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Lower secondary intended curricula of science subjects and mathematics: a comparison of the Czech Republic, Estonia, Poland and Slovenia

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ABSTRACT

Comparative studies on science curricula provide insights into educational standards worldwide. Accordingly, in this study, we analysed the intended curricula of mathematics and science subjects of the Czech Republic, Estonia, Poland and Slovenia by comparing their lower secondary (ISCED 2) National Curriculum Documents on mathematics, physics, chemistry, biology, geography and geology from the perspective of learning outcomes. By document analysis, we extracted obligatory learning outcomes from the national curricula, assessing their level of detail and structure. A team of seven coders also measured cognitive demands of the learning outcomes using the revised Bloom's taxonomy. Our results showed considerable differences in the number of learning outcomes across countries and in the structure of these outcomes across subjects, even within national documents. Cognitive demands determined by learning outcomes were similar across the countries, but metacognitive knowledge and cognitive processes of higher level (Evaluate and Create) were mostly overlooked. We also found a lack of learning outcomes explicitly requiring the use of ICT, experimental or field work or data analysis. Although these requirements are usually formulated in general sections of curriculum documents, we recommend explicitly incorporating them into these documents as individual learning outcomes.

KEYWORDS

Cognitive objectives; comparative analysis; curriculum research; outcomes of education; secondary education

Introduction

Enhancing educational goals is a key priority of educational policies in every country. For this purpose, each Ministry of Education sets national curricula or framework educational programmes. These documents should reflect the shift in the country's current priorities and educational demands, focusing on curriculum changes and revisions whilst considering their far-reaching social, political, economic and mostly educational consequences. In the Czech Republic, we are currently revising our national curriculum, finally suggesting a major modification after years of minor changes because the challenges of our modern globalized society have major implications in the design of

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national curricula. As such, these curricula should be extensively revised to provide students with ample opportunities for practical activities, thereby developing their ICT skills and technology proficiency whilst promoting their thinking, organizing and planning (metacognition) abilities, among others.

When preparing curriculum reforms, national authorities find inspiration in other countries with success in international testing (e.g. Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS)) or struggling with similar problems. Therefore, we compared our current science subjects curriculum documents (traditionally, biology, chemistry, physics, geography and geology; and in our conception, mathematics as well) to those of several other countries. These countries were chosen according to the following criteria: (1) showing significantly better results in international surveys, such as PISA, and (2) having a similar cultural and historical background. Among all possible countries from the former Eastern Bloc, Poland, Slovenia and Estonia, meet these criteria, outperforming the Czech Republic in previous PISA testing (OECD, 2014, 2016a, 2019). Members of our team have already participated in five separate studies comparing subject-specific content of science and mathematics education in these four countries. While these partial studies—published in a special issue of the Scientia in Educatione journal (Janoušková et al., 2019)—addressed the comparison of specific topics taught in particular countries, in this paper we will focus on prescribed learning outcomes, their nature, structure and intellectual demands.

Research context

All four post-communist countries share a similar history, that is, they were under communist governance and a planned economy after World War II, but the Union of Soviet Socialist Republics (USSR) influenced those countries to varying degrees. Estonia was a member state of the USSR until 1991, while Poland and the Czech Republic (Czechoslovakia until 1993) maintained their sovereignty formally, albeit within the Eastern Bloc, both until 1989, and subjected to USSR rule in practice. In turn, Slovenia was a founding member of the Socialist Federal Republic of Yugoslavia and was not subjected to the direct influence of the USSR, eventually seceding from Yugoslavia in 1991.

Since their transfer to democratic regimes in the 1990s, all four countries continue to improve their living standards, which are approaching the average standards of western countries. All of them have also joined the European Union in 2004, thereby prompting reforms towards implementing common EU-legislation.

Changes in the education systems of the Czech Republic, Estonia, Poland and Slovenia ran parallel to their historical events. Before the collapse of the communistic regimes in the 1990s, education in these countries focused on factual cognition and transmissive teaching methods, failing to address environmental issues or doing so merely by chance and always under a political ideology (Horváth & Próbald, 2003).

The political changes that occurred in the early 1990s were the same starting point for the education reforms in all four countries. The Czech Republic and Poland tried to prepare new curriculum documents as soon as possible. However, as a result, the content remained almost unchanged, albeit freed from all ideological issues. Conversely, Estonia began to prepare a completely new curriculum, featuring school curriculum autonomy and defining learning outcomes directly inspired by the Finnish National Curriculum. The new curriculum was planned as an effective tool for building an open, democratic, information-based society, geared towards Europe, and for promoting a market economy. Furthermore, this new curriculum included problem solving, critical thinking and personal responsibility within its key objectives to simultaneously motivate pupils and foster their abilities to reflect on and manage their own learning (OECD, 2016b). Within former Yugoslavia, Slovenia had some autonomy in their own education system planning; however, as in other communist countries, its curriculum was ideologically driven. For this reason, in the 1990s, the

democratic and pro-European independent Slovenian Republic adopted a new education policy, including a new curriculum. After moderate revisions in 2007, this curriculum was reformed to its current form from 2008 to 2011 (Vlček et al., 2016).

The governments of these countries have all the interest in succeeding when implementing such reforms. For this reason, they participate in international surveys and assessments. As mentioned above, the Czech Republic differs non-significantly from the OECD average while Poland, Slovenia and Estonia are the only countries from the former Eastern Bloc that regularly rank significantly above the OECD average in science and mathematics, in PISA testing (OECD, 2014, 2016a, 2019). Therefore, policy learning may enable us to design strategies towards improving Czech curriculum documents.

Comparing the curricula: theoretical framework

The diverse success rates of pupils from the selected countries measured in international surveys has led us to reflect on the similarities and differences between the curricula of lower secondary education (ISCED 2) in these countries.

According to Bray and Thomas (1995), comparative studies on education can be classified using three-dimensional system. The first dimension is geographical/ locational (countries, districts, schools and classrooms), the second dimension is based on non-locational demographic variables (religion, age and gender), and the third dimension encompasses other aspects of education and society such as curriculum, teaching methods and educational finance, among others. Furthermore, we only focus on one of the key components in the analysis of educational standards of the selected countries, that is, their curriculum as defined by their national curriculum documents.

Basically, a curriculum can be regarded as a plan for learning, describing what, why and how pupils should learn (Taba, 1962). The curriculum model is based on three aspects: the intended curriculum, the implemented curriculum, and the achieved curriculum (Kridel, 2010). The intended curriculum defines the expectations and goals in terms of knowledge, skills, values and attitudes, which should be achieved and developed by pupils during their formal education, also specifying how the outcomes of the teaching and learning process should be assessed. The implemented curriculum represents teaching and learning activities used in school practice, and the achieved curriculum indicates the knowledge and understanding that pupils have achieved during their education. As stated above, in our research, we only address the intended curriculum, more specifically, the official national curriculum documents and frameworks. These documents should serve as a fundamental vision, a widely accepted direction for all stakeholders in the education process—including government officials, textbook authors, teachers, school principals and teacher educators.

Different perspectives on how to best compare these documents stand out in the field-specific literature. For example, the comparison of curriculum breadth and depth is widely accepted (Murdock, 2008). Yet, while breadth is usually understood in terms of the number of topics prescribed, depth is not uniformly defined (Murdock, 2008); similarly, there is no consensus on whether breadth could be achieved at the expense of only depth and vice versa. Alternatively, Thijs and van den Akker (2009) propose four parameters of curriculum quality, addressing curriculum relevance, consistency, practicality and effectiveness. Notwithstanding the rationale and merits of such parameters, in this study, we follow the approach previously applied by other researcher groups (e.g. Elmas et al., 2020; Lee et al., 2015) comparing intellectual demands of intended curricula.

