to one class of students at the level of primary education. In some education systems, however, generalist teachers also teach students in lower secondary school, at least in some grades. Teaching at general secondary level commonly requires specialisation in one or a group of specific curriculum subjects. Secondary school specialist teachers usually teach one or two subjects to different classes (European Commission / EACEA / Eurydice, 2011). Therefore, the education level is likely to affect teachers' professional profile, including whether or not they teach informatics. In addition, the organisation of the curriculum can determine teachers' professional profiles. For example, when informatics is integrated into another subject, teachers qualified to teach this subject may be expected to teach informatics content. In some cases, mainly to increase the pool of specialist teachers or to diversify the teaching profession, education systems may allow professionals from other sectors without a teaching qualification to have temporary teaching positions at schools. In addition, in the education systems affected by teacher shortages, teachers who are not qualified in informatics may be required to teach it.

This section looks at professional profiles of teachers delivering informatics curricula at primary, lower and general upper secondary levels. Specialist informatics teachers are defined here as teachers who are qualified to teach informatics content, that is, this area of specialisation was already reflected in their ITE. Other specialist teachers are teachers who are specialists in one subject or a group of subjects in the curriculum other than informatics.

3.1.1. Professional profiles of informatics teachers in primary education

Figure 3.1 shows that, in most education systems where informatics is set as a distinct discipline in the primary education curriculum, generalist teachers are responsible for teaching it. This confirms the general trend in Europe that generalist teachers hold responsibility for providing the entire or almost the entire curriculum in primary education. While only generalist teachers are responsible for delivering informatics curricula in 10 education systems ([118]), in Poland (in grades 1–3) ([119]) and Slovakia this responsibility can be given to specialist informatics teachers.

Figure 3.1: Professional profiles of informatics teachers in primary education (ISCED 1), 2020/2021



Source: Eurydice.

Country-specific notes

Greece: In schools where there is a shortage of students and not all grades operate (e.g. schools in remote regions and remote islands with sparse populations) generalist teachers certified in ICT can teach the subject ICT.
Slovenia: Other specialist or generalist teachers can teach computer science (*Računalništvo*) if they have completed a supplementary study programme in computer science and informatics. This programme was discontinued in 2015.

In Spain and Sweden, generalist teachers or teachers specialising in subjects other than informatics can teach informatics curricula.

In **Spain**, where some autonomous communities (*Comunidades Autónomas*) decide to include informatics in their curricula at the level of primary education (see Chapter 1, Section 1.2), all primary school teachers (e.g. generalist and specialist teachers such as those for foreign languages, music and physical education) can teach the subject.

In **Sweden**, specialist mathematics and technology teachers usually teach informatics, as its content is integrated into mathematics and technology subjects, both compulsory for all primary school students (see Chapter 1, Figure 1.1). However, generalist teachers can do so if local/school authorities allow it.

In Estonia, Croatia, Latvia and Hungary, all qualified teachers (generalist teachers, teachers specialising in informatics or other specialist teachers) can teach informatics to primary school students. In Estonia, where schools decide when and how to teach informatics to primary school

([118]) Czechia, France, Cyprus, Finland, Bosnia and Herzegovina, Switzerland, Liechtenstein, North Macedonia, Norway and Serbia.

([119]) In Poland, informatics education is a compulsory learning area in grades 1–3 of primary education; generalist and specialist informatics teachers can teach it in these grades. In grade 4, only specialist informatics teachers can teach the separate subject *Informatyka*.

students (see Chapter 1, Figure 1.1), schools may decide which teachers' professional profiles are most suited to delivering it. Croatia, Latvia and Hungary apply additional requirements to non-specialist informatics teachers.

In **Croatia**, in addition to specialist informatics teachers, teachers of polytechnics can teach informatics in primary schools. Generalist teachers are also allowed to do so if an informatics module was included in their ITE.

In **Latvia**, informatics is being introduced at primary level as a separate subject, which requires both the transformation of the curriculum and the adjustment of teachers' qualifications. During this transition period, and to respond to teacher shortages, all qualified teachers can teach informatics if their subject specialisation includes some informatics-related content.

Similarly, in **Hungary** other specialist teachers and generalist teachers are eligible to teach informatics if their field of studies included some informatics content.

A few other education systems require teachers who teach informatics in primary schools to be specialists. In Greece, Slovenia, Montenegro and Turkey, only specialist informatics teachers can teach this discipline, while in Bulgaria other specialist teachers can do so also if they fulfil specific conditions.

In **Bulgaria,** in grades 3 and 4 of primary education the compulsory subject computer modelling can be taught by specialist informatics teachers or by mathematics, physical sciences, technical sciences or economics teachers with an additional professional qualification in informatics and/or information technology (IT). Moreover, all these specialist teachers also have to be qualified as primary school teachers.

The analysis of the professional profiles of teachers providing instruction on informatics at the level of primary education shows that the organisation of the curriculum does not strongly affect the professional profile of teachers. The assumption that a separate subject is taught by specialist teachers does not apply to primary education. Among the 14 education systems ([120]) where informatics is taught as a separate subject at primary level (see Chapter 1, Figure 1.1), only 4 countries ([121]) assign exclusively specialist teachers to deliver the curriculum: Greece, Slovenia, Montenegro (specialist informatics teachers) and Bulgaria (specialist informatics teachers or other specialist teachers). In Croatia, Latvia, Hungary, Poland (in grades 1–3) and Slovakia, specialist teachers (informatics specialists and/or other subject specialists) as well as generalist teachers may teach informatics, while in the remaining 5 countries (Bosnia and Herzegovina, Switzerland, Liechtenstein, North Macedonia and Serbia), teaching informatics is entirely the responsibility of generalist teachers.

To tackle teacher shortages, some education systems allow IT specialists without a teaching qualification to provide informatics curricula in primary schools. Usually such a deviation from formal requirements for teachers' qualification is a temporary measure and applies to all teachers, not only informatics teachers. For example, in Estonia, primary and secondary schools affected by teacher shortages can recruit IT or informatics specialists without a teaching qualification to teach informatics as an elective subject. The nationwide back to school programmes *Tagasi kooli* ([122]) and *Edumus* ([123]) provide additional opportunities for the diversification of teaching staff.

([120]) Bulgaria, Greece, Croatia, Latvia, Hungary, Poland, Slovenia, Slovakia, Bosnia and Herzegovina, Switzerland, Liechtenstein, Montenegro, North Macedonia and Serbia.

([121]) This is also the case in Poland, but only in grade 4.

([122]) https://tagasikooli.ee

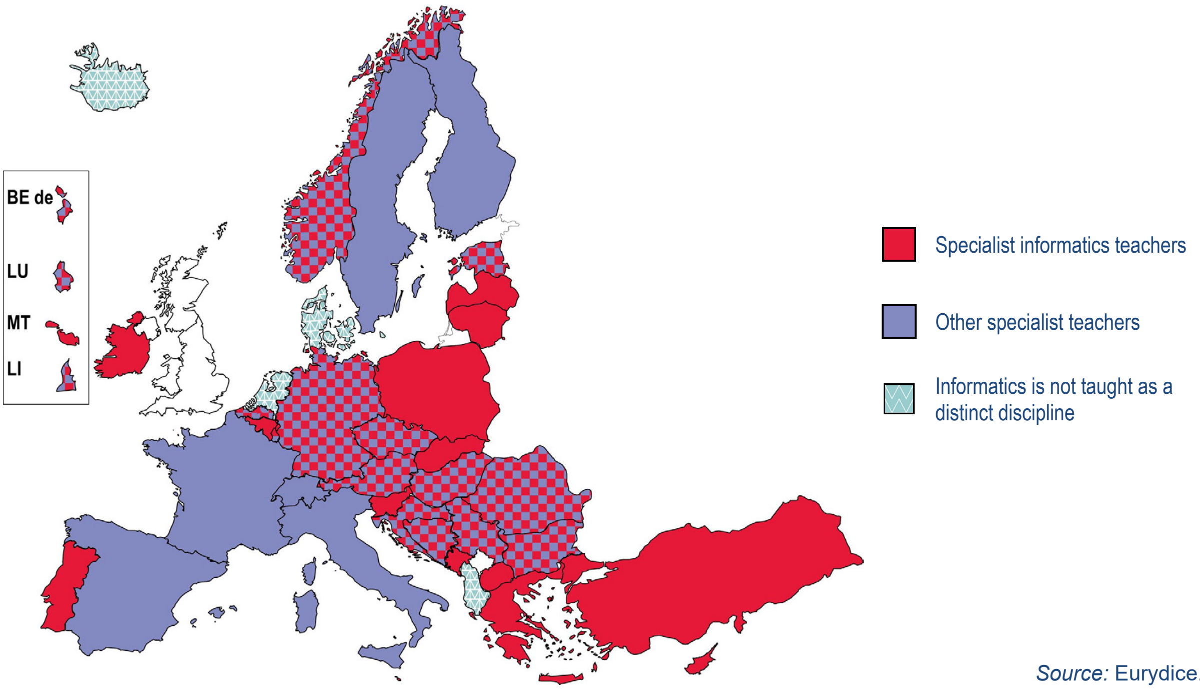
([123]) https://global.edumus.org

3.1.2. Professional profiles of informatics teachers in lower secondary education

Teaching informatics at lower secondary level is mainly the responsibility of teachers specialising in informatics or in other school disciplines. This is probably because at this stage informatics curricula become more complex and they usually cover all the main areas of learning outcomes (see Chapter 2, Section 2.2.2). This requires teachers to be specialised. Moreover, at this education level informatics is taught as a separate subject or integrated into another subject in almost all the education systems (see Chapter 1, Section 1.3).

Figure 3.2 shows that in most education systems specialist informatics teachers teach informatics, and in around one third of them they are the only teachers eligible to teach the subject.

Figure 3.2: Professional profiles of informatics teachers in general lower secondary education (ISCED 24), 2020/2021



Source: Eurydice.

Country-specific notes

Greece: To teach informatics curricula, all newly appointed staff should be specialist informatics teachers. However, the mathematics and science teachers who were appointed during past teacher shortages can continue to teach informatics.
Ireland: In the absence of a specialist computer science teacher, the school can in some instances assign a teacher with relevant experience and/or qualifications to teach computer science.
Slovenia: Other specialist or generalist teachers can teach computer science (*Računalništvo*) if they have completed a supplementary study programme in computer science and informatics. The programme was discontinued in 2015.

Teachers with specialisations other than in informatics are largely involved in teaching informatics at lower secondary level. This is the case in around two thirds of education systems where informatics is taught as a distinct discipline. The other specialist teachers are usually qualified in mathematics, physics, other sciences, technologies or economics (see Annex 3) and in some countries they need to obtain an additional qualification in informatics.

In 15 education systems (see Figure 3.2), specialist informatics teachers and other specialist teachers can teach informatics. In 5 of them (Bulgaria, Czechia, Germany, Austria and Serbia), however, specialist teachers qualified in a school subject other than informatics are required to complete training in informatics to extend their qualification.

In **Germany**, secondary school teachers can teach informatics after completing specific in-service training.

Similarly, in **Czechia** other specialist teachers can teach informatics after completing a specific continuing professional development (CPD) programme extending their qualifications.

In **Austria**, specialist teachers need to complete the academic course 'Digital basic competence'.

In **Serbia**, if the school does not have a candidate who meets the requirements for a specialist informatics teacher, teaching and other forms of educational work in the subject informatics and computer science can be performed by a 'master teacher', a teacher who has achieved 90 credits through the European Credit Transfer and Accumulation System in the field of informatics during their studies or through an additional programme.

In 6 other countries (Spain, France, Italy, Finland, Sweden and Switzerland), only other specialist teachers teach informatics. In Spain, France, Italy and Sweden, where some specific content on informatics is integrated into the compulsory subject mathematics, technology or mathematics and technology (see Chapter 1, Section 1.3), teachers specialising in these subjects are responsible for teaching informatics. In Finland, various specialist teachers can teach informatics content. However, in practice, teachers specialising in mathematics, natural sciences and crafts are mostly responsible for teaching informatics. In Switzerland, all secondary school teachers who have completed specific training in informatics as part of their CPD can teach the compulsory subject media and informatics.

The involvement of generalist teachers in teaching informatics at lower secondary level is extremely limited. In Hungary (in grades 5 and 6), Slovakia and Serbia generalist teachers can teach informatics only if there are no specialist teachers. Moreover, to teach informatics at lower secondary level, Hungary and Serbia require generalist teachers to have specialised in informatics. This specialisation could have taken place during their initial studies or through an additional training programme.

Finally, in Denmark, the Netherlands, Albania and Iceland, informatics is not taught as a distinct discipline at this stage.

3.1.3. Professional profiles of informatics teachers in upper secondary education

At the upper secondary level of general education, informatics curricula become even more complex than in lower secondary schools. This is the 'in-depth study' stage, which deals with ideas that are specific to this scientific discipline (see Chapter 2, Section 2.2.3). Therefore, unsurprisingly almost all European education systems require specialist informatics teachers to teach informatics to students in upper secondary education. In around half of these countries, specialist informatics teachers are the only ones allowed to deliver informatics curricula, while in the other half other specialist teachers can also teach informatics. In Finland, only other specialist teachers teach the subjects that include some learning outcomes on informatics.

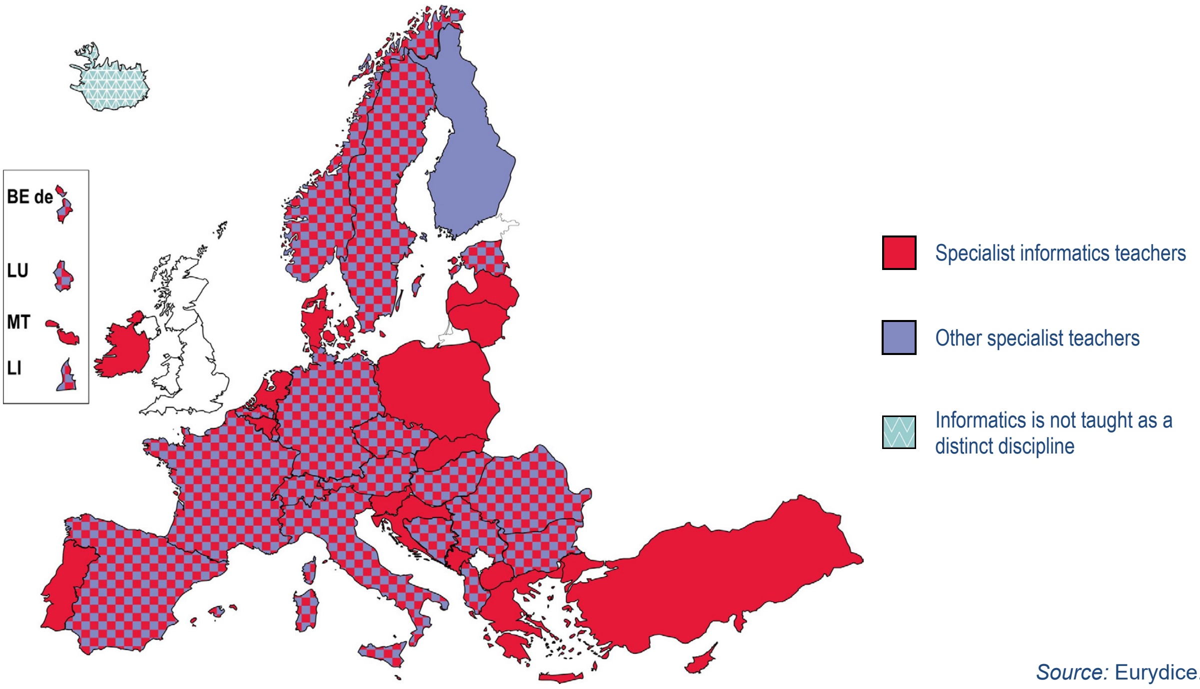
Figure 3.3 shows that in 20 education systems ([124]) other specialist teachers can provide informatics curricula alongside specialist informatics teachers. In Spain (grade 10), France, Italy (grades 9–10), Luxembourg and Sweden, informatics is not only taught as a separate subject; some learning outcomes on informatics are also included in other school subjects (see Chapter 1, Section 1.4). Therefore, teachers specialising in these other disciplines also teach some informatics content. Although informatics is taught as a separate subject in the remaining education systems ([125]), other specialist teachers may also teach it. These teachers are usually qualified to teach mathematics, technologies, engineering or sciences (e.g. physics, economics and natural sciences) (see Annex 3).

