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ORIGINAL ARTICLE

Pre-service Teachers' Preparedness for In-service Science Teaching in Primary Education – A Case Study in Croatia

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ABSTRACT

An experimental science curriculum for primary school was introduced in Croatia for the 1st time in the 2023/24 school year. This is taking place against the backdrop of a shortage of teachers from various science subjects, especially physics. They are increasingly being replaced by non-professional teachers, often those with a Master of Primary Education, which gives access to the profession of primary junior grade teacher. In this study, the subject matter knowledge (SMK) in science of 44 pre-service teachers aiming for the above-mentioned degree is examined using the SMK test. The test contains 40 trends in international mathematics and science study (TIMSS) items from the 4th-grade science content domain Physical Science and allowed us to compare the achievement of our respondents with the achievement of pupils who participated in the TIMSS assessments. The results show that the percentage correctness of the pre-service teachers on the SMK test was statistically significantly higher than that of the 4th-grade pupils. However, the correlation coefficients showed that the pre-service teachers had greater difficulties with the items with which the pupils had greater difficulties, and vice versa. This applies in particular to the items on forces and motion and to the items from the cognitive domain of reasoning. The reason for the unsatisfactory science SMK of our respondents could be the incompatibility of the university science curriculum with the demands placed on pupils in the relevant school subjects and international science assessments such as TIMSS. The results of this study confirm and extend the contribution of existing research and should serve as a basis for subsequent research as well as for the design of a further course of science education reform in Croatia and in the countries of the region.

KEY WORDS: Higher education; primary teachers; science curriculum; science learning and teaching; trends in international mathematics and science study

INTRODUCTION

The reform of science education that has taken place around the world over the past three decades is attracting the attention of scholars who are examining what pre-service or in-service teachers know or need to know to teach science effectively (van Driel et al., 2014). Some of this research (e.g., [D. Anderson and Clark, 2012; Appleton, 2006; Harlen, 1999; Hodson, 2009; Osborne and Simon, 1996]) belongs to the domain of substantive subject matter knowledge (SMK) (Abell, 2007; van Driel et al., 2014) from the natural sciences. It refers to the knowledge of general concepts, principles, and conceptual schemes related to science (Hashweh, 2005; Shulman, 1987). The aforementioned research is mainly inspired by the concern about the unsatisfactory science SMK of teachers, especially novice and primary school teachers (van Driel et al., 2014), as a basic requirement for quality teaching (van Driel et al., 2023). SMK has an impact not only on the quality of teaching (Ahn and Choi, 2004; Sanders et al., 1993a) but also on the acquisition of pedagogical knowledge by teachers (Rollnick et al., 2008), as well as on student achievements (Ahn and Choi, 2004; Chen et al., 2020; Goldhaber and Brewer, 2000). For example, teachers who are outside of subject specialism, that is, who lack science SMK, question the implementation of the science curriculum (Anderson and Clark, 2012; Lewthwaite, 2000; McGee et al., 2003). They rely mainly on textbooks, avoid interaction with students, and carry out practical work that leaves students little autonomy (Childs and McNicholl, 2007; Hashweh, 1987; Lee, 1995; van Driel et al., 2014). In this way, they make teaching rigid and unimaginative (Childs and McNicholl, 2007). Furthermore, non-professional science teachers have difficulties with (i) selecting appropriate teaching resources and activities (Childs and McNicholl, 2007; Hashweh, 1987; Nott and Smith, 1995), (ii) long-term planning, especially with regard to linking different areas of the science curriculum (Childs and McNicholl, 2007; Sanders et al., 1993b), and (iii) explaining scientific concepts, which can also have a negative impact on student motivation and learning (Childs and McNicholl, 2007). On the other hand (Childs and McNicholl, 2007), good in-depth SMK implies a deep understanding of complex scientific concepts and their valid simplification (Summers et al., 1998), as well as the ability to provide different explanations and activities in accordance with the needs of individual learners (Childs and McNicholl, 2007).

As in other countries, Croatia is promoting science education at all levels of education after joining the EU to increase the number of students in STEM programs and improve performance in national and international science tests. This is supported by the emphasis on science in human capital development in the Education, Science, and Technology Strategy (Hrvatski sabor [Croatian Parliament], 2014), which dates back to 2014. However, the results are still unsatisfactory, which can be illustrated by the example of physics education. Interest in studying and pursuing a career in physics education is in fact continuously declining in Croatia (Erceg et al., 2022; 2023). This inevitably leads to the questionable quality of physics teaching in primary and secondary schools, that is, to the poor grades of students in the state school-leaving examination in physics (Ministarstvo znanosti, obrazovanja i mladih RH [Ministry of Science and Education of Croatia], 2024), but also to the below-average results of Croatian students in the Program for International Student Assessment (PISA), which assesses students' knowledge and skills in the natural sciences (Ščurić, 2023). Slightly better results in science at an international level are achieved by Croatian pupils in the 4th-grade of primary school who take part in the trends in international mathematics and science study (TIMSS), which is based on the content of the national curriculum. Although these results are above average, they are far below the results of the top-ranked countries such as Korea and Japan (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2024).