Intellectual demands placed on pupils by national curriculum documents directly shape the implemented curriculum, e.g. by influencing teachers' decisions on the cognitive processes that should be supported through instruction and on the methods chosen to do so. To evaluate the intellectual demands of national curriculum documents, we focused on what these documents prescribe for pupils to manage at the end of the instruction—depending on the country, these requirements are known as educational goals, outcomes or objectives. In this paper, we uniformly use the umbrella term obligatory learning outcomes to express all three concepts, in line with, e.g. Harden (2002).

To assess these learning outcomes, we used an analytical framework of cognitive, affective, and psychomotor knowledge domains (e.g. Wei & Ou, 2019). The cognitive educational objectives[1] target the recall or recognition of knowledge and their taxonomy was originally addressed by Bloom et al. (1956), who outlined six major categories of cognitive processes (Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation). Educational objectives in the affective domain refer to interests, desires, feelings, emotions, values, enthusiasm, or attitudes. Lastly, the psychomotor domain is composed of objectives aimed at developing motor and physical abilities and skills. All three domains are clearly related to each other. As such, these relationships were studied, whilst revising and modifying the taxonomies as well.

In this study, we only address the cognitive domain, which is the only relevant domain when assessing the intellectual demands of obligatory learning outcomes.

Revised Bloom's taxonomy

The frequent use of Bloom's taxonomy has uncovered its limitations. This taxonomy assumes that mastering the simpler categories is a prerequisite for mastering the corresponding 'higher' categories (Bloom et al., 1956). However, Ormell (1974) highlighted that the order of categories can be inverted—e.g. specific demands for Knowledge can be more complex than some demands for Analysis. Furthermore, according to Kreitzer and Madaus (1994), Evaluation is a part of Synthesis and not the other way around. Lastly, the unidimensionality of the taxonomy has been criticized because educational objectives typically consist of two components—content (usually noun) and action (usually verb), thus suggesting two dimensions (Krathwohl, 2002).

These criticisms have led researchers to suggest taxonomies able to suppress unwanted effects. To cover both dimensions mentioned above, models have been developed based on the categorization of mental processes and on types of knowledge. For example, the Depth of knowledge (DOK) model developed by Webb (1997) has four major levels (Recall & Reproduction, Basic Application of Skills/Concepts, Strategic Thinking, and Extended Thinking) and focuses on the complexity of the content and on the cognitive process simultaneously demanded by the educational objective; DOK was used, e.g. in PISA 2018. Other taxonomies (New Taxonomy and SOLO Taxonomy) directly use multiple dimensions (Lee et al., 2017).

Arguably, the most commonly used adaptation of the original Bloom's model is the revised Bloom's taxonomy (RBT) introduced by Anderson et al. (2001). RBT preserves the system with six categories of cognitive processes, which are renamed in verb form, and the two highest levels are reversely-ordered—the RBT cognitive processes are Remember, Understand, Apply, Analyse, Evaluate and Create. In addition, a second dimension is included to differentiate the types of knowledge as Factual, Conceptual, Procedural and Metacognitive. The authors (Anderson et al., 2001) provided examples to make it easier to use the taxonomy. Table 1 presents general definitions and examples of typical verbs linked to cognitive processes. In turn, Table 2 outlines the major types of knowledge, as well as subtypes and their examples.

Despite these guidelines, distinguishing the Metacognitive type of knowledge (not only from other types of knowledge but also from the affective domain) is a particularly complex task, which can be nevertheless facilitated by supplementing the original description of Metacognitive knowledge with other sources and by specifying typical characteristics of metacognition (Anderson et al., 2001; Cambridge Assessment International Education, 2019; Flavell, 1979; Lokajíčková, 2014). According to these authors, metacognitive learning outcomes primarily encompass the following characteristics: interdisciplinary overlap (except when the other discipline is used as a 'tool', such as mathematics in geography), tasks requiring or employing one's own experience and knowledge of different situations and cultural norms on the use of different strategies or on learning how to use different types of information, value, interest beliefs or judgements.

Table 1. Cognitive processes of revised Bloom's taxonomy (based on Anderson et al., 2001).

Cognitive process	Definition	Examples of typical active verbs involved
Remember	The student can recall or remember the information.	Define, duplicate, list, memorize, recall, repeat, reproduce, state
Understand	The student can explain ideas or concepts.	Classify, describe, discuss, explain, identify, locate, paraphrase, recognize, report, select, translate
Apply	The student can use the information in a new way.	Choose, demonstrate, dramatize, employ, illustrate, interpret, operate, schedule, sketch, solve, use, write
Analyse	The student can distinguish between the different parts.	Appraise, compare, contrast, criticize, differentiate, discriminate, distinguish, examine, experiment, question, test
Evaluate	The student can justify a stand or decision.	Appraise, argue, defend,evaluate, judge, select, support, value
Create	The student can create new product or point of view.	Assemble, construct, create, design, develop, formulate, write

Table 2. The major types and subtypes of the knowledge dimension (based on Anderson et al., 2001).

Major types of knowledge	Subtypes	Examples
A. Factual: The basic elements students must know to be acquainted with a discipline or solve problems in it	A_A. Knowledge of terminology	Unit of rate, unit of force
	A_B. Knowledge of specific details and elements	Some common danger warning symbols
B. Conceptual: The interrelationships among the basic elements within a larger structure that enable them to function together	B_A. Knowledge of classifications and categories	The nature of force
	B_B. Knowledge of principles andgeneralizations	Energy conservation law
	B_C. Knowledge of theories,models, and structures	Structure of atom, theory of evolution
C. Procedural: How to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods	C_A. Knowledge of subject-specific skills and algorithms	Friction calculation
	C_B. Knowledge of subject-specific techniques and methods	Scientific methods
	C_C. Knowledge of criteria for determining when to use appropriate procedures	The criteria used to determine when to apply Newton's second law
D. Meta-cognitive: Knowledge of cognition in general as well as awareness and knowledge of one's own cognition	D_A. Strategic knowledge	Knowledge of outlining as a means of capturing the structure of a unit of subject matter in a textbook
	D_B. Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge	Knowledge of the cognitive demands of different tasks
	D_C. Self-knowledge	Awareness of one's own knowledge level

Notwithstanding its quality, RBT is not a flawless tool. Unsurprisingly, dissenting voices underscore its limitations (Amer, 2006; Tutkun et al., 2012), and revisions of the revised taxonomy have already been published (Darwazeh & Branch, 2015). Yet, RBT has become a widely reputable tool, which has proved useful in various research procedures. When analysing official curriculum documents, RBT has been repeatedly used by researchers from various countries, including in Edwards (2010), Elmas et al. (2020), Lee et al. (2017), Wei and Ou (2019), Wei (2020), and Yaz and Kurnaz (2020), thus demonstrating its value in different cultural contexts and applications.

Comparative studies in science subjects and mathematics intended curricula

Various comparative cross-national studies of intended curricula have been conducted in different regions and over various time periods. For instance, Kamens and Benavot (1991) discussed the origin and spread of mathematics and science education in national elementary and secondary school

curricula of world regions. Pawilen and Sumida (2005) published a study on the similarities and differences of intended science curricula for elementary levels between the Philippines and Japan in terms of the aims, content and organization of the curricula. More recently, Lee et al. (2015) compared Korean and Singaporean intended primary science curricula, and in their following and highly detailed study, Lee et al. (2017) provided further insights into primary science curriculum standards in mainland China, Hong Kong, Taiwan, Korea, Japan and Singapore. In turn, Wei and Ou (2019) discussed the similarities and differences of junior high school science curriculum standards among four Chinese regions.