([124]) Flemish- and German-speaking Communities of Belgium, Bulgaria, Czechia, Germany, Estonia, Spain, France, Italy, Luxembourg, Hungary, Austria, Romania, Sweden, Albania, Bosnia and Herzegovina, Switzerland, Liechtenstein, Norway, and Serbia.

([125]) In the Flemish- and German-speaking Communities of Belgium, local/school authorities decide how the curriculum is organised.

In Albania, the compulsory subject ICT, which includes informatics-related learning outcomes, is taught by teachers specialising in ICT, mathematics or physics.

Figure 3.3: Professional profiles of informatics teachers in general upper secondary education (ISCED 34), 2020/2021



Source: Eurydice.

Country-specific notes

Greece: To teach informatics curricula all newly appointed staff should be specialist informatics teachers. However, the mathematics and science teachers who were appointed during past teacher shortages can continue to teach informatics.
Ireland: In the absence of a specialist computer science teacher, the school can in some instances assign a teacher with relevant experience and/or qualifications to teach computer science.
Slovenia: Other specialist teachers can teach informatics (*Informatika*) if they have completed a university study programme or a second-cycle master's study programme and have completed a supplementary study programme in computer science and informatics. The supplementary study programme was discontinued in 2015.

In some education systems, other specialist teachers teaching informatics have a minor specialisation in informatics during their initial training (e.g. Estonia, Romania, Bosnia and Herzegovina). In Bulgaria, Czechia, Germany, Austria, Sweden and Switzerland, to teach informatics in upper secondary education, teachers specialising in subjects other than informatics need to complete supplementary training on informatics (see Annex 3).

In particular circumstances, usually owing to teacher shortages, Czechia, Estonia and Sweden allow schools to temporarily deviate from the official rules and recruit either teachers not qualified in informatics, or informatics specialists without a teaching qualification. In Sweden, non-qualified teachers can be employed for a maximum of 1 year.

3.2. Training specialist informatics teachers

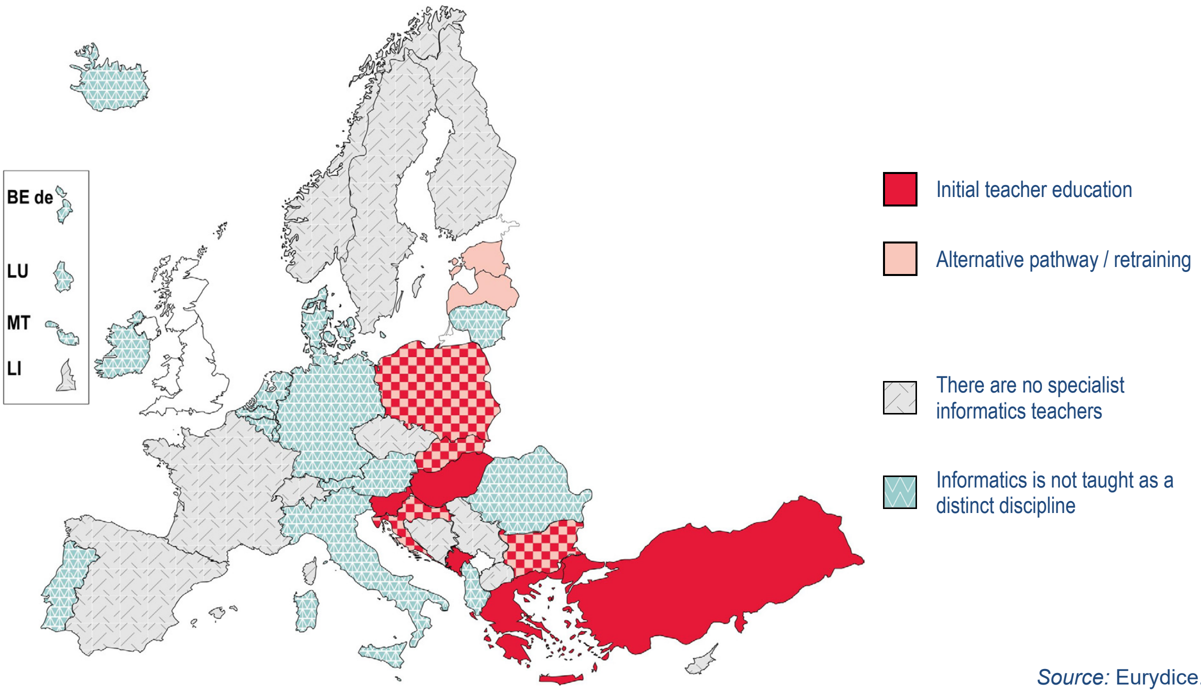
This section focuses on the professional training of specialist informatics teachers. It looks at the existence of ITE, alternative pathways and retraining schemes. While alternative pathways mainly target professionals without teaching qualifications, the main purpose of retraining is to equip teachers qualified to teach other subjects (e.g. teachers of mathematics, physics, engineering and business) with specific knowledge in informatics.

3.2.1. Training specialist informatics teachers for primary education

As explained in the previous section, specialist informatics teachers teach informatics at primary level in fewer than one third of European education systems.

With only a few exceptions, all countries where there are specialist informatics teachers have ITE programmes to prepare such specialists (Figure 3.4). In 5 countries (Greece, Hungary, Slovenia, Montenegro and Turkey), teachers can specialise in informatics only through ITE. In Bulgaria, Croatia, Poland and Slovakia, other routes, such as alternative pathways or retraining programmes, also exist.

Figure 3.4: Training specialist informatics teachers for primary education (ISCED 1), 2020/2021



Source: Eurydice.

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Alternative pathway				●				●					●														●												
Retraining				●												●							●				●												

Explanatory note

Annex 4 provides a brief description of the alternative pathways and retraining programmes in these countries.

In Bulgaria, Croatia and Slovakia, professionals from informatics-related fields, such as mathematics, engineering and IT, can obtain a teaching qualification by completing postgraduate professional training that usually includes pedagogical and psychological disciplines, teaching methods, didactics and practical training.

> For example, in **Bulgaria,** in-service teachers can obtain an additional qualification in informatics through the national programme 'Motivated teachers', while the 'Digital qualification' programme offers opportunities to obtain an additional qualification as informatics or information technologies teacher to both in-service teachers and professionals from informatics related fields.

The way in which training is organised and its duration differs slightly among countries. For example, professional studies last 1 year in Croatia and Bulgaria, while in Slovakia they last 2 academic years.

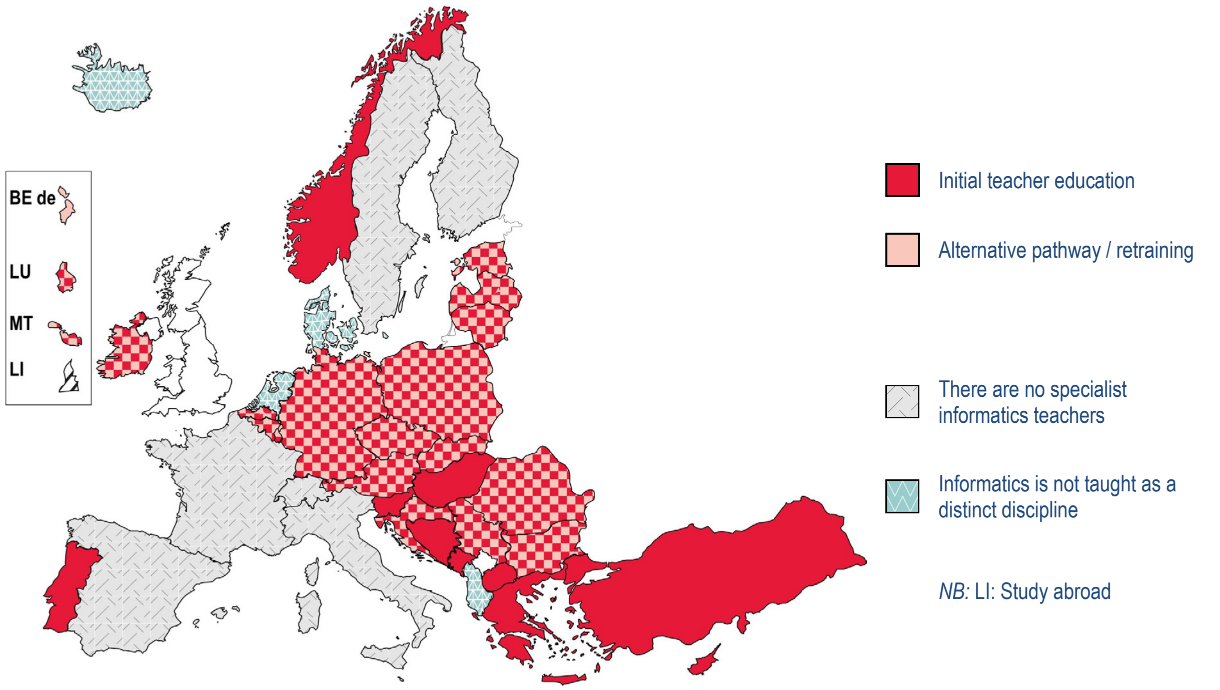
In Estonia and Latvia, there are no ITE programmes preparing informatics teachers to teach in primary schools. However, specialist informatics teachers who are qualified to teach at lower secondary level can also teach informatics content to primary school students. In Latvia, primary school teachers can obtain additional qualifications in informatics by completing special retraining courses. In Estonia, a school head has the authority to recruit anybody who holds a qualification required for teaching at primary level and has the necessary skills to teach informatics at school.

All alternative pathways and retraining programmes described in this section also allow professionals to qualify as secondary school informatics teachers. However, in some education systems a higher academic degree may be required to teach at secondary level of general education.

3.2.2. Training specialist informatics teachers for lower secondary education

At the lower secondary level of general education, informatics is generally taught by specialist informatics teachers. To prepare teachers for this role, all education systems have in place at least one professional development scheme.

Figure 3.5: Training specialist informatics teachers for general lower secondary education (ISCED 24), 2020/2021



Source: Eurydice.

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Alternative pathway	●	●	●	●			●	●					●			●		●		●							●												
Retraining			●	●	●		●	●	●							●	●	●				●	●		●		●											●	

Explanatory note

Annex 4 provides a brief description of the alternative pathways and retraining programmes.

Country-specific notes

Belgium (BE de): No teacher education is organised in the Community. Most teachers are trained in the French Community of Belgium.
Liechtenstein: Specialist informatics teachers are trained abroad.

All education systems with specialist informatics teachers have set up specific ITE programmes (Figure 3.5). The only exceptions are the German-speaking Community of Belgium, and Liechtenstein, where there is no initial teacher training.

In around half of the education systems, the only way to become a specialist informatics teacher for lower secondary schools is to complete the ITE programme. To increase the pool of specialist informatics teachers, other education systems have introduced alternative and/or retraining schemes that run alongside regular ITE programmes. While Czechia, Ireland, Lithuania, Austria, Poland, Romania and Serbia focus on retraining qualified teachers, the French and German-speaking Communities of Belgium, Croatia and Malta offer alternative opportunities for candidates without teaching qualifications to qualify as specialist informatics teachers. In the Flemish Community of Belgium, Bulgaria, Germany, Estonia, Latvia, Luxembourg and Slovakia, all three professional development opportunities are offered: ITE, alternative pathways and retraining programmes.

Among the alternative pathways to a teaching qualification at the level of lower secondary education, professional-oriented programmes seem to be the most common (see Annex 4). They are mainly designed for candidates with a non-teaching academic degree in informatics or an informatics-related area who have some professional experience or none. Other admission criteria can also apply depending on the country and, sometimes, on the programmes' providers. Some education systems, for example Bulgaria, Croatia, Latvia and Slovakia, offer distinct programmes that target professionals from informatics-related fields or newly qualified graduates or both, usually from science-related fields. In Germany, specialists from informatics-related fields can join the second part of ITE programmes to obtain a teaching qualification.

Another way to obtain a teaching qualification is through a certification process. Such an opportunity exists in Belgium (French and German-speaking Communities), Estonia and Luxembourg.

For example, **the French and German-speaking Communities of Belgium** have developed a certification process called the pedagogical aptitude certificates (*certificat d'aptitude pédagogique* (CAP) and CAP+), which allow professionals to obtain teaching qualifications with or without professional training.

A total of 14 education systems ([126]) have retraining programmes that allow secondary school teachers to obtain an additional qualification to teach informatics.

Retraining programmes may be part of the CPD of in-service teachers or full-time studies. They give teachers the opportunity to extend their qualifications to another subject that they did not originally study. Therefore, one of the main criteria for admission is to be a fully qualified teacher. These programmes usually do not lead to an academic degree, but certify participants' ability to teach informatics.

The organisation of the retraining opportunities varies between and within countries. However, some common characteristics can be observed. For example, retraining programmes are commonly provided by teacher-training institutions, often the same ones that organise ITE. The programmes usually last for between 1 and 2 years; their duration is, however, shorter in Czechia, Luxembourg, Latvia and Austria (see Annex 4).

In **Czechia**, for instance, the training for extending qualifications takes the form of lifelong learning courses at a higher education institution and lasts only 188 hours.

In countries that offer various programmes and in those where the programmes are provided by different institutions, their duration may naturally vary. This is the case, for example, in Germany, Ireland, Luxembourg, Austria and Poland (see Annex 4).

In Germany and Ireland, in-service teachers can participate in retraining programmes on a part-time basis or in the evening while continuing to work.

In **Germany**, retraining usually extends over a longer period and includes various courses of several hours per week and, where necessary, additional intensive courses. For the duration of the courses, participants are released from their teaching duties or from

([126]) Flemish Community of Belgium, Bulgaria, Czechia, Germany, Estonia, Ireland, Latvia, Lithuania, Luxembourg, Austria, Poland, Romania, Slovakia and Serbia.

several of their weekly teaching commitments if the school supervisory authority recognises the need for the further training courses concerned.

In **Ireland**, Technological University Dublin Tallaght offers a Higher Diploma in Science in computing with an optional module in computer science for secondary school teachers. This module is specifically aimed at teachers who wish to train to deliver the new leaving certificate subject computer science. This is a 90-credit European Credit Transfer and Accumulation System programme, lasting 2 years. It is delivered in the evening, usually two evenings per week. Teachers seeking CPD can use their own initiative to access retraining programmes.

All the abovementioned alternative pathways and retraining programmes are also available to upper secondary level teachers. In Serbia, however, retraining opportunities are offered only to teachers working in lower secondary schools. In Luxembourg, although retraining opportunities mainly target lower secondary school teachers, upper secondary teachers can also benefit from them.