The recent application of the experimental science curriculum for primary school, which was implemented for the 1st time in Croatia (Ministarstvo znanosti, obrazovanja i mladih RH [Ministry of Science and Education of Croatia], 2023b), speaks for the promotion of science education. The above-mentioned curriculum was approved by the Croatian Ministry of Science and Education (CMSE) in 2023 as part of the curriculum of the experimental program "Primary school as a full-day school – balanced, fair, efficient, and sustainable system of upbringing and education" in the school year 2023/24. In it, science is described as a subject based on the understanding of basic science, including physics, chemistry, biology, physical geography, and geology, with the main objective of developing science literacy (Ministarstvo znanosti, obrazovanja i mladih RH [Ministry of Science and Education of Croatia], 2023a). The science curriculum is organized into three macro-concepts (Organization of Nature, Processes and Interactions, and Energy) that integrate several key concepts for the acquisition of basic knowledge and skills and for the formation of attitudes in science during the 6 years of learning. The CMSE selected 64 primary schools to participate in the experimental program for students in grades one through eight for a period of four school years (Ministarstvo znanosti, obrazovanja i mladih RH [Ministry of Science and Education of Croatia], 2023d), based on a public call for primary schools to submit applications to participate in the experimental program (Ministarstvo znanosti, obrazovanja i mladih RH [Ministry of Science and Education of Croatia], 2023c). In the 1st year of the program's implementation, science was taught in the 1st and 5th grades of primary school (Ministarstvo znanosti, obrazovanja i mladih RH [Ministry of Science and Education of Croatia], 2023c). Science lessons were held by primary junior grade teachers in year 1 and by subject-specific teachers in year 5. The subject-specific teachers mentioned included those with a Master of Primary Education, which allows access to the profession of primary junior grade teacher, but not to the profession of subject-specific teacher. In addition, none of the subject-specific teachers had a degree in physics, which corresponds to the situation in other countries where only a small number of graduate chemists and physicists choose the teaching profession (Kind and Kind, 2011; Moor et al., 2006) so that science lessons are taught by biologists (Moor et al., 2006).

The above statements lead to the expectation that pre-service primary junior grade teachers, as potential teachers of science subjects in primary school, will acquire the relevant SMK as part of their study programs. However, when reviewing the science curricula at four Croatian faculties that train future primary junior grade teachers, we found that the TIMSS content domains (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2024) are not covered, especially with regard to Physical Science. Furthermore, the mentioned university curricula are not aligned with the experimental science curriculum for primary school in Croatia. Hence, the question arises: What is the SMK of these pre-service teachers in relation to content that is not part of the science courses at university and that they must teach their future students and prepare them for international examinations such as TIMSS? The search for an answer to this question implies an insight into the corresponding SMK, with which it is possible to assess the preparation of prospective teachers for in-service teaching (Abell, 2007; Deng, 2007; van Driel et al., 2014). In accordance with this and with the described context, which indicates that pre-service primary junior grade teachers are potential teachers of science and even physics (Erceg et al., 2022) in Croatian primary schools, we defined the following research question: What is the science SMK in the domain of Physical Science among Croatian pre-service primary junior grade teachers compared to the corresponding knowledge of primary school pupils?

LITERATURE REVIEW

The problem of inadequate SMK in science begins in initial teacher education (Leite et al., 2007; Waldron et al., 2007), which is supported by the results of numerous studies on the SMK of pre-service and in-service science teachers. Related to their difficulties in understanding science concepts, Shen et al. (2007) observed K-8 science teachers to have difficulties related to current electricity, and Trundle et al. (2006) found pre-service elementary teachers to have deficits in knowledge of the observable phases of the moon and the pattern of monthly phase changes. According to the research findings of Taber and Tan (2011), graduate pre-service teachers have alternative conceptions about ionization energy that are also common among high school students, while Kariotoglou et al. (2009)

found alternative conceptions about the interactions of distant forces among primary school and preschool student teachers. Cheung et al. (2009) found misconceptions about the effects of adding more reactants or products on chemical equilibrium in a sample of high school chemistry teachers, and Patrick and Tunnicliffe (2010) observed difficulties in understanding the internal structures of the human body in a sample of science teachers. In addition, prospective teachers have been found to have misconceptions about global warming (Bozdogan et al., 2011) and many pre-service and in-service elementary teachers do not have an adequate understanding of concepts related to climate change (Dove, 1996; Hayhoe et al., 2011; Michail et al., 2007; Papadimitriou, 2004; Summers et al., 2000). Kind and Kind (2011) found that although the pre-service science teachers in their study, which included biology, chemistry and physics specialists, were considered academically well qualified to teach science, they had misconceptions about basic chemical ideas taught to 11–16-year-olds, such as particle theory, change of state, conservation of mass, chemical bonding, mole calculations and combustion reactions.

A prerequisite for understanding concepts is the ability to define them correctly (Galili and Lehavi, 2006), but here too there are problems. For example, Galili and Lehavi (2006) found that high school physics teachers have limited ability to define physics concepts. Science vocabulary knowledge also plays a role in understanding science concepts (Carrier, 2013). However, Carrier (2013) found that despite successfully completing a science program in high school and college, pre-service teachers' initial knowledge of elementary science vocabulary was inadequate. In addition, science teachers do not have sufficient conceptual knowledge of science processes (Emereole, 2009), and the knowledge of scientific models and modeling of prospective physics, mathematics and engineering teachers after the 4- or 5-year degree diploma is still rather poor and confused (Danusso et al., 2010).