Among such comparative studies specifically conducted in European countries, the report on the analysis of curriculum documents for science subjects of the Czech Republic, England, Estonia, Finland, France, and Poland conducted by Grajkowski et al. (2014) stands out because the authors compared the Polish science core curriculum at the lower secondary level and the first year of higher secondary school with the corresponding documents of the other countries. Concurrently, a number of Czech research studies on comparative education in the international context have described and compared education systems in different countries. For example, Greger et al., (2006) analysed education systems in Germany, Great Britain and Sweden. However, to our best knowledge, no study has directly compared the science subjects and mathematics curriculum of the Czech Republic to the science subjects and mathematics curriculum of any other country in the context of learning outcomes at the lower secondary level. Even the study by Elmas et al. (2020), which is the most similar to our research, only compared chemistry curricula, doing so at a different level of education, that is, upper secondary school.

Research Questions

Combining our research goals with the theoretical background described above, we formulated the following research questions (RQ):

(1) How detailed are science subjects and mathematics curricula of the Czech Republic, Estonia, Poland and Slovenia in terms of learning outcomes?
(2) Is the structure of learning outcomes similar across subjects within a single country?
(3) How do the cognitive demands of these curricula differ across selected countries?
(4) What are the specific features of Czech, Estonian, Polish and Slovenian curricula?

The first RQ aims to determine the number of obligatory learning outcomes, while the second RQ relates to the internal coherence of national curriculum documents. Cognitive demands (RQ3) of learning outcomes are measured by RBT.

Methodology

For our research purposes, we employed document analysis as a stand-alone method although this technique is most often used for triangulation during qualitative research (Denzin, 1970). Document analysis has several advantages: the documents are non-reactive, unaffected by the research process, and remain stable and suitable for repeated reviews (Bowen, 2009). In this study, our document analysis focused on content rather than thematic analysis, with a deductive category application approach (Mayring, 2000).

Research sample: relevant curriculum documents

All countries compared in this study use a two-level curriculum structure. This curriculum structure consists of (1) a national framework document, which defines basic requirements for education, and (2) a school level document, which provides the framework for implementing education in specific

schools and which is defined by each school itself. In our research, Czech, Estonian, Polish and Slovenian national framework documents on lower secondary education (ISCED 2) were the primary sources of information that provided raw data for our analysis. Hereinafter, we briefly describe these documents and specify their sections analysed in our study.

The Czech primary and lower secondary systems are mostly single structured and termed basic education. Therefore, the national core curriculum for lower secondary education in the Czech Republic (CZC) is found in *The Framework Educational Programme for Basic Education* (2007). This document formulates the conception of basic education, its objectives and the key competencies that should be achieved by pupils. The educational content is divided into educational areas; in this study, we address the areas *Mathematics and Its Application* and *Humans and Nature*, which include the following educational fields: Physics, Chemistry, Geography and Natural Sciences (Czech designation for Biology at ISCED 2). Since 2005, when FEP BE was established in schools, no extensive reform has been implemented, and its minor changes lay outside the scope of our research.

The Estonian curriculum (ESTC) came into force in 1996 and was divided into separate frameworks for lower and upper secondary education in the 2011 revision (Lees, 2016). Estonia also has single structured education with standards determined by *The Estonian national curriculum for basic schools* (National curricula for basic schools, 2017). Its general section specifies core values and objectives of basic education, while appendices contain syllabi of subject areas and compulsory subjects. For our study, we selected the subject fields *Mathematics* and *Natural Science* (i.e. physics, chemistry, biology and geography).

Since the 2017/2018 school year, a single structure education framework covering ISCED 1 and 2 has been implemented in Poland (Wojniak & Majorek 2018). While the impact of the new curriculum document has not been reflected in PISA yet, we analysed the curriculum document that was valid before the reform, i.e. *Podstawa Programowa Kształcenia Ogólnego Dla Szkół Podstawowych* [Curriculum for Primary and Secondary Schools] (PLC) (Dziennik Ustaw, 2012), more specifically the requirements in the subjects *Mathematics, Physics, Chemistry, Biology* and *Geography*. Before the reform, compulsory education included only the primary (ISCED 1) and lower secondary (ISCED 2) levels.

Slovenian education is also single structured, and its current curriculum (SLOC) has been in force since 2011. The curriculum is available as hypertext and consists of a brief general section followed by subject curricula (GOV.SI Portal, n.d.) described in separate, detailed documents containing the definition of the subject, general goals, learning outcomes, knowledge standards and didactic recommendations. Our study focused on the curricula of *Mathematics* (grade 6–9), *Geography, Physics, Chemistry* and *Biology*.

In all countries, the current role of the national curriculum is quite similar, primarily shaping school curriculum documents since learning outcomes must be defined and described in these documents (see national education acts). In the Czech Republic, Poland and Slovenia, the correspondence between national and school curriculum documents is one of the assessment parameters used in centralized school inspections; conversely, in Estonia, the self-evaluation of schools plays a key role in evaluation policy (SICI, 2016).

In Estonia, Poland and Slovenia, pupils undergo an obligatory national examination at the end of ISCED 2. In addition to providing pupils, schools, parents and other stakeholders with external assessment metrics, the results of national examinations can serve as criteria for admission to upper secondary education; however, passing these exams is necessary to graduate from lower secondary school only in Estonia (National curricula for basic schools, 2017). In Estonia, Poland and Slovenia, the requirements of the national examination reflect the general framework of the national curriculum, but the specific content of examinations depends on institutions responsible for preparing them. The situation regarding textbooks is similar—in all four countries, teachers can choose from different editions of textbooks, which must be approved by officials and in accordance with the national curriculum. However, this is only a formal requirement in some countries; for example, the scope of Czech textbooks is much wider than that of the CZC.

Research procedure

For each country, we first extracted obligatory learning outcomes from each national curriculum document, as described above. Learning outcomes are termed expected outcomes in the CZC, learning objectives in the PLC, operational objectives in the SLC and learning outcomes in the ESTC. According to literature (Simpson, 1966), we assumed that each learning outcome (unit of analysis) contains a cognitive component. The learning outcomes were analysed during the multilevel coding process using RBT. The Metacognitive knowledge was coded in terms of a broader perception, as detailed in the Theoretical Framework. Therefore, we did not differentiate specific cognitive processes for metacognitive learning outcomes. We did not specify the subtypes of knowledge dimensions presented by Anderson et al. (2001; see Table 2) either to maintain the scope of this paper focused on its topic.

During the RBT coding process, the team of seven researchers split into six sub-teams of three to four coders by study subject. The leader of each subject prepared (and, if necessary, translated) the outcomes for coding; learning outcomes with geological topics were removed from the geographical and biological curriculum and assigned separately to the geological sub-team. The coding was processed in three levels: (1) the coders in sub-teams coded the learning outcomes on their own and uploaded their codes into a shared table, (2) one day before the joint meeting, the researchers checked the codes in the shared table towards reaching a consensus; when the coding was still inconsistent after the second level, (3) the coding of the learning outcome was discussed during the joint meeting until reaching an agreement.