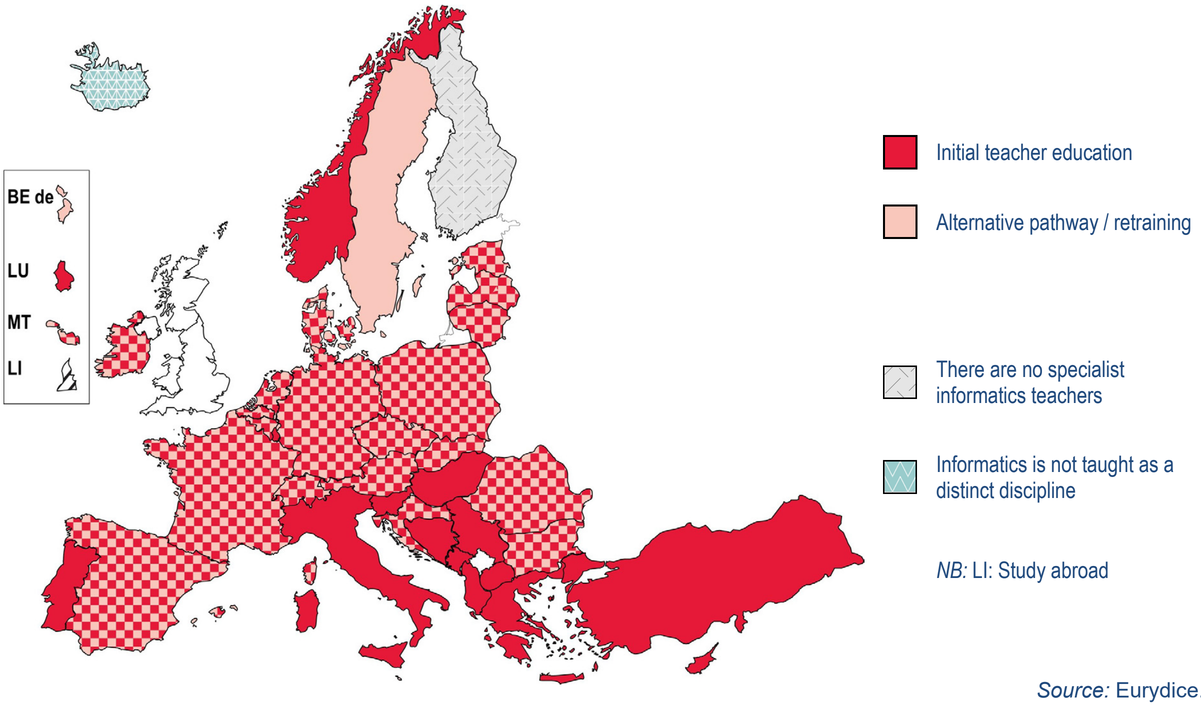
3.2.3. Training specialist informatics teachers for upper secondary education

Most education systems offer various opportunities for teachers to qualify to teach informatics in upper secondary schools. There are opportunities in almost all education systems to enrol in ITE programmes to study informatics for the teaching profession, except the German-speaking Community of Belgium, Sweden and Liechtenstein. Alternative pathways and/or retraining possibilities are available in most education systems. In 14 countries ([127]), however, the only way to qualify as specialist informatics teacher is to complete ITE.

As mentioned in the previous section, in all education systems except Serbia, upper secondary teachers can also obtain the qualification through the same alternative pathways and/or retraining programmes as lower secondary teachers (see Section 3.2.2).

([127]) Greece, Italy, Cyprus, Luxembourg, Austria, Portugal, Albania, Bosnia and Herzegovina, Switzerland, Montenegro, North Macedonia, Norway, Serbia and Turkey.

Figure 3.6: Training specialist informatics teachers for general upper secondary education (ISCED 34), 2020/2021



Source: Eurydice.

	BE fr	BE de	BE nl	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	AL	BA	CH	IS	LI	ME	MK	NO	RS	TR
Alternative pathway	●	●	●	●		●	●	●				●	●			●				●	●						●		●										
Retraining			●	●	●	●	●	●	●		●	●				●	●					●	●		●		●		●			●							

Explanatory note

A brief description of the alternative pathways and retraining programmes is provided in Annex 4.

Country-specific notes

Belgium (BE de): No teacher education is organised within the Community. Most teachers are trained in the French Community of Belgium.
Liechtenstein: Specialist informatics teachers are trained abroad, usually in Switzerland.

In Denmark, the Netherlands and Albania, informatics is taught as a distinct discipline only from upper secondary level, and in Spain, France, Italy, Sweden and Switzerland, specialist informatics teachers start teaching this subject only in upper secondary education. While in Italy and Albania, specialist informatics teachers are qualified only through ITE, in Denmark, Spain, France, the Netherlands and Switzerland, alternative pathways and/or retraining programmes are offered alongside ITE programmes (Figure 3.6; see Annex 4).

The **Netherlands**, besides the 'Informatics for all' and *Zijinstroom in het beroep* alternative programmes (see Annex 4), is currently focusing on increasing the accessibility of the informatics teaching profession. 'Co-teach computer science' is a recent initiative and is a collaboration between the association of Dutch research universities, the association of schools and the Dutch ICT industry. The initial results of the initiative are currently being evaluated and already seem to show that it is a promising collaboration ([128]).

3.3. Support measures for informatics teachers

Informatics teachers, like any others, need systematic and continuous support to do their job effectively, provide good-quality teaching and stay motivated. Structured and comprehensive support is particularly necessary when introducing new or updated informatics content into curricula.

([128]) https://www.co-teach.nl/

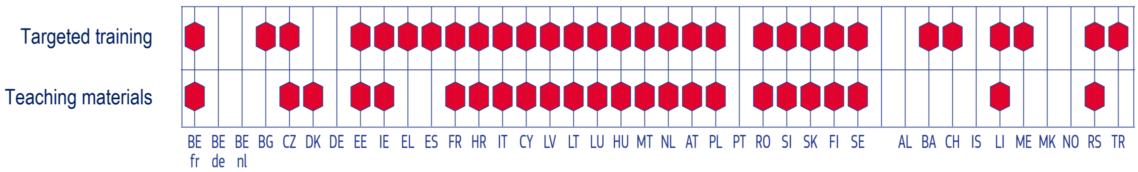
There are many ways to support teachers, such as providing appropriate training (e.g. online or in-person courses, conferences and workshops); developing appropriate teaching methods, materials and approaches to assessing students; and organising individual school support.

Establishing a network of regional hubs for professional development can also help teachers with their training. Establishing a peer support network has proven to be essential in the United Kingdom (England) to increase the number of teachers confident in teaching computing (National Centre for Computing Education, 2020).

Professional learning communities also play a key role in supporting teachers' learning, preventing their isolation and fostering their development (Ni, Bausch and Benjamin, 2021). This kind of support is even more important because in many education systems informatics is quite a new school discipline, so there is a limited amount of available resources for teaching and literature related to methods for delivering the content.

This section focuses on two main support measures, including targeted CPD for in-service informatics teachers and the provision of teaching materials.

Figure 3.7: Support measures for in-service informatics teachers (ISCED 1, 24 and 34), 2020/2021



Source: Eurydice.

3.3.1. Targeted training as part of continuing professional development

Almost all education systems give in-service teachers the opportunity to attend training on a variety of subjects relating to informatics and digital education (see Figure 3.7). In most countries, such training is part of the regular CPD offered to in-service teachers to help them update or broaden their skills.

In Spain, Austria and Poland, informatics-related training is part of broader initiatives or projects.

In **Spain**, the Ministry of Education and Vocational Training, in collaboration with the departments of education of the autonomous communities, has developed a project 'School of computational thinking and artificial intelligence' (*Escuela de Pensamiento computacional e Inteligencia Artificial*) ([129]). This project aims to help teachers develop new skills and teaching practices needed to incorporate computational thinking and artificial intelligence into programming and robotics activities. As part of the project, several open educational resources and training courses have been made available. Moreover, the Ministry of Education and Vocational Training, through the *Instituto Nacional de Tecnologías Educativas y de Formación del Profesorado*, and the autonomous communities, through their teacher training centres, offer several courses relating to informatics that teachers can choose from according to their needs. Examples of these courses are 'Artificial intelligence for the common good', 'Basic digital protection measures', 'Specialisation course in artificial intelligence and big data: big data systems' and 'Robotics applied to primary education' ([130]).

As digitisation is becoming more and more important in the **Austrian** school system, the Ministry of Education and several teacher training colleges have developed a wide range of training courses focusing on digital qualifications and teachers' skills. In addition,

([129]) https://intef.es/tecnologia-educativa/pensamiento-computacional/

([130]) https://enlinea.intef.es/courses/course-v1:INTEF+IABienComun+2021_ED1/about; https://enlinea.intef.es/courses/course-v1:INTEF+ProteccionDIG+2021_ED3/about; http://centroformacionprofesorado.castillalamancha.es/comunidad/crfp/recurso/curso-de-especializacion-en-inteligencia/8ba00c65-3211-49aa-a8f1-b486d33062ca; http://centroformacionprofesorado.castillalamancha.es/comunidad/crfp/recurso/robotica-aplicada-a-educacion-primaria-nivel/0edb6000-168e-4e91-bb35-39e2fef34823?searchid=53d09cee-1851-3c23-0a6b-2bde7e79dacb the ministry-funded measure 'digi.folio' ([131]) brings together all courses offered by the teacher training colleges on computer science / digital learning. The measure gives teachers the opportunity to expand their digital skills in a way that suits them, enabling them, after a digital competence check (digi.check) ([132]), to choose from at least 50 teaching units of individually tailored further training opportunities.

In **Poland**, three large projects are focused on the professional development of informatics teachers. The first project is the 'Lesson: Enter' project (2019–2023), which aims to develop teachers' digital skills through nine different training paths. The pathway for teachers of informatics prepares them to implement the core curriculum in terms of understanding, analysing and problem-solving, as well as programming. The 'Lesson: Enter' website also includes training materials, additional resources and internet tools, including sets of several tutorials. Participation in the training courses is free and voluntary. The training as part of 'Lesson: Enter' for teachers of informatics includes 40 lessons and in-school placements during which teachers are required to implement their own lesson plans in school classes under the observation of other teachers and the school management. The second project is 'Centre for IT Mastery', which aims to improve the skills of teaching staff conducting extracurricular activities, promote IT and activate young people gifted in IT, stimulating their creativity and promoting teamwork within IT communities. Teachers participating in the project take part in two semesters of certified training on algorithms and programming. The training can be provided by one of the top five technical universities in the country (AGH University of Science and Technology in Krakow, Gdansk University of Technology, Lodz University of Technology, Warsaw University of Technology and Wroclaw University of Science and Technology). By the end of 2020, as part of the project, 367 teachers had been trained. Both projects are co-funded by the European Union. Finally, the Challenges in Algorithmic and Programming Project ([133]) is part of the Informatics Talent Development Programme for 2019–2029, funded by the Polish government. The objective of the project is to systematically support talented young people from upper secondary schools in broadening their informatics knowledge and skills, in particular in the field of algorithms and programming. The project also supports teachers working with students talented in informatics through a special scholarship programme and specialised training.

In Austria and Switzerland, besides regular informatics CPD courses, teachers with a specialisation other than informatics can obtain certification to teach informatics through completing CPD training (see also Section 3.2 and Annex 4).

Other countries have developed ad hoc training as part of teachers' CPD to accompany the reforms introducing or updating the informatics curriculum. This is the case in Czechia, Germany, Estonia, Ireland, Croatia, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Romania and Switzerland (see Section 3.4). In all these countries, teacher can take part in this training on a voluntary basis.

3.3.2. Teaching materials

The implementation of informatics curricula requires the availability of a vast amount of learning material and best pedagogical practices so that teachers can choose the most appropriate ones for their specific students. Again, given the novelty of the subject, this material and these practices may not be available in abundance, and not all teachers are able, or have the time, to develop them on their own. In general, teaching resources are focusing on knowledge around the curricular content and provide little pedagogical support, which is, however, an important requirement (Falkner and Vivian, 2015). Efforts aimed at developing them will require solid and evidence-based research about what works for each level of education. As noted by Garneli, Giannakos and Chorianopoulos (2015), there is no pedagogical solution that works for all classes. Moreover, research will have to be done in every country, given the need to produce material adapted to national languages and cultures.

As shown in Figure 3.7, many education systems have developed different formats of teaching materials for informatics teachers.

([131]) https://www.digifolio.at/

([132]) https://digicheck.at/paedagoginnenbildung; https://community.eeducation.at/digicheck/

([133]) map.org.pl

In France, Cyprus, Luxembourg, Malta and Poland, public education authorities such as ministries, training institutes/agencies or universities, sometimes in collaboration with the private companies, take the lead in developing these teaching materials.

For example, in **Cyprus** the Ministry of Education, Culture, Sport and Youth has been developing teaching materials, all accessible on its official website. These include books, worksheets, notes, videos and other digital content.

In **Poland**, teaching materials for informatics teachers are provided on the diverse websites and platforms developed by public authorities. For example, the Integrated Education Platform ([134]) of the Ministry of Science and Higher Education provides free digital educational resources such as interactive e-materials, e-workbooks, curricula and lesson plans, including resources for teaching computer science in schools at every education level. Many teaching materials are available on the websites of the Olympiads in Informatics ([135]) and a project promoting the learning of programming ([136]). Besides the free educational resources, such as lesson plans, offline games and applications, online games and applications, programming courses, webinars and publications for teachers on programming, the website of the second project offers educational materials developed as part of the 'Young Programmers' Club' project. The Young Programmers' Club was set up by the Ministry of Digitalisation and the Research and Academic Computer Network - National Research Institute, as part of which children and young people at school age learn programming. The institute also provides several teaching materials on its own website and on the Nationwide Educational Network IT-School educational platform ([137]).

Czechia, Denmark, Estonia, Ireland Croatia and Latvia have developed, in addition to their existing teaching materials, supplementary resources to support curriculum reforms (see Section 3.4).

3.4. Policy reforms and initiatives relating to training and other support measures for informatics teachers

As already mentioned, the successful introduction of informatics into school curricula depends on the preparation of teachers, the provision of qualitative methodological support and the availability of appropriate teaching materials. Introducing a new informatics curriculum or updating an existing one requires teachers to be familiar with its content and with the teaching methods for delivering it. Chapter 1 of this report examines the current policy reforms regarding changes to curricula such as introducing a new subject or upgrading the curriculum and/or learning outcomes (see Chapter 1, Section 1.5). This section completes this information by giving examples of countries where provisions for teachers' professional development and for other support measures for teachers accompany curricular reforms.

As shown in the following examples, some countries have planned and organised various support measures to prepare teachers for the introduction of new or updated informatics curricula. These provisions vary across countries and may include organising targeted teacher training, creating professional networks, developing teaching materials and teaching methods, and updating initial teacher training programmes.

A first group of countries (Czechia, Estonia, Ireland and Croatia) have implemented a more comprehensive set of support measures accompanying curriculum reforms.

