

Article

Who Teaches Physics in Croatian Elementary Schools?

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Abstract: The shortage of physics teachers is a global and persistent problem, resulting in the employment of nonprofessionals who cannot teach physics in a student-centered, high-quality and effective manner. This situation has implications for the educational policies of governments, universities, and schools. The aim of this study is to identify whether there is a shortage of elementary school physics teachers in Croatia. This type of survey was conducted for the first time in the country. Based on the online survey, we asked elementary school principals how many employees they have working as physics teachers in their schools and the type of education of these teachers. A total of 260 principals responded to the survey, representing 25% of the total population of elementary school principals in Croatia, where physics is taught according to the regular program in the 2020/2021 school year. The respondents did not mention the availability of physics teacher vacancies in their schools. However, they mentioned the engagement of nonprofessional substitute physics teachers accounting for 14% of all physics teaching positions in schools that participated in our study. Among the nonprofessional substitutes, most were from the social-humanities field. Differences in the representation of nonprofessional physics teachers by county were also found, indicating different causes of physics teacher shortages in different geographic areas. The survey results provide a basis for future policy decisions that can lead to better results in resolving the issue of physics teacher shortages in Croatia and beyond.

Keywords: physics education; physics teacher shortage; elementary school physics teachers



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1. Introduction

Concerns about declining student interest in physics [1–3], continuing an education in physics [1,3–5], and professional development in the field [1] raises questions about the general quality and effectiveness of school physics teachers [6–12]. Motivation for learning physics and student achievement in the field depend directly on these teachers. Therefore, the question is whether physics teachers working in schools are sufficiently trained to encourage and develop student interest in learning physics [13–15].

Seeking an answer to this question leads us to the global shortage of physics teachers, which is closely related to a teacher shortage in other science subjects (i.e., biology and chemistry) and mathematics [1,16–25]. The relevant literature provides evidence that since the 1940s [20], this situation has been a permanent problem [26] that only attracts the attention of politicians when reaching crisis levels [20,25]. The problem associated with the teacher shortage in physics and school science is evident in numerous studies and reports by governments and professional associations in countries such as Australia [27–30], the United Kingdom [16,26,31–33], the United States [20], and South Africa [21]. Although the shortage of physics teachers is a worldwide problem that is addressed in different ways in countries relying on the results of studies conducted by relevant institutions, the situation in Croatia is completely different. This has been no study of this kind in the past in Croatia, even though the problem of a shortage of physics teachers has existed for decades. Political measures have been implemented unsuccessfully on the principle of “trial and error”,

which has led to the fact that the survival of the physics profession in Croatia is seriously in question and that the shortage of physics teachers, which has existed for years, has led to poor knowledge of physics among elementary school students (see recent newspaper on this issue [34]).

The shortage of physics teachers can be defined in various ways. For example, according to Sparkes [11], there are four types of shortages: (i) overt shortage, when there is no teacher available to give a physics class; (ii) hidden shortage (permitted by law), when the physics class is held by a teacher not qualified to teach it; (iii) suppressed shortage when physics is unrepresented in the subject timetable due to a lack of suitable teachers; and (iv) contextual shortage when no (physics-qualified) substitute can be provided for a physics teacher who is absent for health reasons or similar grounds.

Even in rare cases where a sufficient number of physics, science, and mathematics teachers with graduate degrees are available for teaching openings in the respective fields, a significant number of experienced professionals end up leaving teaching physics for other, more lucrative careers (e.g., in the industry) [20,21] or other areas of teaching [21,25,33,35]. There is also the problem of employed teachers lacking sufficient professional training for the subjects they teach [36,37].