Coding rules

The learning outcomes were coded according to the type of knowledge (Factual (F), Conceptual (C), Procedural (P) and Metacognitive (M)) and to the cognitive process (Remember (RE), Understand (UN), Apply (AP), Analyse (AN), Evaluate (EV), Create (CR)). The researchers coded the learning outcomes as they were precisely stated in the document and followed the whole context of the learning outcome, not only the separate active verb. The latter remark is crucial because context modifies meaning; therefore, verbs associated with one level of RBT in one context may be associated with another level in another context (Stanny, 2016). Whenever the outcome was difficult to code, in the sense of RBT, the researchers' teaching experience was used to overcome such problems.

The learning outcomes containing two or more active verbs are termed *complex* and coded according to the following criteria: (1) When two or more verbs required the same type of knowledge but different cognitive process, the higher process is coded.[2] (2) When two or more types of knowledge were identified, each of them was coded with the most demanding level of cognitive process.[3] The rules were used even when the verb was not explicitly written, but semantically contained,[4] or when the verb was used in a transgressive form.

The process of analysis was continuously run thanks to a feedback loop. The coding rules and examples, precedents, were collected in a coding agenda and continuously updated whilst checking formerly coded learning outcomes for reliability (Mayring, 2000).

Results

Numbers of learning outcomes

The first parameter on which we focused was the level of detail of the study curricula, which we simply measured by the number of learning outcomes prescribed by curriculum documents, as specified in Methodology. The results are summarized in Table 3. This statistics disregards the complexity of the outcomes (e.g. whether they contain more sub-sections) or their ambitiousness.

Table 3 shows that the geology curricula lack learning outcomes considering their relatively low numbers across the countries. As a result, the use of quantitative measures (percentages or graphs) can be misleading; henceforth, we will present the data on geology only qualitatively, thereby avoiding comparisons using graphs or tables.

In terms of the five remaining subjects, CZC is the briefest and SLOC the most extensive; PLC and ESTC show a generally similar extent (except for mathematics). Across the countries, science subjects account for a relatively similar percentage of all outcomes analysed per country—21–30% in biology, 11–19% in chemistry, 19–23% in physics and 16–20% in geography. In mathematics, this interval is considerably wider, ranging from 8% in Estonia, where the mathematics curriculum is quite short, to 29% in Slovenia, with more than 260 mathematics learning outcomes; CZC and PLC devote approximately as many outcomes to mathematics as they do to major science disciplines (e.g. chemistry or geography).

In total, almost 1900 learning outcomes were analysed, as summarized in Table 3. Although we outline the percentages of learning outcomes instead of their absolute numbers in the following tables, these data must still be interpreted in the context of Table 3—especially for CZC, where a single outcome typically accounts for ca. 3% of total outcomes within the subject.

Structures of the learning outcomes

The information outlined in Table 3 can be further analysed by assessing how the learning outcomes are structured and whether their structure is similar among all subjects in the same country. During the coding process, we differentiated simple (containing one active verb) from complex (two and more verbs) outcomes; for complex outcomes, we also considered their 'gradation', i.e. whether they required two or more different types of knowledge (Table 4).

In CZC and ESTC, ca. one third of the learning outcomes are complex, requiring more than one type of knowledge; in PLC, this ratio is approximately one fourth. Slovenia, whose list of learning outcomes is by far the most extensive, has only 11% of such outcomes, suggesting that, despite the high number of outcomes, they are generally semantically simpler and less structured than the corresponding outcomes of the other curricula.

Especially in CZC and PLC, Table 4 highlights considerable differences in the structure of learning outcomes across particular subjects; cf. biology and chemistry in CZC or chemistry and mathematics in PLC. In turn, SLOC shows low percentages of complex learning outcomes across all subjects, which is the most characteristic feature of the Slovenian curricula.

Table 3. Numbers of obligatory learning outcomes prescribed by national curricula; the percentages between parentheses show the percentage of specific subjects in the total number of outcomes of the country (which is reported in the last row of the table).

	Czech Republic (CZC)	Estonia (ESTC)	Poland (PLC)	Slovenia (SLOC)
Biology	31 (21%)	125 (30%)	109 (25%)	187 (21%)
Chemistry	27 (18%)	62 (15%)	84 (19%)	98 (11%)
Geography	29 (19%)	84 (20%)	69 (16%)	158 (18%)
Geology	6 (4%)	11 (3%)	6 (1%)	10 (1%)
Mathematics	29 (19%)	35 (8%)	73 (17%)	262 (29%)
Physics	29 (19%)	95 (23%)	95 (22%)	175 (20%)
Total per country	151	412	436	890

Table 4. Percentages of complex learning outcomes requiring two or more types of knowledge.

	Czech Republic (CZC)	Estonia (ESTC)	Poland (PLC)	Slovenia (SLOC)
Biology	16%	20%	29%	12%
Chemistry	52%	34%	44%	10%
Geography	31%	33%	22%	6%
Mathematics	28%	29%	3%	15%
Physics	31%	52%	16%	8%
Share per country	30%	33%	24%	11%

Cognitive demands of the learning outcomes

The distribution of learning outcomes based on RBT is presented in Table 5. For each country and subject, the numbers show the percentage of learning outcomes requiring the corresponding combination of type of knowledge and cognitive process. The sums of the percentages exceed 100% because many learning outcomes include two or more different types of knowledge and/or cognitive processes.

The highly detailed data presented in Table 5 can be analysed from two perspectives: types of knowledge and cognitive processes.

Table 5. Percentages of learning outcomes requiring the corresponding combination of type of knowledge (F, C, P and M) and cognitive process (RE, UN, AP, AN, EV and CR).

	Czech Republic					Estonia					Poland					Slovenia				
Biology		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*
	RE	16	0	0	26	*RE*	12	0	1	29	*RE*	33	2	0	17	*RE*	6	32	3	21
	UN	0	48	3		*UN*	0	34	2		*UN*	1	55	1		*UN*	1	39	1	
	AP	0	0	3		*AP*	0	0	3		*AP*	0	4	2		*AP*	0	1	5	
	AN	0	19	10		*AN*	0	30	1		*AN*	0	14	1		*AN*	0	2	1	
	EV	0	0	0		*EV*	0	5	1		*EV*	0	4	0		*EV*	0	1	1	
	CR	0	0	0		*CR*	0	1	4		*CR*	0	0	0		*CR*	0	0	1	
Chemistry		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*
	RE	37	0	0	26	*RE*	19	3	0	13	*RE*	26	5	0	1	*RE*	5	7	2	22
	UN	0	44	4		*UN*	2	37	0		*UN*	3	41	2		*UN*	1	38	2	
	AP	0	4	22		*AP*	0	3	31		*AP*	1	1	19		*AP*	0	0	22	
	AN	0	7	0		*AN*	0	21	6		*AN*	0	3	8		*AN*	0	5	2	
	EV	0	15	0		*EV*	0	3	0		*EV*	0	0	0		*EV*	0	0	0	
	CR	0	0	0		*CR*	0	2	0		*CR*	0	3	13		*CR*	0	0	1	
Geography		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*
	RE	14	0	0	21	*RE*	29	1	5	15	*RE*	14	3	0	12	*RE*	4	3	0	22
	UN	0	7	10		*UN*	0	33	8		*UN*	0	59	6		*UN*	0	24	1	
	AP	3	3	14		*AP*	0	12	13		*AP*	0	4	6		*AP*	2	16	2	
	AN	0	34	0		*AN*	0	17	4		*AN*	0	9	1		*AN*	0	20	1	
	EV	0	24	0		*EV*	0	0	0		*EV*	0	4	0		*EV*	0	11	0	
	CR	0	0	3		*CR*	0	1	1		*CR*	0	0	4		*CR*	0	1	0	
Geology		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*
	RE	0	0	0	17	*RE*	36	0	0	18	*RE*	33	0	0	0	*RE*	0	10	0	20
	UN	0	67	17		*UN*	0	36	9		*UN*	0	100	0		*UN*	0	50	0	
	AP	0	0	0		*AP*	0	36	9		*AP*	0	0	0		*AP*	0	0	0	
	AN	0	33	0		*AN*	0	0	0		*AN*	0	0	0		*AN*	0	0	0	
	EV	0	0	0		*EV*	0	0	0		*EV*	0	0	0		*EV*	0	0	10	
	CR	0	0	0		*CR*	0	0	0		*CR*	0	0	0		*CR*	0	0	0	
Mathematics		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*
	RE	0	0	0	7	*RE*	0	0	0	9	*RE*	0	0	0	0	*RE*	4	8	4	2
	UN	0	17	3		*UN*	3	29	6		*UN*	0	8	3		*UN*	2	13	2	
	AP	3	3	52		*AP*	3	3	74		*AP*	0	11	75		*AP*	0	3	65	
	AN	0	3	14		*AN*	0	0	0		*AN*	0	0	5		*AN*	0	0	5	
	EV	0	3	3		*EV*	0	0	0		*EV*	0	0	0		*EV*	0	1	1	
	CR	0	10	7		*CR*	0	0	6		*CR*	0	0	0		*CR*	0	0	6	
Physics		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*		*F*	*C*	*P*	*M*
	RE	0	0	0	7	*RE*	31	5	0	0	*RE*	11	14	0	0	*RE*	12	9	1	1
	UN	0	17	0		*UN*	12	61	26		*UN*	1	45	3		*UN*	4	34	3	
	AP	0	41	38		*AP*	0	1	20		*AP*	0	4	13		*AP*	1	4	17	
	AN	0	21	3		*AN*	0	0	8		*AN*	0	5	11		*AN*	0	6	13	
	EV	0	0	0		*EV*	0	2	0		*EV*	0	0	2		*EV*	0	1	0	
	CR	0	0	3		*CR*	0	7	2		*CR*	0	0	7		*CR*	0	0	3	