In Czechia, the curricular reform ([138]) introducing the new informatics curriculum (see Chapter 1, Section 1.5) also provides for the transformation of ITE and CPD programmes for teachers. ITE is being revised to prepare prospective teachers to provide the new informatics curricula. In the meantime, to help schools and informatics teachers introduce the new curricula on informatics into

([134]) www.zpe.gov.pl
([135]) https://oi.edu.pl; https://oi.edu.pl/l/40/; https://oij.edu.pl
([136]) https://www.gov.pl/web/koduj
([137]) https://it-szkola.edu.pl/
([138]) Strategy 2030+ (https://www.msmt.cz/vzdelavani/skolstvi-v-cr/strategie-2030); https://revize.edu.cz/podpora-skolam)

school education, a start-up package has been developed. This package includes various support measures for schools, such as courses and workshops for teachers, and individual consultations for schools. It has also organised four educational events for informatics teachers, school educational programme coordinators, experts in ICT methodologies and school management. The training and workshops cover diverse areas related to the new informatics curricula. The recently developed *Digiplovárna* platform allows teachers to share their learning and teaching experiences, and ideas on informatics and on the development of digital skills. The project 'Support for the Development of Informatics Thinking' includes the portal *iMyšlení*, specifically dedicated to informatics teachers ([139]). Moreover, a network of regional experts in ICT methodologies ([140]) and methodical advisory groups, *metodické kabinety* ([141]), were set up to provide free, tailored professional support to schools in the area of informatics and digital education. Finally, teaching materials and digital teaching resources were developed and made available to teachers. All pedagogical faculties in Czechia and the National Pedagogical Institute of the Czech Republic participate in the preparation of these materials and methods.

Estonia has recently reformed its ITE programme to ensure a sufficient workforce of informatics teachers ([142]). The main change consists of making admission requirements and the organisation of ITE more flexible. Thus, candidates without a bachelor's degree in teacher training can take more courses in pedagogy, while candidates without formal qualifications in mathematics or IT can take extra courses in these subjects during their studies or have their prior learning and experience recognised. In addition, the acquisition of a multisubject teaching qualification is encouraged. The government also supports informatics teaching students with a special scholarship to increase enrolment. Moreover, state-commissioned in-service training courses are offered under the programme *ProgeTiiger* ([143]). These courses support curriculum reforms updating and introducing the new informatics syllabi for basic and upper secondary schools. The courses are optional for teachers, and can last between 2 and 40 hours. There are also thematic training courses and teachers' guides available. In addition, the programme aims to increase the popularity of informatics among teachers and helps them purchase equipment.

In Ireland, while gradually introducing the junior cycle short course in coding in schools (2014–2021) ([144]), the Department of Education offered several CPD opportunities to in-service lower secondary teachers. The Department of Education also provides a professional development programme for all schools that introduce or teach Leaving Certificate Computer Science at upper secondary level. This programme consists of a number of components, including national workshops, fundamental skills development workshops and communities of practice. Regional cluster meetings were established to encourage teachers to collaborate at local level and to share experiences and practices. The participants also had access to webinars, online massive open online courses and additional resources on the CompSci website ([145]). A leadership workshop was held for school principals and an industry day was held, which was open to all teachers.

In Croatia, during the preparation for the implementation of the new informatics curriculum (2018–2020 reform) ([146]), until July 2020, professional training for informatics teachers was organised in

([139]) https://imysleni.cz
([140]) https://www.projektsypo.cz/e-poradenstvi.html
([141]) https://www.projektsypo.cz/metodicke-kabinety-kontakty.html
([142]) Framework requirements for teacher training, 2019 (https://www.riigiteataja.ee/akt/122082019010).
([143]) https://harno.ee/progetiigri-programm
([144]) https://www.curriculumonline.ie/Junior-cycle/Short-Courses/Coding/
([145]) www.compsci.ie
([146]) https://skolazazivot.hr/vrednovanje-eksperimentalnoga-programa-skola-za-zivot-u-skolskoj-godini-2018-2019/

virtual classrooms. It included 31 topics, among which were computational thinking and programming; information and digital technology; digital literacy and communication; e-society, e-safety and cyberbullying prevention; assessment; and informatics as a cross-curricular topic. Participating in a variety of activities allowed teachers to share their ideas and experiences and reflect on their learning and teaching. They could learn about different methods of teaching and assessment, and create a shared base of learning resources and ideas for future teaching. In additions, as part of the e-Schools project ([147]), informatics teachers created digital learning materials that have been made available to all teachers. Finally, several resources for teaching were created, for example methodological guidelines and interactive digital education resources for grades 1, 5 and 6 in primary school and the 1st grade in secondary school ([148]), and video lessons ([149]).

Other countries have mainly focused on targeted teacher training and/or the development of teaching materials while introducing a new or updated informatics curriculum. Some countries planned teacher training to prepare for future curriculum reforms.

In Denmark, a project group prepared teaching materials ([150]) when the experimental subject *Informationsteknologi* was launched, and the Centre for Computational Thinking and Design developed teaching materials when *Informatik* subject was launched.

In Germany (Lower Saxony), where informatics is being gradually introduced as a separate subject at lower secondary level ([151]), 2 years' in-service training has been organised to prepare teachers. This training includes various activities, such as eight 3- to 4-day events, webinars and courses. The content is organised around four learning areas: data and its traces, computer competence, algorithmic problem-solving and automated processes. In Schleswig-Holstein, where informatics will be a compulsory subject at lower secondary level from the 2022/2023 school year, the Ministry of Education is focusing on informatics training to ensure it can recruit enough informatics teachers. Starting in August 2021, an initial 75 teachers could be qualified.

In Italy, Law 233/2021 provides for the updating of the national training plan for teachers in all public schools. This plan will have to include, among the national priorities focusing on digital teaching and learning, specific courses in computer programming (coding), consistent with the commitments made in the recovery and resilience plan ([152]).

Poland is supporting the process of further educating teachers of informatics by providing additional funds in the state budget. The funds are allocated to the universities that offer a full informatics study programme and in-service postgraduate studies in informatics.

In Cyprus, as Python will replace the Pascal programming language at ISCED 24 (grade 9) in 2022/2023 and at ISCED 34 (grade 10) in 2023/2024, short training courses will be organised in 2021/2022 to introduce the language to informatics teachers at these levels.

Latvia has been developing the new study programme 'Teachers' as part of informatics teachers' CPD to prepare them to deliver the updated curriculum. The teaching materials are available on the

([147]) https://edutorij.e-skole.hr/

([148]) https://skolazazivot.hr/obrazovni-sadrzaji/metodicki-prirucnici/metodicki-prirucnici-za-osnovnu-skolu/; https://skolazazivot.hr/obrazovni-sadrzaji/metodicki-prirucnici/metodicki-prirucnici-za-srednju-skolu/

([149]) https://skolazazivot.hr/video-lekcije/

([150]) http://iftek.dk; http://informatik-gym.dk

([151]) https://www.mk.niedersachsen.de/startseite/aktuelles/presseinformationen/informatik-wird-ab-dem-schuljahr-2023-2024-pflichtfach-weitere-qualifizierungskurse-fur-lehrkrafte-starten-184807.html

([152]) President of Italy, Law No 233/2021 of 29 December 2021 (https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:2021-12-29;233); Government of Italy, *Piano Nazionale di Ripresa e Resilienza*, 2021 (https://www.governo.it/sites/governo.it/files/PNRR.pdf), p. 187.

curriculum reform home page developed by the project working group ([153]). In addition, the private company 'Start IT', supported by the National Centre for Education and the IT business association Latvian Information and Communication Technology Association ([154]), has also developed additional teaching materials.

In Lithuania, two in-service training programmes have been organised for primary education teachers. They focus on teaching practices and on how to develop students' digital and informatics skills. To increase the pool of informatics teachers, the number of state-funded places on informatics courses in ITE was increased in 2020.

In Luxembourg, tailored teacher training is still a substantial part of the roll-out of the new school discipline digital sciences. Although digital sciences is not considered a stand-alone subject in primary education, training was provided for both primary and secondary school teachers.

Malta offers training for teachers in the new subject ICT C3, which has been gradually introduced in lower and upper secondary schools since 2018.

As Romania is to update the whole curriculum of general upper secondary education, including the area of informatics, teacher training is also planned.

The cantons in Switzerland provide targeted CPD training for teachers who will teach the updated curriculum for the subject digital education/media and informatics.

Finally, France and Serbia focused on initial teacher training. For example, France, following the introduction of informatics as a separate subject into the curriculum of upper secondary schools in 2018, set up competitive examinations to become an informatics teacher in upper secondary school: *Certificat d'Aptitude au Professorat de l'Enseignement du Second degré* in 2020 ([155]) and *Agrégation* in 2022 ([156]). Since 2019, Serbia has been publishing annually an open call for scholarships to attract student teachers into ITE programmes for informatics teaching.

([153]) https://www.skola2030.lv
([154]) https://likta.lv/en/home-en/
([155]) https://www.devenirenseignant.gouv.fr/cid137910/creation-capes-numerique-sciences-informatiques.html&lang=fr
([156]) https://www.devenirenseignant.gouv.fr/cid158841/creation-de-l-agregation-d-informatique.html

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GLOSSARY

Alternative pathways: In the present report, the definition of alternative pathways is restricted to training programmes / schemas / mechanisms other than mainstream initial teacher education that allow individuals to become qualified informatics teachers. These target individuals who do not hold any formal teaching qualifications but have professional experience (e.g. in informatics, information and communications technology and educational activities).

Artificial intelligence (AI): 'AI' refers to information technology systems that display intelligent behaviour by analysing their environments and taking action – with some degree of autonomy – to achieve specific goals. AI-based systems can be purely software based, acting in the virtual world (e.g. voice assistants, search engines, and speech and face recognition systems), or embedded in hardware (e.g. advanced robots, autonomous cars and drones).

Compulsory for some students: As opposed to subjects that are compulsory for all students, this category applies to subjects that are compulsory only for students in specific educational tracks, programmes or subject clusters.

Computational thinking: This is shorthand for 'thinking like a computer scientist', and refers to the ability to understand the underlying core concepts and mechanisms of digital technologies to formulate and solve problems (Bocconi et al., 2016). Similarly, as Jeannette Wing puts it, 'Computational thinking is the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer – human or machine – can effectively carry out' (Wing, 2017).

Computer science: see **informatics**.

Concurrent model: Student teachers receive theoretical and practical professional training along with their general education. The upper secondary school leaving certificate is the qualification required to undertake training in accordance with this model, and in some cases a certificate of aptitude for tertiary education is also required. Other selection procedures for admission may also apply.

Consecutive model: Student teachers receive theoretical and practical professional training after completing their general education. In this model, students who have undertaken higher education in a particular field move on to professional training in a separate phase.

Continuing professional development: This is the in-service training undertaken throughout a teacher's career that allows them to broaden, develop and update their knowledge, skills and attitudes. It may be formal or informal and include both subject-based and pedagogical training. Different formats are offered, such as courses, seminars, workshops, degree programmes, peer observation or self-observation and/or peer reflection or self-reflection, support from teacher networks and observational visits. In certain cases, continuing professional development activities may give teachers supplementary qualifications.

Curriculum: This is the term used to describe the official study programmes issued for schools by top-level education authorities. National curricula may include learning content, learning objectives, attainment targets, syllabuses or assessment guidelines, and it may be published in any type or in any number of official documents. In some countries, the national curriculum is set out in legal decrees. More than one type of curriculum document may contain provisions relating to informatics/computer science, and these may impose different levels of obligation on schools to comply. They may, for example, contain advice, recommendations or regulations. However, whatever the level of obligation, they all establish the basic framework around which schools develop their teaching to meet their pupils' needs.

Cybersecurity: This refers to all the measures adopted to defend information systems from external unauthorised access and user actions that compromise the confidentiality, integrity and availability of both information and systems.

Differentiated tracks or pathways: These are clearly distinct education pathways that students can follow during secondary education as one form of curricular differentiation. Typically, these pathways differ in their focus, offering general, vocational or technical education, and they often lead to different types of certificate. Different tracks/streams/pathways can be provided in the same school or by specific types of school.

Digital literacy: Digital literacy is defined in the European framework for digital competence as the ability to articulate information needs; to locate and retrieve digital data, information and content; to judge the relevance of data sources and their content; and to store, manage and organise digital data, information and content. It is the first of the five areas of digital competence (i.e. being digitally literate is part of being digitally competent) (Carretero et al., 2017). It means the basic skills or ability to use a computer confidently, effectively and safely, including the ability to use office software such as word processors, email and presentation software, and the ability to use a web browser and internet search engines. Digital literacy also includes understanding the morality and ethics of the personal and societal implications of digital technologies (The Royal Society, 2017, p. 16).

Generalist teachers: These are teachers (usually in primary education) who are qualified to teach all (or almost all) subjects in the curriculum.

Informatics: Informatics, known as computer science in many countries, is a distinct scientific discipline, characterised by its own concepts, methods, body of knowledge, and open issues. It covers the foundations of computational structures, processes, artefacts and systems, and their software designs, their applications, and their impact on society (Committee on European Computing Education, 2017).

Information and communications technology (ICT): ICT as a subject means the general use of computers to support learning across the curriculum and is therefore distinct from computer science / informatics. Terminological issues related to ICT have been noticed, as the term is commonly used to mean many different things, for example the name of a school curriculum subject; the use of generic information technology to support teaching and learning; the use of technologies to support teachers' administrative processes; a school's information management systems; and the physical infrastructure of a school's computer systems, such as networks and printers (The Royal Society, 2012, p. 16).

Instruction time: This information is collected as annual instruction time in hours per grade. When the data is provided in periods (e.g. 50 minutes), per week or per year, the standard annual data in hours is calculated.

International Standard Classification of Education

The International Standard Classification of Education (ISCED) has been developed to facilitate the comparison of education statistics and indicators across countries on the basis of uniform and internationally agreed definitions. The coverage of ISCED extends to all organised and sustained learning opportunities for children, young people and adults, including those with special educational needs, irrespective of the institutions or organisations providing them or the form in which they are delivered. The first statistical data collection based on the new classification (ISCED 2011) took place in 2014. Text and definitions have been adopted from UNESCO (1997), UNESCO/OECD/Eurostat (2013) and UNESCO / UNESCO Institute for Statistics (2011)).

ISCED 1: Primary education

Programmes at ISCED level 1, or primary education, provide learning and educational activities typically designed to give students fundamental skills in reading, writing and mathematics (i.e. literacy and numeracy). This level establishes a sound foundation for learning and a solid understanding of core areas of knowledge, and fosters personal development, thus preparing students for lower secondary education. It focuses on learning at a basic level of complexity with little, if any, specialisation.

Age is typically the only entry requirement at this level. The customary or legal age of entry is usually not below 5 years old or above 7 years old. This level typically lasts 6 years, although its duration can range between 4 and 7 years.

ISCED 2: Lower secondary education

Programmes at ISCED level 2, or lower secondary education, typically build on the fundamental teaching and learning processes that begin at ISCED level 1. Usually, the aim at this education level is to lay the foundations for lifelong learning and personal development, preparing students for further educational opportunities. Programmes at this level are usually organised around a more subject-oriented curriculum, introducing theoretical concepts across a broad range of subjects.

This level typically begins around the age of 10 or 13 and usually ends at age 14 or 16, often coinciding with the end of compulsory education.

The ISCED designator 24 denotes general lower secondary education.

ISCED 3: Upper secondary education

Programmes at ISCED level 3, or upper secondary education, are typically designed to complete secondary education in preparation for tertiary or higher education or to provide skills relevant to employment, or both. Programmes at this level offer students more subject-based, specialist and in-depth programmes than in lower secondary education (ISCED level 2). They are more differentiated, with a wider range of options and streams available.

This level generally begins at the end of compulsory education. The entry age is typically 14 or 16. There are usually entry requirements (e.g. the completion of compulsory education). The duration of ISCED level 3 varies from 2 to 5 years.

The ISCED designator 34 denotes general upper secondary education.