The results of the study by Burgoon et al. show how persistent the teachers' misconceptions are and how similar they are to those of the students (Burgoon et al., 2010). According to this study, even after three decades of research on misconceptions, elementary science teachers still have similar misconceptions as students about gravity, magnetism, gases and temperature. Papageorgiou et al. (2013) found that primary school teachers have a number of misconceptions about the chemical changes of substances that are similar to those of students. There are also studies showing that there are similar conceptual difficulties between pre-service and in-service teachers. Such similarity was found, for example, by (Leite et al., 2007), who compared student-teachers' and in-service teachers' explanations of liquid-state phenomena and concluded that science education seems to have limited influence on their conceptions.

Prospective teachers are expected to acquire the science SMK they will teach as part of their science courses at faculties (Grossman et al., 1989). However, there are findings (Anderson et al., 1990; Barenthien et al., 2020; Davidowitz and Potgieter, 2016; Diamond et al., 2014; Gess-Newsome, 1999; Gess-Newsome and Lederman, 1995; Jordan et al., 2018; Nixon et al., 2017; 2019; Nowicki et al., 2013; Smith et al., 2022; Stoddart et al., 1993) that indicate that university science courses do not build teachers' SMK. This is particularly true for primary school science teachers, who often complete only one or two science courses in the faculty (National Academies of Sciences, Engineering, and Medicine [NASEM], 2015). These courses are more likely "random collection" than a deliberate combination of contents (Anderson and Mitchener, 1994). On the other hand, there are findings according to which pre-service high school science teachers attend more university science courses than pre-service primary school science teachers and achieve better results in SMK tests (Großschedl et al., 2015; Mthethwa-Kunene et al., 2015; Nixon et al., 2016; Nixon and Swain, 2024; Schiering et al., 2021; Sorge et al., 2019). These inconsistencies indicate insufficient research on the effects of university science courses on teachers' SMK (Nixon and Swain, 2024; van Driel et al., 2023; Wilson et al., 2001), which is particularly problematic considering that these courses are the only formal opportunity for many prospective science teachers to acquire science SMK (Nixon and Swain, 2024).

METHODOLOGY

Through an exploratory case study (Cohen et al., 2017), we conducted a research on the substantive SMK in the science domain of Physical Science among Croatian pre-service teachers who are preparing to become primary junior grade teachers and are potential subject-specific teachers of science and even physics in Croatian primary schools. This study can be considered as mixed research with an emphasis on the quantitative approach (Ary et al., 2013; Johnson, 2014). As a matter of fact, in addition to the statistical analysis of the numerical data, we used our participants' answers to the open-ended questions to further deepen, extend, and clarify the results of our research. The following subsections contain descriptions of the sample, the data sources, the analyses performed, and the limitations of the study. In these subsections, we have described the selected materials and methods in detail and explained their suitability for the context of the study, giving specific examples, relevant references, and limitations. In this way, we have shown how the methodology aligns with our research question: What is the science SMK in the domain of Physical Science among Croatian pre-service primary junior grade teachers compared to the corresponding knowledge of primary school pupils?

Participants

A total of n = 44 pre-service teachers voluntarily participated in the study, which represents 36% of the total population of university students who attended the 3rd, 4th, or 5th year of the integrated undergraduate and graduate teacher education study program at the Faculty of Humanities and Social Sciences, University of Split, Croatia, in the academic year 2023/2024. This program leads to the title of Master of Primary Education, which gives access to the profession of primary junior grade teacher. The sample included 18 pre-service teachers from the 3rd year, 19 from the 4th year, and 7 from the 5th year. All of them have completed the compulsory course Natural Science, and the participants from the 4th and 5th year have passed it. In accordance with (Sveučilište u Splitu, Filozofski fakultet [University of Split, Faculty of Humanities and Social Sciences], 2015), the course is taught in the summer semester of the 3rd year by the same lecturers and assistant and according to the same syllabus. It consists of 30 h of lectures, 30 h of seminars, and 15 h of laboratory exercises and is worth 6 ECTS. The aim is to master the basics of natural science content, to learn about the basic laws of life, the structure of living beings, and their connection to nature, with the aim of developing general and specific competencies for high-quality work in the teaching process and application in everyday life. The sample consisted of 2% male and 98% female respondents. The majority of respondents (68%) have a high school diploma, while the remaining 32% have a vocational school diploma. The respondents who voluntarily agreed to participate in the study were informed about the purpose, nature, and procedure of the study and their right to privacy was guaranteed in accordance with the authorization granted by the Ethics Committee.

Data Sources

We measured the substantive SMK of our respondents using the SMK test, which consists of 40 items used in TIMSS research and taken from the collection of test items for 4th-grade primary school pupils from 2011, 2015, and 2019 TIMSS cycles (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2022) in which Croatian pupils participated. Since we focused on the examination of the science SMK from the Physical Science 4th-grade content domain, we included all 40 items from the collection (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2022) that relate to the mentioned domain in the test. Each item also belongs to one of the three cognitive domains: Knowing, applying, and reasoning. These domains encompass the range of cognitive processes involved in learning science concepts and then applying these concepts and reasoning with them (Centurino and Jones, 2019). SMK test numbers (TN) of items and the corresponding original item numbers (IN) are listed in Table 1. An example of such an item is shown in Table 2, including all the data listed with it: IN, year/cycle, TIMSS fundamental subject, content domain, main topic, cognitive domain, item label, maximum points, correct response, percent correct statistics for the item, that is, the percentage of pupils who could answer the question correctly in group of all TIMSS examination participants (TIMSS correctness), and in group of Croatian TIMSS examination participants (Cro TIMSS correctness).