Perspective of types of knowledge

The graphs in Figure 1 show the percentage of learning outcomes requiring a specific type of knowledge within each subject, regardless of the level of required cognitive process.

In all science disciplines, across the countries compared in this study, Conceptual knowledge was the most frequently required type of knowledge, accounting for more than 50% of learning outcomes. In mathematics, Procedural knowledge prevailed (ca. 80%) in all four countries. Procedurally oriented outcomes are also quite frequent in chemistry and physics curricula (usually found in 30% of outcomes and more) and the least frequent in biology. Factual knowledge is only sporadically required in more than 30% of outcomes, namely in biology, in PLC, in chemistry, in CZC, and in physics, in ESTC; in mathematics, Factual knowledge is virtually not required at all. Metacognitive knowledge is generally the least emphasized in the learning outcomes of PLC and almost absent (< 10% of learning outcomes) from the mathematics and physics curricula of all four countries.

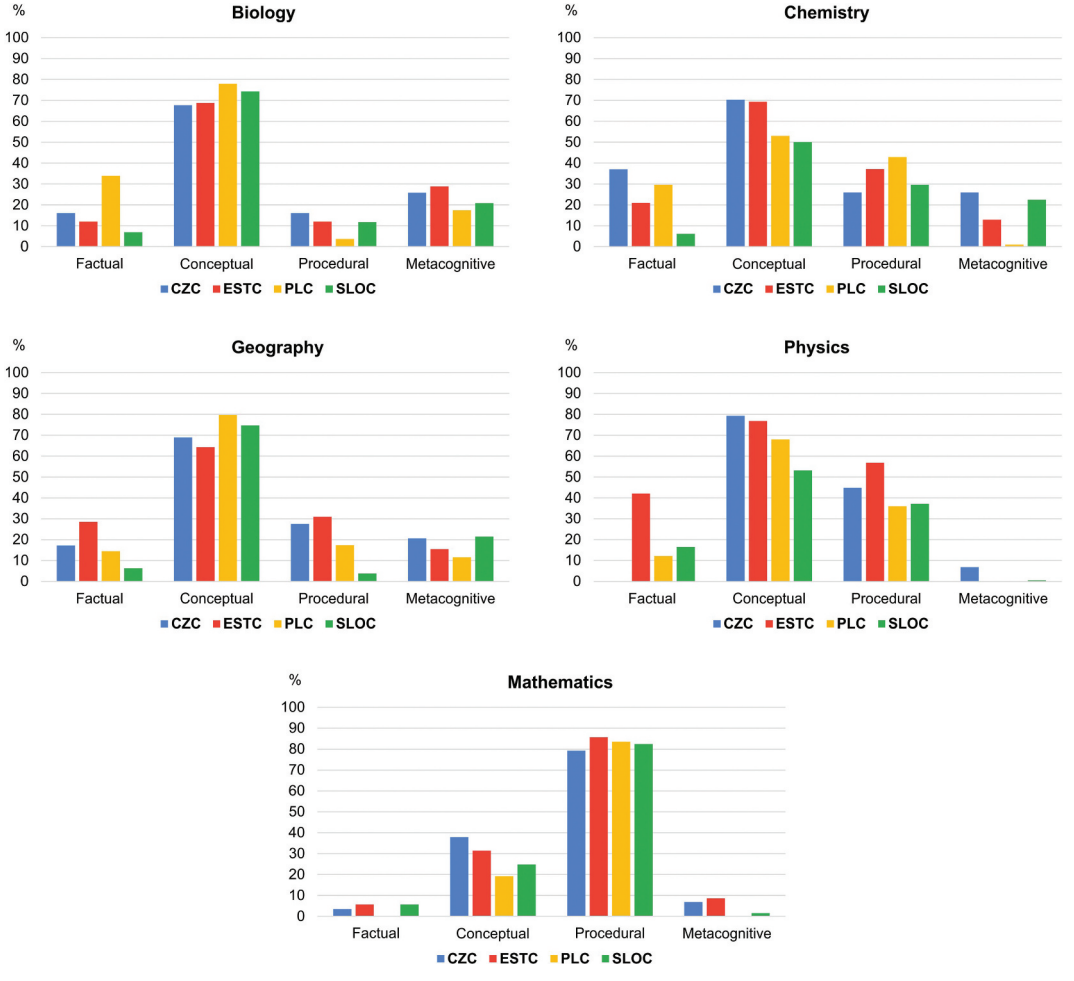

Figure 1. Percentages of learning outcomes requiring different types of knowledge.

Perspective of cognitive processes

The graphs of Figure 2 show the percentages of learning outcomes with specific cognitive processes. Complex outcomes containing the same cognitive process several times (e.g. requiring both Conceptual and Procedural knowledge at the Understand level) were included only once in the graphs.

The two highest levels of cognitive processes, i.e. Evaluate and Create, are very rare (< 10%, most often even < 5% of learning outcomes) across subjects and countries. In science disciplines, the level Understand prevails, except in CZC, where Apply and Analyse are the most frequent levels in physics and geography, respectively. Notably, the numbers of outcomes requiring the level Apply in biology is generally very low.