For more information on the ISCED classification, see ISCED 2011 (http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-isced-2011-en.pdf).

Large-scale initiative/programme/scheme: This refers to an initiative/programme/scheme that operates throughout the whole education system or a significant geographical area rather than in a particular institution or geographical location.

Learning outcomes (including learning objectives): Learning outcomes are statements of what a learner knows, understands and is able to do on completion of a learning process in formal non-formal or informal education. Learning outcomes indicate actual attainment levels, while learning objectives define the competences to be developed in general terms.

Mainstream initial teacher education programmes: These are formal teacher training programmes preparing individuals to become informatics teachers. They can be organised around two main models: **concurrent** and **consecutive**.

Retraining (reskilling): This gives professionals who hold teaching qualifications (e.g. teachers of mathematics, physics, engineering and business, and generalist teachers) the opportunity to develop the skills needed to become informatics teachers without completing full academic training.

Specialist informatics teachers: These are teachers who are trained to teach informatics. This area of specialisation is reflected in their initial teacher education.

Subject category: The categories, as defined in the instruction time database, are reading, writing and literature; mathematics; natural sciences; social sciences; languages; physical education and health; arts education; religion / ethics / moral education; information and communications technology and technology; practical and vocational skills; and other subjects.

Top-level authority: This is the highest level of authority responsible for education in a given country, usually located at national (State) level. However, for Belgium, Germany and Spain, the *Communautés*, *Länder* and *Comunidades Autónomas*, respectively, either are wholly responsible or share responsibilities with the State for all or most areas of education. Therefore, these administrations are considered the top-level authorities for the areas for which they hold the responsibility, while for areas for which they share the responsibility with the State both are considered top-level authorities.

Annex 1: Informatics subjects in the curriculum of primary and general secondary education (ISCED 1, 24 and 34)

Key:

No shading	On the main or single track
Blue shading	Not on the main track

Status: a = compulsory for all b = compulsory for some c = optional m = not available

Country code	*Name of the subject*	*Name of the subject in English*	*Status*	*Starting grade*	*Ending grade*	*Comments*
BE fr	*Informatique*	Informatics	c	9	12	*Enseignement Technique de Transition*
BE de						
BE nl						
BG	*Kompiutarno modelirane*	Computer modelling	a	3	4	
	Informacionni tehnologii	Information technologies	a	5	10	
	Informatika	Informatics (profile: intensive foreign language)	b	8	8	General profiled secondary education
	Informacionni tehnologii	Information technologies (profile: training)	b	11	12	General profiled secondary education
	Informatika	Informatics (profile: training)	b	11	12	General profiled secondary education
CZ	*Informatika a informační a komunikační technologie*	Informatics and information and communication technologies	a	10	13	
DK	*Informatik C*	Informatics C	c	11	11	Higher General Examination Programme (STX). Grades 11–13 are 10–12 in the Danish education system.
	Informatik B	Informatics B	c	11	12	
	IT A	IT A	c	11	13	Commercial upper secondary (Higher Commercial Examination Programme (HHX))
	Informatik C	Informatics C	b	11	11	Commercial upper secondary (HHX)
	Informatik B	Informatics B	c	11	12	Commercial upper secondary (HHX)
	Informatik B	Informatics B	c	11	12	Technical upper secondary (Higher Technical Examination Programme (HTX))
	Informatik C	Informatics C	c	11	11	Technical upper secondary (HTX)
DE	*Informatik*	Informatics	c	5	12	Informatics is an optional subject in *Gymnasien* (grades 5–7, 9 and 10) and *Gymnasyale Oberstufe* in most *Länder*, but in some it is compulsory.
	Informatik	Informatics	c	5	10	Intermediate schools
	Informatik	Informatics	c	5	9	Secondary general schools
	Informatik	Informatics	c	5	10	Comprehensive schools (grades 5–10)
	Informatik	Informatics	c	5	10	Schools with several educational programmes
	Informatik	Informatics	c	11	13	*Fachgymnasium* (general programme)
EE	*Informaatika*	Informatics	m	1	9	Local/school autonomy
	Informaatika	Informatics	c	10	12	
IE	Leaving Certificate Computer Science	Leaving Certificate Computer Science	c	11	12	
	Junior cycle short course in coding	Junior cycle short course in coding	c	8	10	
EL	*Τεχνολογίες Πληροφορίας και Επικοινωνιών (ΤΠΕ)*	Information and communication technology (ICT)	a	1	6	
	Πληροφορική	Information technology	a	7	9	
	Εφαρμογές Πληροφορικής	Information technology applications	a	10	10	
	Εισαγωγή στις αρχές της επιστήμης των Ηλεκτρονικών Η/Υ	Introduction to the principles of computer science	a	11	11	
	Πληροφορική	Informatics	b	12	12	Compulsory only in the economics and informatics subject cluster

Country code		*Name of the subject*	*Name of the subject in English*	*Status*	*Starting grade*	*Ending grade*	*Comments*
ES		*Tecnologías de la Información y la Comunicación*	Information and communication technologies	c	10	12	The *Comunidades Autónomas* (autonomous communities) may offer other informatics subjects.
	Madrid	*Tecnología, programación y robótica*	Technology, programming and robotics	a	7	9	
	Madrid	*Tecnología, programación y robótica: Proyectos tecnológicos*	Technology, programming and robotics: technological projects	b	10	10	
	Andalusia	*Computación y robótica*	Informatics and robotics	c	7	9	
	Andalusia	*Creación digital y pensamiento computacional*	Digital creation and computational thinking	c	11	11	
	Andalusia	*Programación y computación*	Programming and computing	c	12	12	
FR		*Sciences numériques et technologie (SNT)*	Digital science and technology	a	10	10	
		Numérique et sciences informatiques (NSI)	Digital technology and computer science	b	11	12	Compulsory for students in the informatics specialisation
		Outils et langages numériques	Tools and digital languages	b	11	11	
		Sciences de gestion et numérique	Management and digital sciences	b	11	11	*Enseignement général du second degré* (*Baccalauréat technologique*)
		Management, sciences de gestion et numérique	Management and digital sciences	b	12	12	
HR		*Informatika*	Informatics	c	1	4	
		Informatika	Informatics	a	5	6	
		Informatika	Informatics	c	7	8	
		Informatika	Informatics	b	9	12	Informatics is compulsory in grades 9–12 in the mathematics and natural science grammar schools, in grade 9 in the general grammar schools, in grade 10 in the language and classical grammar schools, and in grades 9 and 10 and in the natural science grammar schools. In the other grades it is optional.
IT		*Informatica*	Informatics	b	9	13	Informatics is compulsory for students in the applied sciences section in the *Liceo Scientifico*.
CY		*Πληροφορική/Επιστήμη Ηλεκτρονικών Υπολογιστών*	Informatics / computer science	a	7	10	
		Πληροφορική/Επιστήμη Ηλεκτρονικών Υπολογιστών	Informatics / computer science	c	11	12	
		Δίκτυα	Computer networks	c	11	12	
LV		*Datorika*	Computing	a	1	9	Computing is a separate subject from grade 4. In grades 1–3, it can be taught separately or integrated into other subjects depending on the school.
		Datorika	Computing	a	10	10	
		Programmēšana I	Programming I	c	10	11	Students can choose programming I in grade 10 or 11 and programming II in grade 12.
		Programmēšana II	Programming II	c	12	12	
LT		*Informatika*	Informatics	a	1	4	Mandatory for all schools from September 2023
		Informacinės technologijos	Information technologies	a	5	10	Informatics from September 2023
		Informacinės technologijos	Information technologies	c	11	12	Informatics from September 2023
LU		*Informatique*	Informatics	b	9	13	In grade 9, informatics is compulsory for all students in *Enseignement Géneral* (approximately two thirds of the students) but not in *Classique*. In grades 10–13, it is compulsory for students in some sections of the *Enseignement Général*.
		Programmation	Programming	b	12	13	
		Architecture des ordinateurs	Computer architecture	b	12	12	
		Bases de données	Databases	b	13	13	
		Téléinformatique et réseaux	Computing networks	b	12	13	
		Technologies de l'information et de la communication	Information and communication technologies	b	12	13	
HU		*Informatika*	Informatics	a	4	4	In the 2012 national curriculum, the name of the subject was informatics. In the 2020 national curriculum, which is being phased in, its name is digital culture and it will be a compulsory subject in grades 3–11. In 2020/2021, the new curriculum was in place for grades 1, 5 and 9.
		Digitális Kultúra	Digital culture	a	5	5	
		Informatika	Informatics	a	6	8	
		Digitális Kultúra	Digital culture	a	9	9	
		Informatika	Informatics	a	10	10	
		Informatika	Informatics	c	11	12	

Country code	Name of the subject	Name of the subject in English	Status	Starting grade	Ending grade	Comments
MT	ICT C3	ICT C3	a	7	11	ICT C3 is the new informatics subject. In 2020/2021, it was not yet introduced in grades 10 and 11.
	Computing	Computing	c	9	11	
NL	*Informatica*	Informatics	c	10	12	In pre-university education, schools may offer informatics as an optional subject.
	Informatica	Informatics	c	10	11	In senior general secondary education, schools may offer informatics as an optional subject.
AT	*Informatik*	Informatics	a	9	9	
	Informatik	Informatics	b	10	12	Schools decide whether to provide the subject
PL	*Edukacja informatyczna*	Informatics education	a	1	3	Informatics education is one of the compulsory learning areas in grades 1–3. Schools can also assign a teacher to teach informatics separately for 1 hour per week.
	Informatyka	Informatics	a	4	11	
	Informatyka (zakres rozszerzeny)	(Advanced) informatics	b	9	12	Compulsory for students in specialisations with advanced informatics offered in some schools.
PT	*Aplicações Informáticas B*	Informatics applications	c	12	12	Optional subject in the scientific-humanistic courses
RO	*Informatica și TIC*	Informatics and ICT	a	6	9	Grades 5–8 in the Romanian education system
	TIC	ICT	a	10	13	Grades 9–12 in the Romanian education system
	Informatica	Informatics	b	10	13	Grades 9–12 in the Romanian education system. Informatics is only compulsory in the mathematics and computer science and natural science programmes.
SI	*Računalništvo*	Computer science	c	4	6	Students can choose to take the subject in one or more years. There is no requirement for continuity.
	Informatika	Informatics	c	11	13	
SK	*Informatika*	Informatics	a	3	8	
	Informatika	Informatics	a	10	13	
FI						
SE	*Programmering*	Programming	b	10	12	Compulsory in one specialisation of the technology programme and optional in the other specialisations and programmes
	Webbutveckling	Web development	b	10	12	Compulsory in one specialisation of the technology programme and optional in the other specialisations of this programme, and in the natural science, social science and arts programmes
	Dator- och kommunikationsteknik	Computers and ICT	b	10	12	Compulsory in one specialisation of the technology programme and optional in the other specialisations of this programme and in the natural science programme
	Gränssnittsdesign	Interface design	c	10	12	Optional in the technology, social sciences and arts programmes
	Tillämpad programmering	Applied programming	c	10	12	Optional in all programmes
AL						
BA	*Informatika (Federation of Bosnia and Herzegovina)*	Informatics	a	1	5	
	Osnove informatike (Republika Srpska)	Basics of informatics	a	6	9	
	Informatika (Federation of Bosnia and Herzegovina)	Informatics	a	6	9	
	Računarstvo i informatika (Republika Srpska and Federation of Bosnia and Herzegovina)	Computing and informatics	a	10	13	

Country code	Name of the subject	Name of the subject in English	Status	Starting grade	Ending grade	Comments
CH	*Medien und Informatik* (German-speaking cantons)	Media and informatics	a	m	m	International Standard Classification of Education (ISCED) 1 and 24: cantons decide in which grades to teach the subject. In the Italian- and French-speaking cantons, informatics was still a cross-curricular area in 2020/2021.
	Informatik/informatique/informatica	Informatics	a	m	m	ISCED 34: cantons decide in which grades to offer the subject.
IS						
LI	*Medien und informatik*	Media and informatics	a	4	9	In grades 1–3, the focus is on digital literacy.
	Informatik	Informatics	a	10	10	Only in the gymnasium
ME	*Informatika sa tehnikom*	Informatics with technology	a	5	8	
	Izrada grafike i obrada slike i fotografije	Creating graphics and image and photography processing	c	7	9	
	Uvod u programiranje	Introduction to programming	c	8	9	
	Informatika	Informatics	a	10	10	
	Računarske i veb prezentacije	Computer and web presentations	c	11	11	
	Poslovna informatika	Business informatics	c	12	12	
	Algoritmi i programiranje	Algorithms and programming	c	12	13	Students can choose the subject only in one grade.
MK	*Работа со компјутер и основи на програмирање*	Working with computers and programming basics	a	3	5	
	Информатика	Informatics	a	6	7	
	Програмирање	Programming	c	8	9	
	Информатика	Informatics	a	10	10	Gymnasium
	Информатичка технологија	Informatics technology	c	11	11	Gymnasium
	Порграмски јазици	Programming languages	c	12	13	Gymnasium
	Информатика	Informatics	a	10	13	In 2020/2021, the new mathematics/informatics gymnasium was implemented only in grade 10.
	Програмирање	Programming	a	10	13	
	Објектно-ориентирано програмирање	Object-oriented programming	a	12	12	
	Бази на податоци	Databases	a	13	13	
	Напредно програмирање	Advanced programming	c	12	12	
	Веб-програмирање	Web programming	c	13	13	
	Програмски парадигми	Programming paradigms	c	13	13	
NO	*Programmering*	Programming	c	8	10	
	Programmering og modellering	Programming and modelling	c	12	12	Specialisation in general studies
	Informasjonsteknologi 1	Information technology 1	c	12	12	Specialisation in general studies
	Informasjonsteknologi 2	Information technology 2	c	13	13	Specialisation in general studies
RS	*Digitalni svet*	Digital world	a	1	4	The implementation of this new subject started in grade 1 in 2020/2021.
	Informatika i računarstvo	Informatics and computer science	a	5	8	
	Računarstvo i informatika	Computer science and informatics	a	9	12	
TR						

Annex 2: Sources and existing competence frameworks with learning outcome examples in primary and general secondary education (ISCED 1, 24 and 34)

This annex briefly introduces the sources and competence frameworks used for this analysis. It also aims to present core areas and examples of related learning outcomes that characterise informatics as a distinct scientific discipline (irrespective of whether it is taught as a separate subject or integrated into other subjects) in primary and general secondary education curricula. The purpose is to provide a better understanding of the discipline and its content. The descriptions and learning outcome examples are not prescriptive but aim to explain how this analysis has been framed and, beyond this, to support discussions among stakeholders.

Sources and frameworks

The selection of areas and learning outcome examples supporting the analysis of informatics education across Europe in this report has been drawn from the following sources and frameworks, some of which are from the United States, some of which are international and some of which are European. These frameworks cover different proficiency levels from primary to upper secondary education.