Therefore, in the absence of professional teachers, many students (especially at lower levels of education) are taught physics by nonprofessional teachers from other fields who do not have an adequate degree, certification or training to teach physics [2,26,38–40]. In England, for example, 18% of physics teaching in the 1990s was conducted by teachers who had no higher education in physics [11], and science was taught by teachers who did not have to be physicists [41]. In some U.S. states in the 1960s, many physics teachers, in addition to having a degree in biology, also had degrees in other fields such as business and the arts [20]. In the 1980s, teachers in the United States were legally permitted to teach in fields for which they were not certified. Nonprofessional physics teachers lack the relevant (scientific and pedagogical) knowledge base, meaning they cannot provide quality and effective student-centered physics instruction [38]. Therefore, creating hidden shortages by transforming nonprofessional substitute teachers into “professional” substitute teachers based on legislative procedures further deepens physics teacher shortages [25]. This approach hampers student interest in learning physics and also negatively affects future career choices in the science, technology, engineering, and mathematics (STEM) fields [42]. It creates a self-perpetuating cycle [11,27] given that better-qualified physics teachers definitely provide better physics instruction in schools. These better-qualified teachers encourage greater student interest in learning physics, greater numbers of physics students, and increases the number of potential physics teachers in the future.

1.1. Number of Physics Education Graduates versus Physics Teaching Vacancies in Croatia

The number of physics education graduates and physics teaching vacancies in Croatia is worrying (Figure 1). Publicly available data from the Croatian Employment Service (CES) [43] and data from universities in Croatia training physics teachers, such as the Faculty of Science at the University of Zagreb, Faculty of Science at the University of Split, Faculty of Physics at the University of Rijeka, and the Department of Physics at the Josip Juraj Strossmayer University in Osijek, indicate that the number of vacancies in the seven years between 2014 and 2020 was 8–12 times higher than the number of physics education graduates. Hence the question remains: *Who teaches physics in Croatian schools?*

Importantly, the number of physics education graduates (Figure 1) is insufficient for estimating the number of future physics teachers, i.e., the physics teacher shortage in Croatia (in terms of total physics teacher openings). New graduates represent only a fraction of the potential teachers [44]. Some physics education graduates go on to other (nonteaching) jobs in the labor market [25]. For example, Rumberger’s research [25] shows that the number of graduate physics teachers interested in working in schools increases as their salary increases. On the other hand, engineers with relevant qualifications receive additional training to teach in schools, in line with the relevant legal acts (see Section 1.2.).

Potential teachers are also those who have graduated from physics but who do not work in schools.