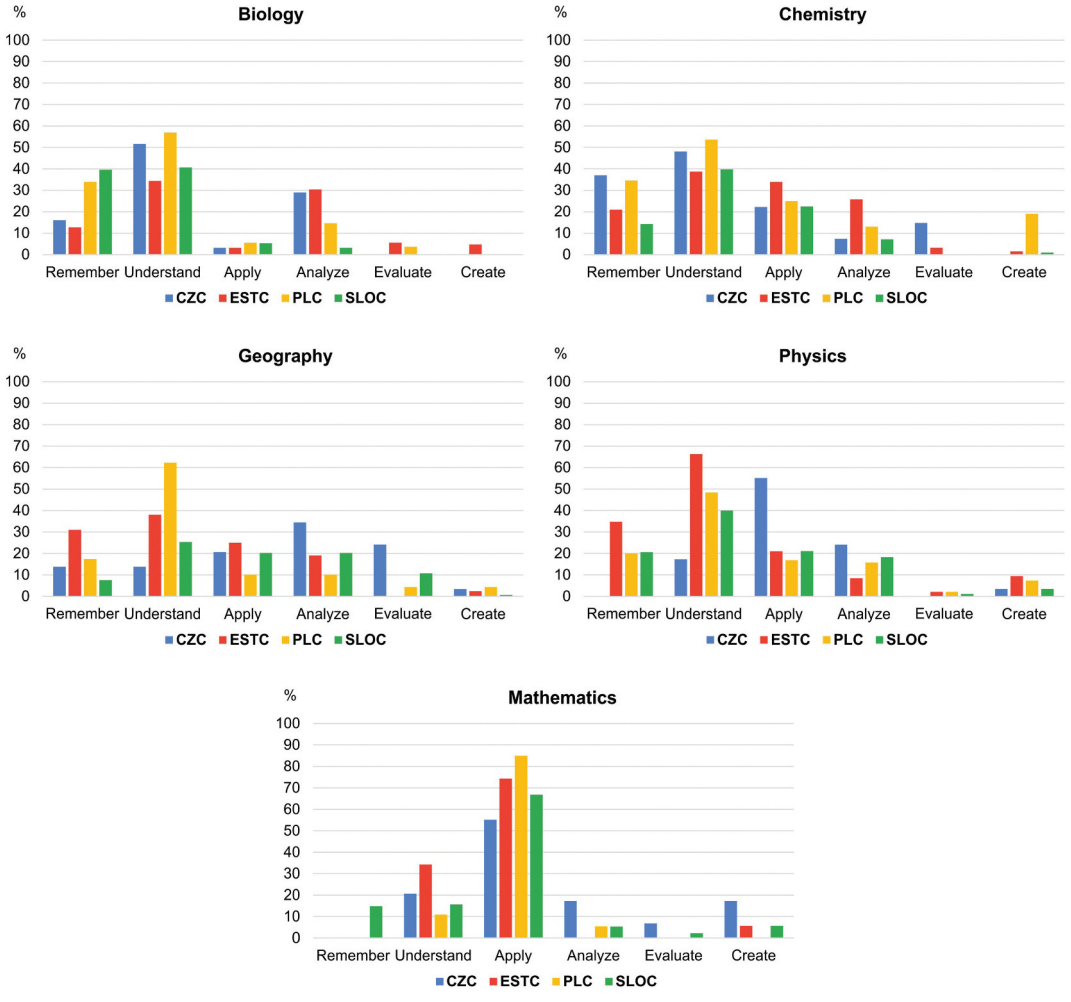

Figure 2. Percentages of learning outcomes requiring specific cognitive processes.

Specific qualitative features of the curriculum documents

In addition to the quantitative approach used in RBT, we selected some qualitative characteristics of the national curriculum documents, again focusing on obligatory learning outcomes. However, many relevant requirements are contained in the general sections of the national curricula (e.g. common characteristics of specific subjects or educational areas). Therefore, in the next paragraphs, we will also address these aspects of the intended curricula.

The most specific aspects of science disciplines are experimenting and practical work. In some subjects, ESTC, PLC and SLOC apply the concept of prescribed experiments that pupils should or must perform, listing these experiments. All three curricula require that pupils conduct experiments in physics, ESTC and PLC require performing experiments in chemistry as well, and PLC recommends them in biology. In biology and chemistry, SLOC also emphasizes more general experimental skills (e.g. '*know how to select and use appropriate tools and technology to conduct experiments*'). ESTC lists learning outcomes, often followed by *Practical work and use of ICT*, a section containing brief tips on how to incorporate experiments/ICT into the current topic. ESTC and PLC also encourage pupils to plan experiments (biology in Estonia and physics and chemistry in Poland) or to formulate hypotheses and expectations (biology and physics in Estonia and physics in Poland). In contrast to the national curriculum documents of other countries, CZC does not specify experiments (except for three measurements mentioned in physics and one pH measurement in chemistry), although experimental work is mentioned within the educational area *Humans and Nature*.

Currently, science subjects and mathematics curriculum documents require working with data, either collected during experiments or retrieved from external sources. Yet, in ESTC and PLC, only a few outcomes inherently encourage pupils to work with data (biology and physics in ESTC and mathematics and physics in PLC), such as recording, processing and interpreting data. In SLOC, this emphasis on working with data is stronger: all subjects, except geology, include learning outcomes focused on processing and analysing data from different sources or observations. CZC only explicitly mentions work with geographical data.

Digital competence is one of the seven Key Competences for Lifelong Learning defined by the European Parliament and the Council (2006). Presently, being digitally competent means having competences in all areas defined by The European Digital Competence Framework, also known as DigComp (Vuorikari et al., 2016). Yet, none of the learning outcomes of all countries analysed in this study target the development of digital competence in this sense of DigComp. For this reason, we also assessed whether the learning outcomes promote at least the use of ICT among pupils. Across countries and subjects, we found that only approximately 10–15 of all 1900 outcomes analysed in this study explicitly call for the use of ICT (personal computers, laptops and bring your own device (BYOD), among other technologies) during instruction, almost invariably in mathematics, in ESTC and SLOC. Furthermore, the extent to which the national curricula focus on ICT varies significantly across countries. In CZC, the role of ICT is mentioned in two sentences at the level of educational area *Mathematics and Its Applications*; for science subjects, a similar note is missing. In PLC and SLOC, the importance of ICT is emphasized more often and repeatedly, in passages describing general goals of specific subjects. ESTC is the most specific in offering tips in the sections *Practical work and use of ICT* that follow most thematic units into which the learning outcomes are divided in the curricula.

In the context of environmental education, field trips or work are considered powerful educational methods. However, their implementation in the national curricula varies across the selected countries. For example, in geography, field trips or work are only mentioned at the level of learning outcomes in PLC and SLOC. In CZC, field education is stated as one of seven thematic units of geography; nevertheless, the learning outcomes of this unit are formulated vaguely. Lastly, field trips or work are not mentioned in ESTC at all. Similarly, in the biology curricula of all four countries, some learning outcomes are often too general as well (e.g. environmental topics or first aid) and fail to clearly state that they aim to develop practical skills (during field trips, laboratory work, experimenting and practising).

Specifically focusing on geography, the approach to the regional geography varies significantly. CZC provides a list of the general topics that should be applied to any region. In turn, PLC divides regional geography into three parts—Poland, Europe, and the rest of the World, while ESTC focuses only on the regional geography of Estonia and Europe. Regions listed in PLC and ESTC are used as models for teaching general topics of social and physical geography. SLOC is the most detailed curriculum in terms of regional geography, mentioning all main regions of the world in individual topics reflecting specific problems and typical geographical processes.

Our analysis also showed no interdisciplinary overlaps between learning outcomes beyond the field of natural sciences and mathematics. In all countries, geography is the only subject with learning outcomes explicitly referring to social sciences (e.g. economy or sociology), which is unsurprising considering that geography lies at the border between natural and social sciences.