National curriculum in England for computing (Department for Education of the United Kingdom, 2013)

The curriculum for the subject computing replaced the former subject ICT in 2014/2015. While the core of computing is computer science, it also aims to equip pupils to use information technology and to become digitally literate. For each education level from primary to upper secondary education, the curriculum provides attainment targets. These are accompanied by guidance for teachers.

https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study; https://www.computingatschool.org.uk/

K–12 computer science framework (2016)

This framework was developed in the United States by the Association for Computing Machinery, Code.org, the Computer Science Teachers Association (CSTA), the Cyber Innovation Centre and the National Math and Science Initiative. Its objective is to inform the development of standards and curricula, teachers' professional development and the implementation of computer science pathways. A large community of practice joined forces in writing and reviewing this framework, representing a variety of academic perspectives, experiences and student populations. It is structured in five core concepts (computing systems, networks and the internet, data and analysis, algorithms and programming, and impacts of computing) and seven core practices. Standards and learning outcomes related to this framework have been issued by the CSTA (revised in 2017).

www.k12cs.org; http://www.csteachers.org/standards

Massachusetts curriculum framework for digital literacy and computer science (2016)

This curriculum framework covers the progression from pre-primary to upper secondary education for both digital literacy and computer science, articulating critical learning outcomes. It refers, among other things, to the K–12 computer science standards (set by the CSTA). The core concepts are included in four strands: computing and society, digital tools and collaboration, computing systems and computational thinking. Each strand is further divided into topics and related standards. Moreover, seven practices are interwoven with the framework.

https://www.doe.mass.edu/bese/docs/fy2016/2016-06/item3-DLCS-Framework.pdf

Computational thinking construct in the International Computer and Information Literacy Study (2018)

Conducted by the International Association for the Evaluation of Educational Achievement, this survey assesses pupils' digital competences in relation to two concepts: computer and information literacy and computational thinking. The latter has been analysed in this report to find examples of how the related competences are operationalised in terms of learning outcomes. The International Computer and Information Literacy Study describes computational thinking in two stands (conceptualising problems and operationalising solutions), with an achievement scale and learning outcomes for each of the three levels (lower, middle and upper).

https://education.ec.europa.eu/document/the-2018-international-computer-and-information-literacy-study-icils-main-findings-and-implications-for-education-policies-in-europe

Computational thinking framework from the Raspberry Pi Foundation (2020)

The Raspberry Pi Foundation pursues its mission to empower all people in the area of computing and digital making by supporting the learning of the related skills with hands-on educational approaches, underpinned by a rigorous understanding of computer science. This framework was developed in collaboration with experts and experienced educators. It defines computational thinking as comprising 'a set of ideas and thinking skills that people can apply to design solutions or systems that a computer or computational agent can enact' (Raspberry Pi Foundation, 2020, p. 7). Each of the six components (decomposition, algorithms, patters and generalisations, abstraction, evaluation and data) are further separated into themes and learning objectives.

https://www.raspberrypi.org/app/uploads/2020/09/Raspberry_Pi_Foundation_Computational_Thinking_Framework_v1.pdf

Microsoft computer science framework

This framework is based on Microsoft's expertise as a leading computer business in addition to academic research and experiences in teaching computer science around the world. It includes a curriculum structure and guidance, and learning objectives for learners aged 5 to 18. The framework covers three areas (working with code, working with data and working with computers) and six domains (software development, robotics and automation, data and artificial intelligence, platforms and cloud, human–computer interaction and cybersecurity), each containing three learning pathways, big ideas, big questions and, finally, supporting content (teaching methods and learning materials).

https://edudownloads.azureedge.net/msdownloads/Microsoft-Computer-Science-Framework.pdf

Informatics reference framework for school (Informatics for All coalition, 2022)

This general reference framework developed by the Informatics for All coalition aims to support the advancement of informatics as a fundamental discipline for all in school education from primary to upper secondary level. As a common reference framework, it intends to support the design of school informatics curricula across Europe, setting out 11 core topics (data and information; algorithms; programming; computing systems; networks and communication; human–computer interaction; design and development; digital creativity; modelling and simulation; privacy, safety and security; and responsibility and empowerment). These are illustrated with their contemporary context and implications as well as by providing a small range of high-level learning outcome examples by topic and education level.

https://www.informaticsforall.org/wp-content/uploads/2022/03/Informatics-Reference-Framework-for-School-release-February-2022.pdf

Description of core areas and examples of learning outcomes

While analysing several widely used frameworks, as introduced above, the most recurrent and common areas have been identified and summarised as 10 broad areas considered core to informatics education.

1. Data and information	6. People–system interface
2. Algorithms	7. Design and development
3. Programming	8. Modelling and simulation
4. Computing systems	9. Awareness and empowerment
5. Networks	10. Safety and security

In the following sections, each of the 10 areas content related to informatics is briefly introduced and illustrated by several exemplary learning outcomes extracted from the different frameworks.

1. Data and information

Computing systems ([157]) process data represented in digital form, as a finite set of signs/characters taken from a finite alphabet. As the amount of digital data generated is rapidly expanding, effective data processing is becoming increasingly important.

> *Data is collected and stored so that it can be analysed to better understand the world and make more accurate predictions. … Core functions of computers are storing, retrieving, and processing data. In early grades, students learn how data is stored on computers. As they progress, students learn how to evaluate different storage and processing methods, including the trade-offs associated with those methods. … Transmitting information securely across networks requires appropriate protection. In early grades, students learn how to protect their personal information. As they progress, students learn increasingly complex ways to protect information sent across networks* (K–12 Computer Science Framework, 2016, pp. 89–90).

Area	Examples of learning outcomes	Source
Data and information	Understand how data of various types (including text, sounds and pictures) can be represented and manipulated digitally, in the form of binary digits	Department for Education of the United Kingdom
Data and Information	Identify, with illustrative examples, ways in which computers can acquire data, including automatic approaches, and indicate how those data may be stored	Informatics for All
Data and Information	Apply multiple methods of encryption to model the secure transmission of information	Computer Science Teachers Association (CSTA; K–12 computer science framework)
Data and Information	Develop an understanding of the idea of machines being able to 'learn'	Microsoft Computer Science Framework (MCSF)

2. Algorithms

Informally speaking, 'an algorithm is a sequence of steps designed to accomplish a specific task. Algorithms are translated into programs, or code, to provide instructions for computing devices. … In early grades, students usually learn about age-appropriate algorithms from the real world. As they progress, students learn about the development, combination, and decomposition of algorithms, as well as the evaluation of competing algorithms' (K–12 Computer Science Framework, 2016, p. 91).

([157]) This report only deals with 'digital computing systems', that is systems that process data represented in digital form. The term 'computing systems' is used as a shorthand for digital computing systems. 'Analogue computing systems', based on the representation of values to be manipulated by means of continuous physical quantities (e.g. voltage or current), were generally phased out during the late 1970s (https://dl.acm.org/doi/10.5555/1074100.1074123).

Area	Examples of learning outcomes	Source
Algorithms	Understand what algorithms are; how they are implemented as programs on digital devices; and that programs execute by following precise and unambiguous instructions	Department for Education of the United Kingdom
Algorithms	Use logical reasoning to explain how some simple algorithms work and to detect and correct errors in algorithms and programs	Department for Education of the United Kingdom
Algorithms	Create an efficient algorithm that meets all of the given task objectives for a low-/medium-/high-complexity problem (i.e. a problem with a limited set of available commands and objectives)	International Computer and Information Literacy Study
Algorithms	Understand several key algorithms that reflect computational thinking (e.g. algorithms for sorting and searching) and use logical reasoning to compare the utility of alternative algorithms for the same problem	Department for Education of the United Kingdom

3. Programming

Programs implementing algorithms:

> *control all computing systems, empowering people to communicate with the world in new ways and solve compelling problems. The development process to create meaningful and efficient programs involves choosing which information to use and how to process and store it, breaking apart large problems into smaller ones, recombining existing solutions, and analysing different solutions. … Programs are developed through a design process that is often repeated until the programmer is satisfied with the solution. In early grades, students learn how and why people develop programs. As they progress, students learn about the trade-offs in program design associated with complex decisions involving user constraints, efficiency, ethics, and testing. … Modularity involves breaking down tasks into simpler tasks and combining simple tasks to create something more complex. In early grades, students learn that algorithms and programs can be designed by breaking tasks into smaller parts and recombining existing solutions. As they progress, students learn about recognizing patterns to make use of general, reusable solutions for commonly occurring scenarios and clearly describing tasks in ways that are widely usable* (K–12 Computer Science Framework, 2016, p. 91).

Area	Examples of learning outcomes	Source
Programming	Develop programs with sequences and simple loops, to express ideas or address a problem	CSTA (K–12 computer science framework)
Programming	Use sequence, selection and repetition in programs and work with variables and various forms of input and output	Department of Education of the United Kingdom
Programming	Design, write and debug programs that accomplish specific goals, including controlling or simulating physical systems, and solve problems by decomposing them into smaller parts	Department of Education of the United Kingdom
Programming	Design and develop modular programs that use procedures or functions	Department of Education of the United Kingdom

4. Computing systems

> *People interact with a wide variety of computing devices that collect, store, analyse, and act upon data in ways that can affect human capabilities both positively and negatively. The physical components (hardware) and instructions (software) that make up a computing system communicate and process data in digital form. An understanding of hardware and software is useful when troubleshooting a computing system that does not work as intended. … Computing systems use hardware and software to process and communicate data in digital form. In early grades, students learn how systems use both hardware and software to represent and process information. As they progress, students gain a deeper understanding of the interaction between hardware and software at multiple levels within computing systems* (K–12 Computer Science Framework, 2016, p. 89) ([158]).

([158]) This report only deals with 'digital computing systems', that is systems that process data represented in digital form. The

Area	Examples of learning outcomes	Source
Computing systems	Illustrate ways computing systems implement logic, input and output through hardware components	CSTA (K–12 computer science framework)
Computing systems	Understand the hardware and software components that make up computer systems, and how they communicate with one another and with other systems	Department of Education of the United Kingdom
Computing systems	Understand how instructions are stored and executed within a computer system	Department of Education of the United Kingdom
Computing systems	Determine potential solutions to solve simple hardware and software problems using common troubleshooting strategies	CSTA (K–12 computer science framework)

5. Networks

Computing devices typically do not operate in isolation. Networks connect computing devices to share information and resources and are an increasingly integral part of computing. Networks and communication systems provide greater connectivity in the computing world by providing fast, secure communication and facilitating innovation. … Computing devices communicate with each other across networks to share information. In early grades, students learn that computers connect them to other people, places, and things around the world. As they progress, students gain a deeper understanding of how information is sent and received across different types of networks (K–12 Computer Science Framework, 2016, p. 89).

Area	Examples of learning outcomes	Source
Networks	Understand computer networks including the internet and how they can provide multiple services, such as the world wide web	Department of Education of the United Kingdom
Networks	Model the role of protocols in transmitting data across networks and the internet	CSTA (K–12 computer science framework)
Networks	Understand data transmission between digital computers over networks, including the internet, that is, IP addresses and packet switching	MCSF
Networks	Demonstrate conceptual understanding of layered network systems	Informatics for All

6. People–system interface

The area of people–system interface, also called human–machine interaction, aims to develop an understanding of the requirements of the interaction between people and computing artefacts (Caspersen et al., 2022). ‘Developing effective and accessible user interfaces involves the integration of technical knowledge and social sciences and encompasses both designer and user perspectives’ (K–12 Computer Science Framework, 2016, p. 88). In early grades, students learn how to consider diverse user and community needs in the design of digital artefacts. As they progress, students study the people–system interface to test and improve the design of digital artefacts, considering usability, security and accessibility, among other things.

Area	Examples of learning outcomes	Source
People–system interface	Explain, using examples, differences between interfaces designed for novices and those for experts	Informatics for All
People–system interface	Brainstorm ways to improve the accessibility and usability of technology products for the diverse needs and wants of users	MCSF
People–system interface	Recommend improvements to the design of computing devices, based on an analysis of how users interact with the devices	CSTA (K–12 computer science framework)
People–system interface	Consider the specific needs and limitations of a range of potential and actual users of systems and software	Raspberry Pi Foundation

term ‘computing systems’ is used as a shorthand for ‘digital computing systems’. Indeed, ‘analogue computing systems’, based on the representation of values to be manipulated by means of continuous physical quantities (e.g. voltage or current), were generally phased out during the late 1970s (see https://dl.acm.org/doi/10.5555/1074100.1074123).

7. Design and development

The area of design and development involves planning and creating digital artefacts through an iterative and incremental process, taking into account stakeholders' viewpoints, critically evaluating alternatives and their outcomes, and modelling suitable representations of information and behaviour (Caspersen et al., 2022). 'This process … includes understanding the development life cycle, such as testing, usability, documentation, and release' (Massachusetts Department of Elementary and Secondary Education, 2016, p. 16). In early grades, students learn how and why people develop digital artefacts. As they progress, students learn about the trade-offs in the design and development process associated with complex decisions involving user constraints, efficiency, ethics, and testing (K–12 Computer Science Framework, 2016, p. 91).

Area	Examples of learning outcomes	Source
Design and development	Design and iteratively develop computational artefacts for practical intent personal expression, or to address a societal issue by using events to initiate instructions	CSTA (K12 computer science framework)
Design and development	Evaluate computational artefacts to maximise their beneficial effects and minimise harmful effects on society	CSTA (K12 computer science framework)
Design and development	Design iteratively simple digital artefacts. Modify an existing design to explore alternatives	Informatics for All
Design and development	Illustrate and present broad principles of design through an analysis of digital artefacts	Informatics for All

8. Modelling and simulation

> *Computational modelling and simulation help people to represent and understand complex processes and phenomena. Computational models and simulations are used, modified, and created to analyse, identify patterns, and answer questions of real phenomena and hypothetical scenarios* (Massachusetts Department of Elementary and Secondary Education, 2016, p. 16).
>
> *Data science is one example where informatics serves many fields. [With informatics methods and techniques, one can] use data to make inferences, test theories, or formulate predictions based on the data collected from users or simulations. In early grades, students [usually] learn about the use of data to make simple predictions. As they progress, students learn how models and simulations can be used to examine theories and understand systems and how predictions and inferences are affected by more complex and larger data sets* (K–12 Computer Science Framework, 2016, p. 90).

Area	Examples of learning outcomes	Source
Modelling and simulation	Design, use and evaluate computational abstractions that model the state and behaviour of real-world problems and physical systems	Department of Education of the United Kingdom
Modelling and simulation	Create a model of a real-world system and explain why some details, features and behaviours were required in the model and why some could be ignored	Massachusetts Department of Elementary and Secondary Education
Modelling and simulation	Create computational models of scenarios and use these to make predictions and implications and assess limitations of the model	Informatics for All
Modelling and simulation	Create models and simulations to help formulate, test and refine hypotheses	Massachusetts Department of Elementary and Secondary Education

9. Awareness and empowerment

> *Computing affects many aspects of the world in both positive and negative ways at local, national, and global levels. Individuals and communities influence computing through their behaviours and cultural and social interactions, and in turn, computing influences new cultural practices. An informed and responsible person should understand the social implications of the digital world, including equity and access to computing. Computing influences culture – including belief systems,*

language, relationships, technology, and institutions – and culture shapes how people engage with and access computing. In early grades, students learn how computing can be helpful and harmful. As they progress, students learn about trade-offs associated with computing and potential future impacts of computing on global societies (K–12 Computer Science Framework, 2016, p. 92).

Data is collected with both computational and non-computational tools and processes. In early grades, students learn how data about themselves and their world is collected and used. As they progress, students learn the effects of collecting data with computational and automated tools (K–12 Computer Science Framework, 2016, p. 90).