The assessment items included in the SMK test were rigorously developed and previously validated by the TIMSS and PIRLS International Study Center and the National Research Coordinators. This validation process ensures that the assessment items reliably measure the science knowledge of pupils in different countries. Therefore, we can assume that the reliability of the SMK test items for pre-service teachers is also ensured, that is, that the SMK items are accurate, aligned with primary school concepts and as such require the use of our respondents' SMK to answer correctly. The reliability of the SMK test was examined on a sample of pre-service teachers. We obtained a Cronbach's alpha of 0.848, indicating good internal consistency and reliability of the test items, meaning that they consistently measure the same construct.

Respondents completed the SMK test using the paper-and-pencil method, and in the introductory part of the test, they were also asked to provide the following information: Personal identification number, gender, completed secondary school, name of the study program they are attending, year of the study program they are currently attending, and grade of the science course if they passed it. They solved the SMK test under the supervision of the co-author of the article.

Analysis

We coded pre-service teachers' scores to obtain numerical data comparable to 4th-grade primary students' scores on the TIMSS assessment in the year in which they performed best. Coding was done according to the instructions in (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2022), that is, "1" point was assigned to answers that were completely correct, and "0" points were assigned to answers that were non-existent, incorrect, incomplete, or partially correct. The item with the number 16

Table 1: SMK test numbers (TN) of items and the corresponding TIMSS item numbers (IN) taken from the collection (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2022)

TN	1	2	3	4	5	6	7	8	9	10
IN	S031068	S031418	S031371	S051086	S041049	S041060	S031410	S031421	S041187	S04104
TN	11	12	13	14	15	16	17	18	19	20
IN	S031204	S041052	S051105	S041191	S041050	S061142A S061142B	S031197Z	S051119	S041120	S031298
TN	21	22	23	24	25	26	27	28	29	30
IN	S031076	S051179	S051074	S041311	S041067	S031077	S041069	S031273	S031299	S051121
TN	31	32	33	34	35	36	37	38	39	40
IN	SE71128	S041305	S051071	S041117	S031311	S041119	S041077	S061081	S051147	SE71147

SMK: Subject matter knowledge, TIMSS: Trends in international mathematics and science study

Table 2: Item with the SMK test number 4, which corresponds to the TIMSS item number S051086 in the collection (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2022)

Item number	S051086
Year/cycle	2011
TIMSS fundamental subject	Science
Content domain	Physical science
Main topic	Classification and properties of matter
Cognitive domain	Knowing
Item label	Temperature of ice, steam, water
Maximum points	1
Correct response	A
TIMSS correctness	73%
Cro TIMSS correctness	87%
Water, ice, and steam all have different temperatures. What is the order from coldest to hottest?	
A. ice, water, steam	
B. ice, steam, water	
C. steam, ice, water	
D. steam, water, ice	

SMK: Subject matter knowledge, TIMSS: Trends in international mathematics and science study

in the SMK test is the only one that was scored with a total of 2 points. Therefore, each of its two parts 16a (S061142A) and 16b (S061142B) was considered as a separate item and the responses to it were coded in the manner described above. Consequently, the total number of items in the data analysis was n = 41. For each item, a statistic of percentage correctness was calculated, that is, the percentage of pre-service teachers who solved the item correctly in their entire group (n = 44).

Using the IBM SPSS Statistics v29 program for data analysis, we investigated the statistical significance of the difference in the percentage correctness of the items obtained by the pre-service teachers who solved the SMK test compared to the pupils who solved the same items in the TIMSS research using the nonparametric Mann–Whitney test. This is consistent with the fact that our respondents' data did not fit the normality assumption. The percentage correctness of the SMK test items was a continuous dependent variable, and the categorical independent variable consisted of two categories. In the first case, these categories were represented by groups of pre-service teachers and all TIMSS examination pupils, and in the second case by groups of pre-service teachers and Croatian TIMSS examination pupils. We also examined the correlation of the percentage correctness of the SMK test items between the different groups mentioned. Pearson's correlation coefficients were calculated when the data fit the necessary assumptions of linearity and homogeneity.

Limitations

The limitation of this study arises from the fact that the results come from a relatively small sample of pre-service teachers from a single university. This calls into question the possibility of generalizability of the results of our exploratory case study, which, in line with Yin (2009), should be investigated in future research. Indeed, Yin (2009) points out that an exploratory case study can be used as a pilot study for other studies or research questions, that is, it can be used to generate hypotheses that are tested in larger-scale surveys, experiments, or other forms of research. On the other hand, there is the benefit that all participants were taught by the same teachers who had the same access to university science coursework. In any case, the data met the requirements of the statistical tests. Furthermore, taking into account the fact that the university students did not benefit directly from participating in the SMK test, their turnout of 36% was good compared to, for example, the average turnout of Croatian citizens in EU elections of <30%, with the lack of voter interest also cited as one of the reasons for poor turnout (European Economic and and Social Committee, 2023).

The limitation of this study is also the possibility of the influence of additional factors on success in solving the SMK test, such as the grades of students in the university science course and secondary school graduates with different science curricula. We were unable to analyze the influence of these factors due to the insufficient number of respondents belonging to the respective groups. However, this does not affect our ability to answer the research question.