Finally, in all countries, we found excessively widely, even vaguely, formulated learning outcomes, as clearly observed in several subjects (physics, mathematics and geography, among others) in CZC. For example, in physics and mathematics, one fourth of the outcomes contain the phrases '*solving practical problems*' or '*solving real-life problems*'; the teachers select the problems that they address in class. In SLOC, various outcomes use the active verb 'spoznajo' which can be translated into 'know' or 'learn'. Thus, the required cognitive process is not specified. Similarly, outcomes in PLC (in physics and chemistry) frequently use the general phrasing '*use the concept of sth.*', also failing to clearly identify the cognitive process required for the corresponding learning outcome.

Discussion

Number, structure and nature of learning outcomes

Despite the lack of a general rule for the 'ideal' number of learning outcomes within national documents, some opinions prevail. Popenici and Millar (2015) indicate that an excessive number of learning outcomes can be a source of confusion for students regarding specific expectations; in turn, a minimum number of learning outcomes is necessary to ensure adequate information for a comprehensive assessment of student learning. Although the authors provide these guidelines primarily for university courses, such guidelines may also apply to national curriculum documents.

In Results, we showed that the curricula differ in the number of learning outcomes prescribed at a national level. For example, SLOC has the highest number of learning outcomes, which are however mostly simple (including one active verb). Conversely, CZC has a low number of learning outcomes across subjects, yet Czech teachers have considerably more autonomy to develop their own syllabi than their Slovenian counterparts. Hence, in addition to this number of learning outcomes, other factors, such as their complexity, must also be considered when analysing intended curricula which provide teachers with a high degree of autonomy.

In fact, the enhanced autonomy that Czech teachers are afforded also comes with its caveats. Lee et al. (2015) state that, apart from textbooks, most teachers seek guidance in the intended curriculum, and primarily novices and less experienced teachers do so; in line with this argument, Kuiper and Berkvens (2013) underscore that increasing teacher autonomy can be controversial, especially when teachers lack professional experience and expertise. Moreover, as shown in a survey conducted by the Czech Ministry of Education, Youth and Sport (MŠMT, 2019), the Czech Republic is facing a shortage of qualified teachers or even teachers as such, regardless of background. Therefore, a brief intended curriculum should be adapted to meet the needs of a specific national context by explicitly defining suitable learning outcomes (Elmas et al., 2020).

The structure of learning outcomes also differed considerably between subjects, even in the same country—in CZC and PLC, the ratio of complex learning outcomes requiring two or more types of knowledge ranges from zero to 50%, depending on subject. Focusing on the clarity of learning outcomes, Kennedy et al. (2007) recommend using only one verb per learning outcome and avoiding complicated sentences. Popenici and Millar (2015) further propose avoiding statements composed

of multiple sentences or including more active verbs in the analysis. Conversely, Kennedy et al. claim that the list of the outcomes may be too long and elaborate if the learning outcomes are very narrow, thus suggesting using more sentences to clarify learning outcomes. Hence, experts recommend using simple rather than complex learning outcomes, but this approach is not always possible. As such, balancing the complexity and the number of learning outcomes may be the most feasible strategy.

The conceptual apparatus (set of active words used in a curriculum) significantly varies by subject in all curricula compared in this study, excluding ESTC. Whether these differences within national curricula are intentional or merely reflect the lack of a common conception and agreement among curriculum builders across subjects remain unanswered questions. The latter hypothesis is supported by studies showing that expert commissions addressing curriculum changes mostly rely on the experience of their leading members, not on expertise, formal investigations, or systematic research (Westbury et al., 2016). This strong influence of renowned experts may exacerbate the fragmentation of common conceptions. Consequently, the inconsistent terminology and structure of learning outcomes across subjects can mislead and confuse teachers of more than one subject, raising concerns about whether interdisciplinary overlaps are involved in the design of curricula meaningfully and thoughtfully or only for formal reasons.

Considering these inconsistencies within the same country, the question arises as to whether the authors of intended curriculum create the documents following any taxonomy, e.g. RBT. Although this intention is not obvious, the selection of active verbs in all four curricula indicates that the RBT concepts were used to design most learning outcomes. After all, using RBT to design curriculum documents at different levels is the standard strategy in some countries, e.g. the United Kingdom (Council for the Curriculum, Examinations & Assessment, 2019; Uhlenwinkel, 2014).

Cognitive demands

As shown in Results, we found differences in cognitive demands across subjects and countries; however, they are not systematic enough to enable us to reach extensive conclusions. For example, we cannot conclude that any of the four national curricula generally demand higher or lower levels of a required type of knowledge and/or cognitive process than the other. Similarly, our data do not demonstrate that the disciplines show dramatically different cognitive demands but for two exceptions.

The first exception is mathematics, which tends to require higher types of knowledge and cognitive processes due to its focus on applications, regardless of country. The second exception is biology, whose generally formulated learning outcomes could be related to the lower frequency of Procedural knowledge, not only in the intended curricula but also in school reality. As a result of these vague formulations, some topics can be taught mostly theoretically although they offer numerous opportunities for more appropriate and relevant practical lessons (Kuba et al., 2019; Wilks & Pendergast, 2017). For instance, the topic of first aid is included in the curricula of all four countries, and even in more than one subject, albeit without detailing practical guidelines. Thus, the national curricula of these countries should recommend not only specifying the key first-aid measures (Bakke et al., 2017) but also training safety procedures and practising assessing consciousness and breathing, simulating resuscitation and calling emergency services, among other exercises (Greif et al., 2015).

Across all countries and subjects, Metacognitive knowledge is the most neglected type of knowledge in the national curricula. Moreover, mathematics and physics curricula mostly overlook Metacognitive knowledge in their learning outcomes, in all four countries, despite extensive studies on metacognition demonstrating its importance for both teaching and learning (Hartman, 2001). Georghiades (2006) further supports the notion that metacognitive activities enhance the pupils' ability to use their conceptions of science cross-contextually. Accordingly, the curriculum must be flexible to allow pupils to practice their metacognitive skills and to help teachers prepare activities

that concurrently develop metacognitive thinking, according to Braund (2017). Therefore, Metacognitive knowledge should be considered when designing learning outcomes and curriculum documents (Wei & Ou, 2019).

ICT in learning outcomes

Notes on the use of ICT are rarely included in science subjects and mathematics learning outcomes based on the findings of our study. Even when the importance of ICT is emphasized, it is done so at the level of educational areas (CZC) or subjects (PLC, SLOC). We consider the approach applied in ESTC the most appropriate because the use of ICT is advocated in most thematic units, immediately following learning outcomes. However, in line with Hennessy et al. (2005), we believe that the requirements of using ICT and developing digital competences should be formulated directly in clear guidelines of obligatory subjects specifying learning outcomes considering the field-specific evidence. Several studies have shown that curricula often fail to link digital competences inside and outside the school (Sefton-Green et al., 2009) and to reflect how everyday experiences can be challenged in school-based settings. Therefore, relevant obligatory learning outcomes should directly encourage pupils to process real-life data in spreadsheets or to use their own smart devices meaningfully (i.e. BYOD) in various ways (Hennessy et al., 2005).

The position of geoscience

During our analysis, we found differences in a few key aspects of teaching geoscience. The first aspect is the conception of regional geography, which is among the most discussed topics of school geography in post-communist European countries (Daněk, 2020; Horváth & Próbald, 2003). In the 1990s, regional geography mostly focused on the uniqueness of various regions of the world, often applying descriptive teaching methods and mainly fostering memorization learning strategies (Knecht & Hofmann, 2020; Řezníčková, 2009). The curricula analysed in this study brought about changes in approaches to regional geography, especially in the selection of the regions taught in class. Yet, based on the number of learning outcomes of these national curriculum documents, regional geography still prevails, except in CZC. CZC specifies topics of regional geography very widely and lets schools select the specific regions; nevertheless, most Czech teachers still prefer the descriptive model from the 1990s (Knecht & Hofmann, 2020). Therefore, when implementing educational reforms on regional geography, Czech schools should strike a balance between generalizations and specifics, using the concept of New Regional Geography and replacing simple descriptions of regions with regional case studies and analyses (Daněk, 2020; Knecht & Hofmann, 2020; Paasi et al., 2018).