Area	Examples of learning outcomes	Source
Awareness and empowerment	Compare how people live and work before and after the implementation or adoption of new computing technology	CSTA (K–12 computer science framework)
Awareness and empowerment	Discuss computing technologies that have changed the world and express how those technologies influence, and are influenced by, cultural practices	CSTA (K–12 computer science framework)
Awareness and empowerment	Describe trade-offs between allowing information to be public and keeping it private and secure	CSTA (K–12 computer science framework)
Awareness and empowerment	Evaluate the ways computing impacts personal, ethical, social, economic and cultural practices	CSTA (K–12 computer science framework)

10. Safety and security

Various ways of using computing devices may affect the safety and security of individuals. 'Security refers to the safeguards surrounding information systems and includes protection from theft or damage to hardware, software, and the information in the systems' (K–12 Computer Science Framework, 2016, p. 88). 'In early grades, students learn the fundamentals of digital citizenship and appropriate use of digital media. As they progress, students learn about the legal, social and ethical issues that shape computing practices' (K–12 Computer Science Framework, 2016, p. 92). Digital data need to be kept secure both when stored and when transmitted across networks. 'In early grades, students learn how to protect their personal information. As they progress, students learn increasingly complex ways to protect information sent across networks' (K–12 Computer Science Framework, 2016, p. 89). This area involves understanding the risks when using technology, and learning how to protect individuals and systems.

Area	Examples of learning outcomes	Source
Safety and security	Discuss real-world cybersecurity problems and how personal information can be protected.	CSTA (K–12 computer science framework)
Safety and security	Establish ethical protocols for the online world	MCSF
Safety and security	Explain the concepts of ethics, bias and fairness in the context of AI and automation	MCSF
Safety and security	Test and refine computational artefacts to reduce bias and equity deficits.	CSTA (K–12 computer science framework)

Annex 3: Other specialist teachers allowed to teach informatics in primary and general secondary education (ISCED 1, 24 and 34), 2020/2021

	ISCED 1	ISCED 24	ISCED 34
BE fr	—	Teachers with specialisations in engineering and in computer graphics techniques'	Teachers with specialisations in engineering and in computer graphics techniques'
BE de	—	Mathematics teachers, science teachers, language teachers, economics teachers, teachers of text processing / secretarial work	Mathematics teachers, science teachers, language teachers, economics teachers, teachers of text processing / secretarial work
BE nl	—	Mathematics and science teachers	Mathematics and science teachers
BG	In grades 3 and 4 of primary education, the compulsory subject computer modelling can be taught by specialist informatics teachers or by mathematics, physical sciences, technical sciences or economics teachers with an additional professional qualification in informatics and/or information technology. Moreover, all these specialist teachers must also be qualified as primary school teachers.	Mathematics, mathematics and informatics, physical sciences, technical sciences and economics teachers who have additional professional qualifications in informatics and/or information technology	Mathematics, mathematics and informatics, physical sciences, technical sciences and economics teachers who have additional professional qualifications in informatics and/or information technology
CZ	—	Other specialist teachers can teach informatics after completing a specific study programme in informatics to extend their professional qualifications.	Other specialist teachers can teach informatics after completing a specific study programme in informatics to extend their professional qualifications.
DE	—	Other specialist teachers can teach informatics after obtaining a qualification in informatics as part of their continuing professional development.	Other specialist teachers can teach informatics after obtaining a qualification in informatics as part of their continuing professional development.
EE	Teachers of mathematics with a minor specialisation in informatics, educational technologists with a minor specialisation in informatics, etc.	Mathematics teachers with a minor specialisation in informatics, educational technologists with a minor specialisation in informatics, etc.	Mathematics teachers with a minor specialisation in informatics, educational technologists with a minor specialisation in informatics, etc.
IE	—	In the absence of a specialist computer science teacher, the school can in some instances identify a teacher or teachers with relevant experience and/or qualifications who are willing to teach computer science.	In the absence of a specialist computer science teacher, the school can in some instances identify a teacher or teachers with relevant experience and/or qualifications who are willing to teach computer science.
EL	—	—	—
ES	Foreign language, physical education and music teachers, therapists and speech therapists	Secondary education teachers specialised in technology	Secondary education teachers specialised in technology
FR	—	Mathematics teachers and technology teachers	Mathematics, technology and physical science teachers
HR	Teachers of polytechnics	Teachers of polytechnics	—
IT	—	Graduates in architecture, chemistry, engineering and sciences	Graduates in astronomy, nautical disciplines, physics, computer science, mathematics, information science, statistical science and engineering are entitled to teach mathematics with computer science in the first 2 years of general upper secondary education (*Liceo Scientifico*).
CY	—	—	—
LU	—	Mathematics and natural sciences teachers	Mathematics and natural sciences teachers
HU	IT engineers	IT engineers	IT engineers
MT	—	—	—
NL	—	There is no computer science curriculum. Schools may design their own computer science courses and decide on teachers' profiles. Others may only teach as guest teachers (under the supervision of qualified teachers).	Computer science is taught by other professionals under the supervision of qualified teachers (often in other subjects).

	ISCED 1	ISCED 24	ISCED 34
AT	—	Specialist teachers who have completed the academic course 'Digital Basic Competence'	Specialist teachers (e.g. mathematics, science, technologies) who have completed academic courses such as the academic course 'Digital Basic Competence'
PL	—	—	—
PT	—	—	—
RO	—	Mathematics and informatics teachers	Mathematics and informatics teachers
SI	—	—	—
SK	—	—	—
FI	—	Various specialist teachers can teach informatics content. However, in practice, mathematics, natural sciences and crafts teachers are mostly responsible for teaching informatics.	Various specialist teachers can teach informatics content. However, in practice, mathematics and natural sciences teachers are mostly responsible for teaching informatics.
SE	Mathematics, technology and science teachers	Mathematics, technology and science teachers	To be qualified to teach the subject computer science, upper secondary school teachers (usually mathematics, technology or science teachers) need to complete additional studies worth 90 credits through the European Credit Transfer and Accumulation System in computer science subjects. To teach applied programming, the completion of studies worth 60 credits through the European Credit Transfer and Accumulation System in programming is required.
AL	—	—	Mathematics and physics teachers
BA	—	Teachers of physics and informatics and teachers of mathematics and informatics	Teachers of physics and informatics and teachers of mathematics and informatics
CH		Other specialist teachers who completed a continuing professional development module in addition to the regular teaching diploma	Teachers with teaching authorisation for the additional subject informatics in addition to the regular teaching diploma
IS	—	—	—
LI	–	Mathematics teachers and English teachers, among others, teach informatics as a part of their curricula	Mathematics teachers and English teachers, among others, teach informatics as a part of their curricula
ME	—	—	—
MK	—	—	—
NO	—	Mathematics, science, technology and social sciences teachers	Mathematics and science teachers
RS		Teaching and other forms of educational work in the subject informatics and computer science can be performed by: • retrained generalist master teacher who has achieved 90 credits who has achieved 90 credits through the European Credit Transfer and Accumulation System in the field of informatics during their studies or through an additional programme; • other specialist teachers without any formal or non-formal retraining (professor in the field of mathematics, physics, electrical engineering etc.)	Other specialist teachers without any formal or non-formal retraining (professor in the field of mathematics, physics, electrical engineering etc.)
TR	—	—	—

Explanatory notes

Only the most common 'other specialist teachers' providing informatics at schools are listed here.
'—' means not applicable or none.

Annex 4: Alternative pathways to becoming an informatics teacher, 2020/2021

Belgium – French Community

Pedagogical aptitude certificates (*certificat d'aptitude pédagogique* (CAP) and CAP+) – alternative pathway

As part of social advancement education (*l'Enseignement de promotion sociale*; also known as adult higher education), teachers can obtain a teaching qualification for general secondary education through a certification process called the pedagogical aptitude certificate (*certificat d'aptitude pédagogique* (CAP) and CAP+).

The CAP is obtained either at the end of a training course, organised by social advancement institutions (adult higher education institutions), or through an examination panel.

ISCED levels: 24 and 34

Duration: 120 European Credit Transfer and Accumulation System (ECTS) credits

Provider: Adult higher education institutions

Admission criteria: Acquired professional experience (minimum 9 years) or professional experience in a teaching position

Websites: www.promsoc.cfwb.be; http://enseignement.be/index.php?page=26826&navi=3427

Belgium – German-speaking Community

Pedagogical aptitude certificates (*Certificat d'aptitude pédagogique* (CAP) and CAP+) – alternative pathway

ISCED levels: 24 and 34

Duration: 15 ECTS credits or 30 ECTS credits

Provider: *Autonome Hochschule in der Deutschsprachigen Gemeinschaft*

Admission criteria: Having a bachelor's degree or being a non-qualified teacher already in service

Websites: https://www.ahs-ostbelgien.be/weiterbildungen/zusatzausbildungen/paedagogischer-befaehigungsnachweis-cap/; https://www.ahs-ostbelgien.be/weiterbildungen/zusatzausbildungen/lehrbefaehigung-paedagogik-cap/

Belgium – Flemish Community

Alternative pathway: short educational bachelor's programme and shortened master's programme for secondary education give possibility to professionals holding bachelor's or master's degree in a field taught at schools to obtain a teaching degree

ISCED levels: 24 and 34

Duration: -

Provider: -

Admission criteria: Having a bachelor's degree in the informatics related subjects (1st programme): having masters' degree in the informatics related subjects (2nd programme)

Retraining programme: short educational bachelor's programme for secondary education allows qualified teachers to extend their qualification to teach an additional subject (informatics).

ISCED levels: 24 and 34

Duration: -

Provider: -

Admission criteria: Being qualified teacher

Websites: https://www.vlaanderen.be/lerarenopleidingen

Bulgaria

Postgraduate professional qualification 'Teacher of Informatics and Information Technologies' – alternative pathway / retraining programme

ISCED levels: 1, 24 and 34

Duration: 1 year

Provider: Higher education institutions

Admission criteria: Being a higher education graduate such as a computer scientist, mathematician, engineer, architect, economist, financier, accountant, physics and/or astronomy teacher

Reference: Ordinance No 15 of 22 July 2019 on the status and professional development of teachers, principals and other pedagogical specialists (https://dv.parliament.bg/DVWeb/showMaterialDV.jsp?idMat=140012), Art. 45, para. 1, Section 2.

Czechia

Study to extend professional qualifications – retraining programme

This is a lifelong learning study accredited by the Ministry of Education. It mainly targets teachers who want to extend their qualification. The programme ends with the defence of a thesis and a final examination in front of a commission; the leaver gets a certificate.

ISCED levels: 24 and 34

Duration: Minimum of 188 hours

Provider: Higher education institutions

Admission criteria: Having a teaching qualification; other admission criteria are defined not centrally but by institutions

Reference: Decree No 317/2005 on in-service training of education staff, Art. 6b.

Denmark

Masters in informatics – alternative pathway

Qualified general upper secondary school teachers who do not have a university degree in informatics can acquire the skills necessary to qualify as teachers of informatics if they pass university courses.

ISCED level: 34

Duration: 120 ECTS credits (some of the 120 ECTS can be replaced by relevant work experience)

Provider: Universities

Admission criteria: Bachelor's degree

Reference/website: *Gymnasieloven* (https://www.retsinformation.dk/eli/lta/2021/1375), Art. 56(1) and (2).

Masters in teaching informatics – retraining programme

This course gives insight into themes such as programming, system architecture and data structures.

ISCED level: 34

Duration: 60 ECTS credits

Providers: Aarhus University, in cooperation with Aalborg University, the University of Southern Denmark, the University of Copenhagen, Roskilde University and the IT University of Copenhagen

Admission criteria: Qualified to teach in at least one subject at ISCED 34 level and mathematics at level B (ISCED 34), and 2 years of relevant work experience after completing a master's degree.

Website: https://www.ug.dk/uddannelser/masteruddannelser/naturvidenskabeligeogtekniskeuddannelser/master-i-informatikundervisning

Germany

Lateral entry (*Seiteneinstieg*) – alternative pathway / retraining programme

The main teacher education institutions provide opportunities for graduates from other areas to directly access the second part of mainstream ITE programmes (*Vorbereitungsdienst*). The minimum requirements for lateral entry (*Seiteneinsteiger*) are completion of the preparatory training (*Vorbereitungsdienst*) or comparable training that also provides basic educational skills through a (second) State examination (*Staatsexamen*) or an equivalent State-certified qualification. Requirements for the individual programmes for lateral entrants vary between Länder.

If there are further requirements, a qualification can also be obtained on the basis of a university master's degree or an equivalent university degree from which at least one subject related to the teaching profession can be derived. The missing qualification requirements for a second subject related to the teaching profession are initially to be compensated for by part-time studies, followed by a preparatory programme or comparable training. In addition, basic skills in educational science are to be obtained. The qualification is attained through a (second) State examination or the Land in question establishes an equivalent State-certified qualification.

Länder are also free to take further Land-specific measures. By agreeing on joint guidelines and requirements for lateral entry, the Standing Conference can also facilitate the transfer of lateral entrants who later move to a different Land.

In the Länder, there are various offers for further training for teachers who want to acquire the teaching qualification for informatics.

Further training usually extends over a longer period and includes various courses of several hours per week and, where necessary, additional intensive courses. Because of the length of the course, participants can be released from their teaching duties or from several of their weekly teaching commitments provided that the school supervisory authority recognises the need for the further training course concerned.

ISCED levels: 24 and 34

Duration: May vary between *Länder*

Providers: Teacher training institutions

Admission criteria:

- The minimum requirement for the qualification of lateral entrants (*Seiteneinsteiger*) is a university master's degree or equivalent higher education qualification from which at least two teaching-related subjects can be derived.
- Individuals then have to complete the preparatory training (*Vorbereitungsdienst*) or comparable training, which also provides basic educational skills through a (second) State examination or equivalent State-certified qualification.
- *Länder* are also free to take further *Land*-specific measures.

Website: http://www.kmk.org/fileadmin/veroeffentlichungen_beschluesse/2013/2013_12_05-Gestaltung-von-Sondermassnahmen-Lehrkraefte.pdf

Estonia

National occupational qualifications system

Professional certificates can be obtained by anybody who demonstrates the necessary skills described in the teacher's professional standards. Training courses are not obligatory.

ISCED levels: 1, 24 and 34

Provider: Estonian Qualifications Authority

Admission criteria: Master's degree or equivalent qualification

Reference/website: Professions act, 2008 (https://www.riigiteataja.ee/en/eli/521032019015/consolide)

Ireland

Retraining opportunity

1. Generalist or specialist secondary education teachers can, on their own initiative and interest, commit to studying extra computer science modules to meet the Teaching Council requirements. The Limerick Institute of Technology provides the master of science in computer science for teachers degree programme, which lasts 2 years (90 ECTS credits).

ISCED levels: 24 and 34

Duration: 2 years (90 ECTS credits)

Provider: Limerick Institute of Technology

Admission criteria: —

Website: https://lit.ie/en-IE/Courses/Master-of-Science-in-Computer-Science-for-Teachers

2. Technological University Dublin Tallaght offer a higher diploma in science in computing with an optional module in computer science for secondary school teachers. This module (which primary school teachers can also take if they so wish) is specifically aimed at teachers who wish to upskill for the new leaving certificate subject computer science. It is delivered in the evening, usually two evenings per week.

   ISCED levels: 24 and 34

   Duration: 2 years (90 ECTS credits)

   Provider: Technological University Dublin

   Admission criteria: ISCED 6 honours degree graduates of subjects with a significant numeracy element

   Website: https://www.tudublin.ie/study/part-time/courses/computing-tu067/

Spain

Process of access and acquisition of new specialties: retraining

Teachers of secondary education may acquire new specialties by sitting a test. The test consists of an oral presentation about a subject of the speciality. The duration and characteristics of this test are set by the educational administrations.