RESULTS

Figures 1-3 show the results obtained by our respondents, that is, the pre-service primary junior grade teachers from the University of Split, in the SMK test, compared to the results obtained by all pupils and only Croatian pupils in the TIMSS assessments. For the sake of clarity, the results are grouped according to the TIMSS framework. There are three main topics: Classification and Properties of Matter (Figure 1), Sources and Effects of Energy (Figure 2), and Forces and Motion (Figure 3), which are part of the Physical Science content domain in TIMSS Fundamental Subject Science. The items within each group are divided into three cognitive domains: Knowing, Applying, and Reasoning.

The Mann–Whitney test shows a statistically significant difference with a large effect size (Cohen, 1988) in the percentage correctness of the SMK test items achieved by the pre-service teachers, that is, our respondents ($Md = 84$, n = 41), compared to (i) all pupils who solved the same items in the TIMSS assessment ($Md = 49$, n = 41), $U_1 = 356$, $z_1 = -4.496$, $p_1 < 0.001$, $r_1 = 0.5$, and (ii) only Croatian pupils who participated in the TIMSS assessment ($Md = 51$, $n = 41$), $U_2 = 399.5$, $z_2 = -4.092$, $p_2 < 0.001$. In addition, Pearson correlation coefficients show a strong (Cohen, 1988) positive and statistically significant correlation between the percentage correctness of SMK test items achieved by pre-service teachers and (i) all pupils ($r = 0.763$, $p < 0.001$) and (ii) Croatian pupils ($r = 0.688$, $p < 0.001$), who participated in the TIMSS assessments.

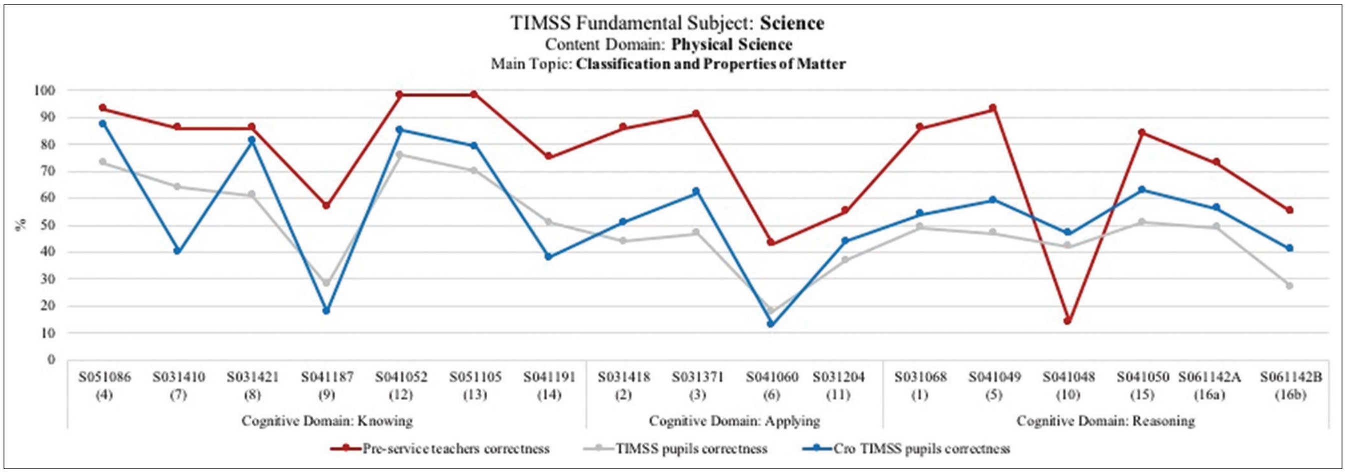

Figure 1: Percentage correctness of SMK test items by our respondents (Pre-service teachers correctness) compared to the percentage correctness achieved in the TIMSS assessments by all pupils (TIMSS pupils correctness) and by Croatian pupils only (Cro TIMSS pupils correctness). The items test three cognitive domains (Knowing, Applying and Reasoning) and relate to the main topic Classification and Properties of Matter from the Physical Science content domain in TIMSS fundamental subject Science. The SMK test numbers in brackets are linked to the original TIMSS item numbers. SMK: Subject matter knowledge, TIMSS: Trends in international mathematics and science study