In geology, CZC similarly interprets individual geological disciplines almost separately, paradoxically covering the widest range of geological topics (among all four countries) and yet defining the lowest number of learning outcomes. The other curricula cover a narrower scope of geological topics, directly connecting theoretical knowledge to regional examples. Thus, we deem this arrangement more appropriate because pupils receive complex information about a specific region whilst learning general geological knowledge through specific examples.

The role of geology among other science disciplines is an even more general topic. At ISCED 2, geology has been gradually less taught as a separate discipline (Lewis, 2008). More specifically, in CZC, geological topics are included in biology syllabi, while the other national curricula incorporated them, each in their own way, in geography. Including geology within other subjects subordinates the subject (Meléndez et al., 2007). The decreasing ratio of geological topics at ISCED2 raises concerns within the geology community for the substantial drop in geological contents in secondary and tertiary education (Arthurs, 2019). Consequently, such a decline will inevitably lower the number of geology students at universities and adversely affect research and knowledge on Earth (Arthurs, 2019).

Conclusions and recommendations

In this study, we analysed science subjects and mathematics national curriculum documents of the Czech Republic, Estonia, Poland and Slovenia from the perspective of obligatory learning outcomes. The most conspicuous difference among these curricula is their extent—the highly detailed SLOC has six times as many learning outcomes as the very brief CZC. A compromise must thus be reached between these two slightly extreme approaches, that is, between providing teachers with the necessary autonomy to empower them to develop their own activities and establishing clear guidelines and orientations. Moreover, research conducted in the Czech Republic (MŠMT, 2019) has revealed that schools in this country rely on a high number of non-certified teachers. For this reason, the ongoing school reform should develop a more detailed curriculum with a higher number of more specific learning outcomes to help teachers to create meaningful and applicable curriculum documents of their schools.

Within some curricula (PLC, CZC), we found clear differences in the typical structure of learning outcomes and active verbs used among subjects. These differences may indicate that, for each subject, requirements were formulated by a different group of people, according to their expertise. A closer collaboration between such groups could help to create a more uniform document with further interdisciplinarity. Ideally, learning outcomes should use a single set of semantically unambiguous active verbs across subjects to facilitate the work of teachers who teach more than one if not several of them.

Our measurement of cognitive demands using RBT found no significant systematic difference among countries. The most frequent types of knowledge are Conceptual (in science subjects) and Procedural (in mathematics). In turn, the most prevalent cognitive processes are Understand (in science subjects) and Apply (in mathematics).

Across the curricula examined in this study, the cognitive processes Evaluate and Create are underrepresented in all subjects. Since the level Evaluate has the potential to develop the critical thinking of pupils and the level Create can encourage their independence and responsibility when conducting a project, these cognitive processes must be strengthened in education reforms. In all countries, we also recommend supporting metacognition, especially in mathematics and physics, which almost completely overlook this cognitive process, by integrating it into topics such as Energy and Environment, Renewable Energy or Financial Literacy. In biology and geosciences, we recommend supporting Procedural knowledge, especially in the form of practical tasks, observation and field work.

Based on our analysis, the Czech Republic is the only country of the quartet examined in this study where geological topics are taught in biology. However, the theoretical knowledge on geology should be connected to regional examples. Therefore, we propose incorporating geological topics into geography, as in ESTC, PLC and SLOC.

Finally, we strongly recommend explicitly incorporating cross-curricular demands (e.g. using ICT, working with data and conducting experiments and practical and field work) into each subject whilst specifying learning outcomes in the new Czech curriculum. Describing these demands and their importance only in the general sections of national curricula is not enough for teachers or textbook authors to take them into account in their work. In this context, Slovenian physics and chemistry curricula, which specify the learning outcomes that should be achieved experimentally, emerge as paradigmatic examples of good educational guidelines.

Limitations of the study

Among the main limitations of our study, the research method stands out because only exploring the national curriculum documents precludes a complex examination of the educational reality in any country. The main issue overlooked in this study due to its methodological approach is how the autonomy of some schools in preparing school curriculum documents (based on national curricula)

affects learning outcomes in these school documents. In addition, the extent to which national curriculum documents influence teaching, e.g. how teachers and textbook authors follow curriculum requirements, is another key question that remains unanswered. Similarly, by analysing only obligatory learning outcomes, we are necessarily disregarding other, often general, sections of national curriculum documents, which also provide valuable information. Although we doubt that the general sections of these documents are followed as thoroughly as the specific learning outcomes, these sections should be analysed in follow-up research, for example, using latent semantic analysis. In future research, other topics should be addressed in this area—for example, given the increasing importance of the integrated Science, Technology, Engineering, and Mathematics (STEM) approach, it could be suitable to analyse the incorporation of STEM in national curricula.

In terms of the coding process, by using a feedback loop (see Methodology), we strove for a consistent approach across countries and subjects. However, for some outcomes, finding a consensus among the three coders was very difficult, thus preventing us from presenting their final decision as absolutely unambiguous. This potential source of inconsistency could be eliminated by automatic text analysis of the learning outcomes. Due to the absence of a coherent text, such an analysis may have difficulty in following the entire context of the outcomes, which is crucial for determining the level of RBT. However, it can warn of inconsistency in the coding of the same (or similar) phrases and characteristic word combinations, thus partially doing the job of our 'manual' feedback loop.

As we have already noted, even within a single country we found considerable variation in the way how intended learning outcomes are formulated across different subjects. Our experience shows that the curricula of some subjects are easier to assess than others because they more closely match the terminology and the spirit of RBT. Therefore, the applicability of RBT itself across subject-specific contexts seems to be another limiting factor of our research framework.

Finally, PLC and SLOC are not available in English and required translation. Although we cross-checked ambiguously translated terms with our foreign colleagues (native researchers) whenever necessary, we may not have avoided sporadic involuntary misinterpretations. Nevertheless, our RBT analysis was not based on isolated active words but on the whole context of the learning outcomes, thereby minimizing this study limitation.

Notwithstanding the aforementioned limitations, we believe that our results provide relevant insights and highlight clear strategies for curriculum makers to plan and prepare effective education reforms, not only in the context of the Czech education but also across cultures and education systems with overlapping issues.

Notes

1. In agreement with the terminology used in taxonomies, we exceptionally use the term *educational objective* instead of the above defined term *learning outcome* in a few following paragraphs dedicated to taxonomies.
2. '*Explain and compare the functions of the respiratory systems of different vertebrates*' contains Conceptual knowledge at both Understand ('explain') and Analyse ('compare') level, ultimately coded as Conceptual-Analyse (C-UN + C-AN = C-AN).
3. '*Read chemical equations and, employing the Law of Conservation of Mass, calculate the mass of the reactants or product*' were coded as C-UN and P-AP because of the two knowledge fields (C, P) and the higher cognitive process ('read' = C-RE, 'employing' = C-UN, 'calculate' = P-AP).
4. '*Describe Estonia's geological structure according to drawings, thematic maps and the geochronological scale*' was coded as C-AP. 'According to' in the sense of 'using' shifts the cognitive process from Understand to Apply.

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