ISCED level: 34

Duration: Not applicable

Provider: Autonomous communities following national legislation

Admission criteria: Being a civil servant teacher and having an academic degree required for the education level at which teachers will teach

Reference/website: Royal Decree 276/2007 of 23 February, which approves the regulation of entry, access and acquisition of new specialties in the teaching bodies referred to in Organic Law 2/2006 of 3 May on education, and regulates the transitional entry regime referred to in the 17th transitory provision of the aforementioned law (https://www.boe.es/buscar/pdf/2007/BOE-A-2007-4372-consolidado.pdf).

France

Third competition (*le troisième concours*) and internal competition (*le concours interne*) – alternative pathway

The third competition (*le troisième concours*) is available for those who have at least 5 years of professional experience in any activity in the private sector.

Non-qualified teachers with at least 3 years of professional experience in public services or institutions that depend on them (at a school or not, as a teacher or not, as a civil servant or not, it includes teachers from private and State-funded schools) and those who hold a bachelor's degree or equivalent level can take the internal competition (*le concours interne*).

Admission criteria: For the 3rd competition, 5 years of professional experience in any activity in the private sector and for the internal competition, at least a bachelor's degree and a minimum of 3 years of professional experience in the public sector.

Website: https://www.devenirenseignant.gouv.fr/pid33985/enseigner-college-lycee-general-capes.html

University diploma (*Diplôme inter-universitaire 'Enseigner l'informatique au lycée'*) – alternative pathway / retraining

This programme is a training course designed to help prospective computer science teachers to acquire the minimum knowledge and skills required to teach the new digital technology and computer science specialisation (*Numérique et sciences informatiques*) in grades 11 and 12. The DIU targets the candidates with a solid background in informatics. The candidates who do not have such a background need to complete beforehand a preparatory course for the DIU called 'block 0'.

ISCED level: 34

Duration: 125 hours of face-to-face teaching (block 0 lasts 50 hours).

Providers: Universities and Institut national de recherche en informatique et en automatique

Admission criteria: Candidates should have advanced skills in informatics or complete block 0

Reference/website: DIU Enseigner l'informatique au lycée (https://sourcesup.renater.fr/www/diu-eil/); https://sourcesup.renater.fr/www/diu-eil/medias/diu-eil-habilit-bloc0.pdf

Croatia

Alternative pathway

Professionals from other fields holding a master's degree can obtain the teaching qualification by completing the supplementary pedagogical study programme offered by education/philosophical faculties. This programme may also be attended in parallel to or after a non-pedagogical master's degree. It includes pedagogical and psychological disciplines, methodology, didactics and practical training.

ISCED levels: 1, 24 and 34

Duration: 55 ECTS credits

Providers: Education, philosophical, mathematics or informatics faculties

Admission criteria: Bachelor's or master's degree

Reference/website: Primary and secondary school education act (OG 87/08, 86/09, 92/10, 105/10, 90/11, 5/12, 16/12, 86/12, 126/12, 94/13, 152/14, 7/17, 68/18, 98/19); Ordinance on the appropriate type of education of teachers and expert associates in primary schools (OG 6/19) (https://narodne-novine.nn.hr/clanci/sluzbeni/2019_01_6_137.html)

Latvia

Professional development programmes leading to an additional qualification in informatics or in pedagogy: alternative pathway / retraining

There are programmes that allow teachers qualified in other fields to get additional qualification in informatics (160 hours) and there are programmes in pedagogy that allow candidates who have bachelor's degrees in science, including computer science (72 hours), to get teaching qualifications.

ISCED levels: 24 and 34

Duration: 160 hours or 72 hours

Provider: —

Admission criteria: —

Reference/website: Amendments to the regulations on the education and qualifications required of teachers; Regulation of the Cabinet of Ministers No 569 of 11 September 2018 (https://likumi.lv/ta/id/319048).

Lithuania

Retraining to become informatics teachers

ISCED levels: 1, 24 and 34

Duration: 1.5 years (3 semesters) or 1 485 hours

Provider: Vytautas Magnus University

Admission criteria: Teaching qualification

Website: https://www.vdu.lt/lt/vdu-kviecia-pedagogus-i-perkvalifikavimo-studijas/

Luxembourg

Teacher training – alternative pathway / retraining

The National Education Training Institute provides several opportunities for continuing training. Some of them are for in-service teachers who want to obtain an additional qualification to teach informatics. Other courses target master's graduates from informatics-related fields who want to obtain pedagogical skills to teach informatics in schools. Training is based more on pedagogy but contains subject-related elements.

ISCED level: Mainly 24

Duration: Various depending on the provider

Provider: National Educational Training Institute (*Institut de formation de l'Éducation nationale*)

Admission criteria: Master's diploma in the subject studies

Website: https://legilux.public.lu/eli/etat/leg/loi/2021/08/06/a615/jo

Malta

Bachelor of education – alternative pathway

The bachelor of education degree programme is offered as a series of part-time evening courses.

ISCED levels: 24 and 34

Duration: 4 years (180 ECTS credits)

Provider: Institute for Education

Admission criteria: Level 3 qualifications in Maltese, English and mathematics (according to Malta Qualifications Framework (MQF)) and:

- level 4 (general education) matriculation certificate qualification in one of the subjects taught in the primary curriculum;
- an MQF level 4 (vocational education and training) qualification in early childhood education and care);
- three subjects at MQF level 4 (general education) in one of the subjects taught in the primary school curriculum.

Website: https://instituteforeducation.gov.mt/en/Documents/Prospectus/IfE_Prospectus 2020-21 Desktop friendly.pdf

Netherlands

Side entry into the profession (*Zijinstroom in het beroep*)

ISCED level: 34

Duration: Depends on previously acquired experience; maximum duration 2 years part-time (maximum 60 ECTS credits)

Provider: All institutions offering higher education (public and private) are allowed to offer these programmes

Admission criteria: Minimum ISCED 6 level (bachelor's diploma) in a relevant field

Website: https://www.rijksoverheid.nl/onderwerpen/werken-in-het-onderwijs/vraag-en-antwoord/hoe-word-ik-zijinstromer-in-het-onderwijs

Informatics for all

ISCED level: 34

Duration: 48 ECTS credits

Provider: Consortium of nine Dutch universities.

Admission criteria: Bachelor's degree in a science, technology, engineering or maths subject, and demonstrable motivation for computer science and for upper secondary school teaching

Website: https://beta4all.nl/inf4all-programma/

Austria

Consecutive academic course 'Digital Basic Competence': retraining

Teachers who have completed this course are able to teach the compulsory exercise 'Digital Basic Competence' at ISCED 24 or to integrate elements of 'Digital Basic Competence' in ISCED 1.

ISCED levels: 1 and 24

Duration: The duration in ECTS credits varies among universities:

Pädagogische Hochschule Oberösterreich: 28 ECTS credits

Pädagogische Hochschule Niederösterreich: 30 ECTS credits

Pädagogische Hochschule Steiermark: 29 ECTS credits

Provider: Teacher training colleges

Admission criteria: Being an in-service teacher

Website: Curricula for the academic course 'Digital Basic Competence'
https://www.phst.at/fileadmin/Mitteilungsblaetter/Studienjahr_2017_2018/MB_31_HLG_Informatik_Sek_I_29_EC.pdf;
https://ph-ooe.at/fileadmin/Daten_PHOOE/Ausbildung_APS/Curriculum/Curriculum_eEducation_f%C3%BCr_Homepage.pdf

Poland

Postgraduate studies – retraining

These courses are designed for graduates of universities with specialisations other than informatics with pedagogical qualifications to teach informatics in schools. The curriculum includes three sections: (1) substantive preparation for teaching the computer science subject; (2) didactics (methodology) of computer science at all educational stages; and (3) school practice (placements). The detailed study programme, the number of semesters and the number of ECTS credits beyond the required minimum is determined by the university.

ISCED levels: 1, 24 and 34

Duration: Minimum 120 hours (2 semesters) for ISCED 1; minimum 360 hours (3 semesters) for ISCED 24 and for ISCED 34, including 90 hours of practice in schools (minimum of 30 ECTS credits)

Providers: Higher education institutions that offer first- or second-cycle studies in informatics / computer science.

Admission criteria: Being a fully qualified teacher and having completed first- and second-cycle studies (bachelor's – ISCED 6; and master's – ISCED 7).

Reference: Regulation of the Minister of Science and Higher Education on the national standards for initial teacher training programmes (consolidated text of 6 April 2021 *Obwieszczenie Ministra Edukacji i Nauki z dnia 6 kwietnia 2021 r. w sprawie ogłoszenia jednolitego tekstu rozporządzenia Ministra Nauki i Szkolnictwa Wyższego w sprawie standardu kształcenia przygotowującego do wykonywania zawodu nauczyciela)*.

Romania

Postgraduate professional conversion courses in computer science

ISCED levels: 24 and 34

Duration: 2 years (120 ECTS credits)

Providers: Accredited higher education institutions

Admission criteria: Bachelor's degree or an equivalent diploma

Reference: Law of National Education No 1/2011, with its subsequent amendments and additions

Slovakia

Supplementary pedagogical study (*Doplňujúce pedagogické štúdium*)

Professionals from other fields holding a master's degree can obtain a teaching qualification by completing the supplementary pedagogical study programme offered by pedagogical/philosophical faculties. This programme may also be attended in parallel to or after a non-pedagogical master's degree. It includes pedagogical and psychological disciplines, methodology, didactics and practical training.

ISCED levels: 24 and 34

Duration: 200 hours (2 academic years)

Providers: Universities – pedagogical/philosophical faculties

Admission criteria: Master's/PhD degree student (if in parallel with the master's/PhD study) or master's/PhD degree (if not in parallel with master's/PhD study). Other criteria can vary depending on the faculty/university.

Reference/website: Act 138/2019 on pedagogical staff and professional staff and on the amendment of certain laws (https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2019/138/?ucinnost=11.07.2022), para. 44.

Extension programme (*rozširujúce štúdium*) – retraining

This is a type of study by which a teacher can acquire a qualification to teach another subject (e.g. informatics).

ISCED levels: 24 and 34

Duration: 200 hours (2 academic years)

Provider: Higher education institutions established by the Ministry of Education

Admission criteria: Previous pedagogical qualification/degree and other criteria set by higher education institutions

Reference/website: Act 138/2019 on pedagogical staff and professional staff and on the amendment of certain laws (https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2019/138/?ucinnost=11.07.2022), para. 45.

Sweden

Retraining schemes

1. To teach subject related to informatics at general upper secondary level, qualified teachers need to complete additional studies in the computer science area, for example computing, programming or ICT.

   ISCED level: 34

   Duration: 90 ECTS credits or 60 ECTS credits depending on the programme

   Providers: Several higher education institutions

   Admission criteria: Having a master's degree, being a qualified teacher at ISCED 24 or ISCED 34 and being eligible for university studies

   Website: https://www.skolverket.se/skolutveckling/kurser-och-utbildningar/lararlyftets-kurser-for-larare

2. Boost for Teachers (*Lärarlyftet*), a professional development programme initiated by the National Agency for Education (*Skolverket*).

   ISCED level: 24

   Duration: 45 ECTS credits

   Providers: Several higher education institutions

   Admission criteria: Being a qualified in-service teacher, with the head teacher's permission

   Website: One example of a provider is the KTH Royal Institute of Technology (https://www.kth.se/student/kurser/kurs/LL137U)

3. National school development programmes (*Nationella skolutvecklingsprogram*) in digitalisation. These are web-based courses for teachers at different educational levels.

   ISCED levels: 1, 24 and 34

   Duration: 16–36 hours; 5 ECTS credits

   Provider: Several higher education institutions

   Admission criteria: No admission restrictions and no age restrictions. Courses in the programme digitalisation are mainly targeted at teachers of technology or mathematics at different education levels.

   Website: https://www.skolverket.se/skolutveckling/nationella-skolutvecklingsprogram#skvtableofcontent2464

4. Additional teacher training *Kompletterande pedagogisk utbildning* – alternative pathway

   Some teacher training in cooperation with school organisers on the local level, make it possible for students to start working as teachers with a full-time salary while studying part-time to become qualified teachers.

   Duration: 90 ECTS credits

   Provider: Initial teacher education institutions

   Admission criteria: At least 90 ECTS credits in a subject relevant to the school curriculum

   Website: https://www.studera.nu/att-valja-utbildning/lararutbildningar/lararutbildningsguiden/kpu/

Serbia

Teacher education programme for teaching informatics – retraining

Generalist teachers who work at primary education level (ISCED 1) can teach the subject digital world without any formal additional training. Generalist master teachers can teach the subject informatics and computer science at ISCED 24 if they achieve at least 90 ECTS credits in the field of informatics during their studies or through an additional programme.

ISCED level: 24

Duration: Minimum of 90 ECTS credits

Providers: Teacher faculties (higher education institutions for teacher training)

Admission criteria: Candidates must have completed higher education at basic level for teacher education (a total of 240 ECTS credits) and acquired the professional title of graduate teacher, or at basic and master's levels for teacher education (a total of 300 ECTS credits) and acquired the academic title of master

Websites: For example, https://pefja.kg.ac.rs/program-obrazovanja-ucitelja-za-izvodjenje-nastave-iz-informatike-i-racunarstva-u-osnovnoj-skoli/, https://pefja.kg.ac.rs/wp-content/uploads/2018/04/Lista_predmeta_Informatika_i_racunarstvo.pdf and https://www.pefja.kg.ac.rs/preuzimanje/Obavestenja_2017_2017/Pages-from-SI2.pdf

Switzerland

Teaching diploma for an additional subject – retraining

The extension diploma awarded supplements the teaching diploma originally obtained.

ISCED level: 34

Duration: 107 ECTS credits

Provider: University of Fribourg, GymInf programme

Admission criteria: A recognised teaching diploma

Website: https://www.unifr.ch/gyminf/de/

Special training programme

Teacher training universities may offer a special training programme for people wishing to be retrained for teaching who are at least 30 years old, and who can demonstrate professional experience. This special programme enables them to take up a paid part-time teaching position corresponding to their degree (on-the-job training) at the earliest at the end of the first year of training. The teaching activity is part of the full-time studies and must be supervised by the university.

Duration: 270–300 ECTS credits (same duration as for regular initial teacher education)

Providers: Teacher training universities

Admission criteria: A minimum of 3 years of professional experience is required and a minimum age of 30 years

Website: http://www.edk.ch/dyn/27621.php

Explanatory note

Only the most widespread alternative pathways and retraining programmes are described here.

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Informatics education at school in Europe

Eurydice report

Informatics education is essential to equip young people with the necessary skills to take an active part in our technology-driven and increasingly digital societies in a responsible and safe manner. European countries are gradually upgrading their school curricula to respond to the new reality and needs.

This report provides a comparative analysis of the curricular approaches to teach informatics as a separate subject or integrated into other subjects throughout primary and general lower and upper secondary education in 2020/2021. It examines the main areas of informatics covered in the learning outcomes of the relevant subjects. It also looks at the qualifications held by the teachers of these subjects, and the training programmes and other support measures in place to support them.

The report covers all the members of the Eurydice Network (the 27 EU Member States and Albania, Bosnia and Herzegovina, Switzerland, Iceland, Liechtenstein, Montenegro, North Macedonia, Norway, Serbia and Turkey).

The Eurydice Network's task is to understand and explain how Europe's different education systems are organised and how they work. The network provides descriptions of national education systems, comparative studies devoted to specific topics, indicators and statistics. All Eurydice publications are available free of charge on the Eurydice website or in print upon request. Through its work, Eurydice aims to promote understanding, cooperation, trust and mobility at European and international levels. The network consists of national units located in European countries and is coordinated by the European Education and Culture Executive Agency (EACEA).

For more information about Eurydice, see:
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