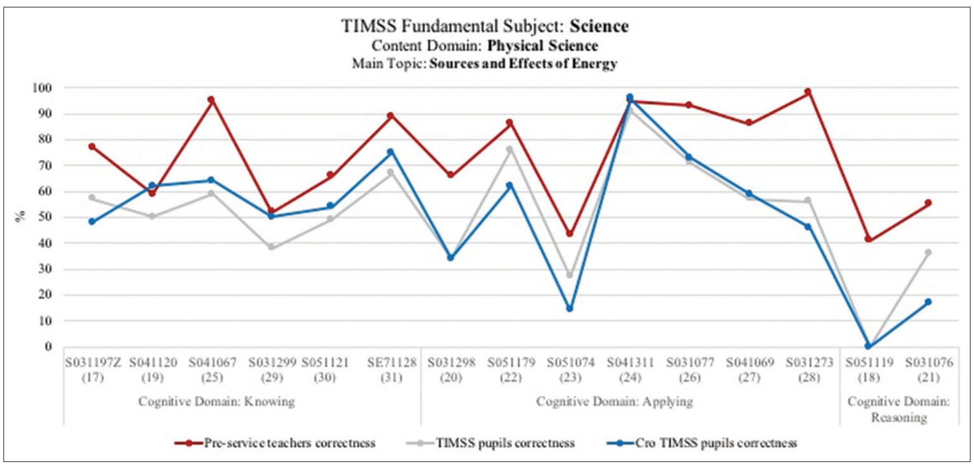

Figure 2: Percentage correctness of SMK test items by our respondents (Pre-service teachers correctness) compared to the percentage correctness achieved in the TIMSS assessments by all pupils (TIMSS pupils correctness) and by Croatian pupils only (Cro TIMSS pupils correctness). The items test three cognitive domains (Knowing, Applying and Reasoning) and relate to the main topic Sources and Effects of Energy from the Physical Science content domain in TIMSS fundamental subject Science. The SMK test numbers in brackets are linked to the original TIMSS item numbers. SMK: Subject matter knowledge, TIMSS: Trends in international mathematics and science study

DISCUSSION

The respondents in this study had limited knowledge or incorrect ideas about the science topics investigated. Although the percentage correctness of the SMK test items is statistically significantly better than the pupils, there is a strong positive correlation of that percentage correctness between the respondents and the pupils who participated in the TIMSS assessment. This indicates that pre-service teachers had more difficulty solving the items that pupils also had difficulty solving, that is, they were better at solving the items that pupils were also better at solving. This is consistent with the findings that primary and secondary science teachers often have misconceptions about science that are very similar to the misconceptions of their students (Knight, 2004; Özcan and Koştur, 2019; Wandersee et al., 1994).

Looking at the main topics, the respondents had the greatest difficulty with the topic of forces and motion (Figure 3), which is consistent with the results of the study (Kikas, 2004; Narjaikaew, 2013). Within this topic, their percentage correctness was below the median percentage correctness (84%) in five out of a total of nine tasks. Looking at the cognitive domains within the Forces and Motion topic, the percentage correctness was below the median in all reasoning tasks, in half of the applying tasks and in a third of the knowing tasks. In addition, the correctness (41%) of the knowing item 39 was even below the median correctness of the pupils (49% for the TIMSS student group and 51% for the Croatian student group). In this task, the name of the force, that is, the gravitational force that moves the ball when it rolls down an inclined path, was to be written down. As many as 15 university

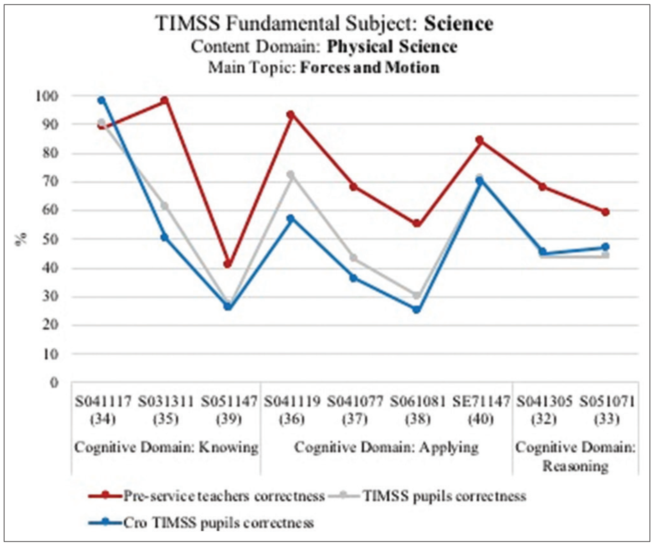

Figure 3: Percentage correctness of SMK test items by our respondents (Pre-service teachers correctness) compared to the percentage correctness achieved in the TIMSS assessments by all pupils (TIMSS pupils correctness) and by Croatian pupils only (Cro TIMSS pupils correctness). The items test three cognitive domains (Knowing, Applying and Reasoning) and relate to the main topic Forces and Motion from the Physical Science content domain in TIMSS fundamental subject Science. The SMK test numbers in brackets are linked to the original TIMSS item numbers. SMK: Subject matter knowledge, TIMSS: Trends in international mathematics and science study

students gave no answer, and the incorrect answers ranged from the very general answer "force of motion," which provided no information about the nature of the force, to "frictional force," which cannot move the ball, and to the term "acceleration" or "energy," which were incorrectly equated with the concept of force. Such responses from prospective primary junior grade teachers are not surprising considering that even university physics students have difficulties with free-body diagrams of motion on an inclined plane (Aviani et al., 2015). The item that caused the greatest difficulties for our respondents in the applying domain was 38 with a percentage correctness of 55%. In this item, knowledge about the repulsion of the same magnetic poles had to be applied to the example of pushing a toy car away. However, the incorrect answers were based on the contrary assumption that the opposite poles of two magnets repel each other. In addition, one respondent stated that "we do not have a magnet in the letter N on the bar," indicating that he did not recognize the mark of the north pole of the magnet. The item with the lowest percentage correctness (59%) in the reasoning domain was 33. In this item, respondents were asked to deduce, based on their knowledge of the law of levers, where on the seesaw (lever) children with different weight ratios (in two cases) must sit to be balanced. The most frequent wrong answer was the one in which the person with twice the weight sat at the very end of the seesaw, while the person with the lower weight sat on the other side of the seesaw near the fulcrum. It is surprising that the university students in this example were not even guided by their own childhood experiences, from which they could conclude that the seating arrangement of two people on a seesaw should be such that the person with twice the weight sits halfway to the fulcrum so that the seesaw is balanced. In addition, respondents who chose the wrong answer showed no understanding of the elementary school physics concept according to which a lever is in balance when the product of the lever arm (the distance from the fulcrum of the seesaw to the child's seat) and force (the child's weight) is equal on both sides of the lever.

In the main topic Sources and Effects of Energy (Figure 2), the percentage correctness of the respondents was below the median in 8 out of a total of 15 tasks. As with the previous topic, the percentage correctness was below the median for all tasks in the reasoning domain. This included task 18, whose correctness (41%) was even below the median percentage correctness of the pupils. Like the previously mentioned task 38, it belongs to the area of magnetism and tests the understanding of the concept of the magnetic field. Specifically, in item 18, the conclusion had to be drawn on the basis of the experiment described that a pin can be attracted by the stronger magnet from a greater distance. However, as many as 16 respondents gave no explanation for the chosen answer, and among the incorrect answers were those which claimed, for example, that (i) a magnet that attracts a pin from a shorter distance is stronger, (ii) a magnet that attracts a pin from a shorter distance is greater (although the magnets shown were the same size), (iii) the stronger magnet is the one that attracts the pin faster (although the speed of attraction was not mentioned in the item), and (iv) the smaller the magnets are, the stronger they are, regardless of the distance from which they attract the pin. These findings are not surprising considering that engineering and physical science students also have misconceptions about the magnetic field (Guisasola et al., 2004). For example, Guisasola et al., in 2004, found that most students could not identify the source of the magnetic field and confused magnetic force and magnetic field. In item 23, which tested the application of knowledge, the percentage correctness (43%) was also below the median of the pupils. It showed a simple open circuit from which it could be concluded that the bulb does not light because the circuit is incomplete. A relatively large number of respondents, namely, 20, again gave no explanation. On the other hand, there were those who mistakenly believed that the bulb would light because "everything is well connected" or that "there is no negative charge" because the battery only has a mark for the positive terminal. Like our respondents, pre-service and high school physics teachers also have alternative ideas about simple circuits (Küçüközer and Demirci, 2008), for example, about the "source of stationary current," the "use of current," "the concept of current, energy, and potential differences is used incorrectly" and the like. In the cognitive domain knowing, there were four out of a total of six items whose percentage correctness was below the median value for the pupils. The worst performing item was 29, in which respondents were asked to name one thing they had seen which shows that sunlight is made up of light in different colors. Most respondents named the rainbow, but there were also those who named "sunset," "glass," "sky," and "mirror" and the like as incorrect examples. Such answers are to be expected to some extent, since pre-service physics teachers have misconceptions about the concept of light, including the concept of refraction (Sri Astika Wahyuni et al., 2019).

The university students solved the items in the main topic Classification and Properties of Matter the best, although they had percentage correctness below the median in seven out of a total of 17 items. Among these, 2 items (10 and 6) stand out with a correctness of 14% and 43%, respectively, which is also below the correctness of the pupils' median. Item 10 belongs to the cognitive domain reasoning, where half of the tasks (i.e., 3 out of 6) had a correctness below the pupils' median. It tested the understanding of the concept of density. Specifically, the example described in the item should have led to the conclusion that objects with a larger volume do not necessarily weigh more or are more massive, as this depends on their density. Respondents arrived at most answers through naïve reasoning based on real-life examples without providing satisfactory explanations. However, since we tested the SMK in science for the 4th-grade of primary school, we also considered the correct answers in which density was not explicitly mentioned, but the property of the material was emphasized as an important factor in the reasoning. An example of such an answer is: "I don't agree that an object that has a larger volume weighs more. It depends on the material the object is made of and the filling of the object, as there may be cavities inside." Some respondents incorrectly stated that weight and volume are not interdependent and that objects with a higher density weigh more, which is in line with research findings (Esprivalo Harrell and Subramaniam, 2014). Furthermore, one respondent wrote down the correct formula for density, but misinterpreted it as follows: "Mass and volume are inversely proportional. The greater the mass, the smaller the volume and vice versa, because density = mass/volume." Item 6 belongs to the applying domain, which also includes half (i.e., two out of four) of the items with a percentage correctness below the median value of the pupils. The ability to apply the concept of the spatial expansion of gas to the example described in the task is tested. Similar to the previously mentioned questions, where an explanation for the chosen answer was requested, a relatively large number of respondents (i.e., 18) did not provide it. Among the incorrect answers were some that referred to liquid rather than gas, indicating a superficial reading of the item by respondents. Furthermore, some pre-service teachers mistakenly believe that the gas only spreads in one part of the space and tends to go downward. They probably overestimate the influence of the gravitational interaction between the gas and the Earth, which is consistent with the results of the study (Erceg et al., 2016). In the group of items from the knowing domain, there were two out of seven items with a correctness below the pupils' median, and 8 (57%) had a lower percentage correctness between them. In contrast to all of the previously discussed low correctness items that examined physics concepts, item 8 belongs to chemistry. It tests the ability to distinguish materials that can burn (wood and gasoline) from materials that cannot burn (water, sand, and air). Among the incorrect answers were 5 that included air as a flammable material (in addition to wood and gasoline) and one that omitted gasoline as a flammable material.

One of the reasons for the better percentage correctness of the items on the topic of classification and properties of matter compared to the other two topics from the content domain Physical Science in the TIMSS fundamental subject Science could be a discrepancy between the content of the university course Natural Science and the content of the SMK test. It follows that university students do not acquire the appropriate theoretical content of science that they need as future teachers. For example, in the curriculum of the natural science course (Sveučilište u Splitu, Filozofski fakultet [University of Split, Faculty of Humanities and Social Sciences], 2015), which was completed by our respondents, there is content from biology and chemistry relating to the topic of classification and properties of matter. However, content from physics is completely missing in the list of lecture titles, while in the list of seminar titles, there is only one on the topic of sources and effects of energy. Even among the titles of the laboratory exercises, there is no title that refers to forces and motion. On the other hand, according to the TIMSS framework for assessing science with an emphasis on physical science (Nacionalni centar za vanjsko vrednovanje obrazovanja [National Center for External Evaluation of Education], 2020), 4th-grade pupils are expected to have a basic understanding of the physical states of matter (solid, liquid, and gas) and how matter changes from one state to another. At this level, pupils should also know the basic sources and effects of energy and their applications and understand the basic concepts related to light, sound, electricity, and magnetism. In the context of forces and motion, the focus is on understanding the relationship between force and motion through examples that pupils can observe, such as the effects of gravity or repulsion and attraction.

The distinction identified in this study between school curriculum content and academic curriculum content in the discourse on teachers' specialized SMK is not an isolated case, but is supported by many studies (Deng, 2001, 2007; Kind, 2009; Morris and Hiebert, 2017; Munby et al., 2000). Nevertheless, it is often neglected (Deng, 2007), although theoretical concepts are an extremely important tool for decision-making and process design in science teaching (Van Driel et al., 2005; 2008). It should be noted that in addition to the studies that show the influence of university science courses on teachers' SMK (e.g., [Großschedl et al., 2015; Nixon and Swain, 2024; Sorge et al., 2019]), there are also those that do not (e.g., [Barenthien et al., 2020; Nixon and Swain, 2024; Smith et al., 2022]). In any case, the consequences of teachers' inadequate SMK in science are formidable (Burgoon et al., 2010). Such teachers cannot be expected to teach students effectively and help them reconstruct their science conceptions. They cannot recognize and address the misconceptions that their students bring to the classroom if they themselves have an inaccurate or incomplete understanding of science concepts.

CONCLUSION

Since joining the EU, Croatia has promoted science education to increase the number of students in STEM programs and improve performance in national and international science tests. However, the reform of science education was introduced for the 1st time in the 2023/24 school year in Croatian primary school with the application of the experimental science curriculum. This is happening in the conditions of a shortage of teachers for various science subjects, especially for work in primary school. Therefore, they are largely replaced by non-professional teachers, among whom there are often those with a Master of Primary Education, which gives access to the profession of primary junior grade teacher.

This study, therefore, poses the question of how the science SMK of Croatian pre-service primary junior grade teachers, as potential primary school teachers in science subjects, compares with the corresponding knowledge of primary school students. The topicality of this question also arises from the fact that the science curricula of universities in Croatia do not match the requirements placed on students in the context of school subjects and international science tests such as TIMSS. This discrepancy mainly concerns content from the domain of Physical Science, which is why the focus of this study is precisely on them.

We conducted an exploratory case study on a sample of 44 students of the integrated undergraduate and graduate teacher education program in the academic year 2023/2024 at the Faculty of Humanities and Social Sciences, University of Split, who completed the Natural Science course. We measured their substantive SMK using the SMK test, which consists of 40 TIMSS items from the Physical Science domain, and fulfills the conditions of validity and reliability. Using the nonparametric Mann–Whitney test, we tested the statistical significance of the difference in the percentage correctness of the items scored by the pre-service teachers who solved the SMK test compared to the pupils who solved the same items in the TIMSS tests. We analyzed the correlation between this correctness using Pearson correlation coefficients.

We found a statistically significant difference with a large effect size in the percentage correctness of SMK test items achieved by our respondents compared to all pupils and to Croatian pupils who solved the same items in the TIMSS assessments. We also found a strong positive and statistically significant correlation between the percentage correctness of SMK test items solved by pre-service teachers and pupils. In other words, although the correctness of the SMK test was statistically significantly better for our respondents than for the pupils, the Pearson correlation coefficients indicate that pre-service teachers had more difficulty solving the items that pupils also had difficulty solving and vice versa. In this sense, the items on the topic of forces and motion stand out, as the percentage correctness in this topic was below the median for most items. In one task, the correctness was even below the median value of the pupils, although it tested the lowest level of knowledge, that is, knowing. Looking at the cognitive domains, the greatest difficulties in each topic were found in the items that tested the highest level of knowledge, that is, reasoning.

The reason for the unsatisfactory science SMK of our respondents could be the fact that they did not have the opportunity to learn the relevant content in the science course at the faculty, which is an integral part of the SMK test and which they need to know as future teachers. Therefore, the results of this study will serve as a basis for further research aimed at generalizing the conclusions and determining the influence of additional factors on success in solving the SMK test. In addition, our findings, as well as the findings of similar studies, will be of great importance for shaping education policy in Croatia and in the countries of the region, especially when it comes to the design and development of programs to strengthen the science SMK of pre-service and in-service science teachers.

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