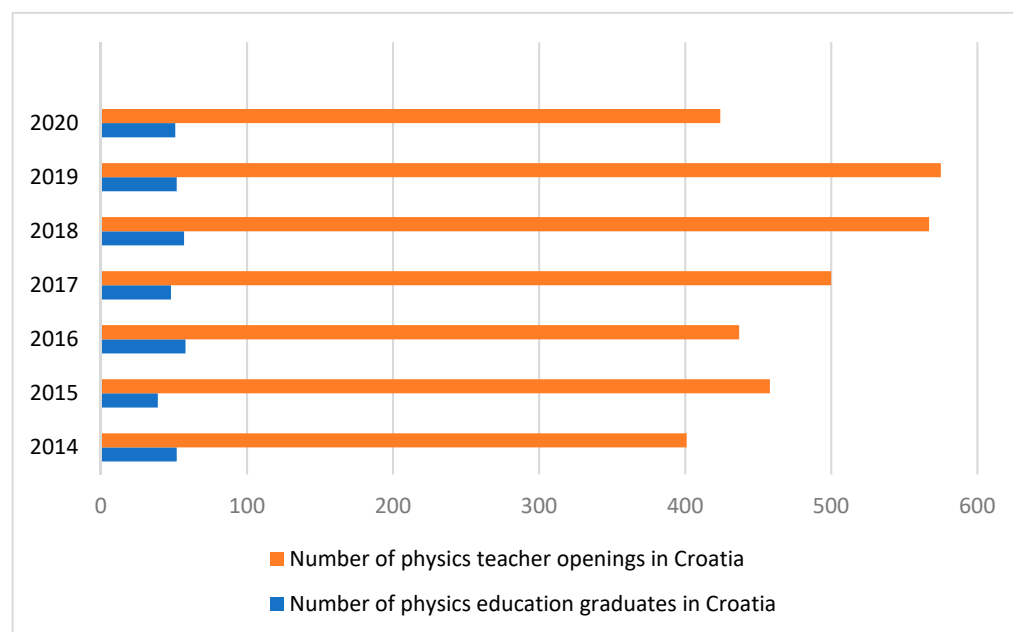


Figure 1. Comparison of the number of physics teacher openings and the number of physics education graduates in Croatia from 2014 to 2020.

The number of openings shown in Figure 1 indicates the total number of physics teachers requested by school principals during the respective year [43]. However, it is unclear whether the openings are unfilled and/or unprofessionally filled and the possible types of unprofessional replacements. Therefore, we sent a request to the CES to clarify the publicly available number of openings. They answered that the information belongs to the employer's business and is their responsibility. In other words, the CES has no record of the kind of positions the employer fills using the submitted application for labor needs, because according to the Labor Market Act [45], employers make autonomous decisions on job advertisements, working conditions and selecting candidates for vacancies. Moreover, the CES is obliged to be impartial towards employers and the unemployed and has no possibility of determining the recruitment procedure.

When asked “*who teaches physics in Croatian elementary schools*”, we did not receive an answer from the Ministry of Science and Education nor the Institute for Social Research, while the Education and Teacher Training Agency and the Croatian Bureau of Statistics do not have this information. Therefore, we conducted an online survey among elementary school principals in Croatia to obtain detailed information on the quantity and type of training their staff employed as physics teachers received. The aim of the study is to identify the current shortage of physics teachers in elementary schools in Croatia in order to monitor future trends while identifying the causes and taking appropriate measures to address the shortages [46]. In other words, we aim to make a concrete contribution to fundamental educational policy decisions undertaken by the government, universities, and schools that would lead to better results in resolving the problem of physics teacher shortages in Croatia and beyond.

1.2. Definition of (Non)Professional Physics Teachers

There are various definitions of (non)professional teachers in terms of certification and qualifications. According to Rumberger [25], upon receiving approval from the appropriate state institutions and bodies, only then is a teacher certified to teach a particular subject. The criteria for obtaining this approval vary by country and change over time. For example,

Levin [20] argued in the 1980s that the minimum criterion for teaching physics in the United States should be an undergraduate degree in physics, whereas, in some U.S. states, it was possible to obtain a certificate to teach any science subject after passing only a few courses in each science subject [20]. Moreover, in the 1940s and 1950s (before the Russian launch of the Sputnik satellite in 1957), physics was taught in some high schools in the U.S. by teachers, very few of whom had majored in physics, and there were also those who had not taken any college physics courses.

In Croatia, the Regulation on the Appropriate Type of Education of Teachers and Professional Associates in Elementary School is currently in force [47], according to which a physics teacher must have completed: (a) a graduate program in physics (teaching-oriented, and lasting two years after a specific undergraduate degree) or integrated undergraduate and graduate program in physics (teaching-oriented and lasting five years) or an undergraduate program in physics (teaching-oriented and lasting four years); (b) a graduate program in physics (research-oriented and lasting two years after a specific undergraduate degree) or integrated undergraduate and graduate program in physics (research-oriented and lasting five years) or an undergraduate program in physics (research-oriented and lasting four years) or a program in another field attributed at least 55 ECTS credits (European Credit Transfer and Accumulation System) in physics; or (c) an undergraduate program in physics (lasting three years). Those who have completed a research-oriented program or a three-year undergraduate program in physics must acquire further pedagogical-psychological-didactic-methodical education in line with the Act on Education in Elementary and Secondary Schools [48]. Recognition of at least 55 ECTS credits in physics is carried out by the university at which the corresponding teaching-oriented program is conducted, according to the Amended Regulation on the Appropriate Type of Education of Teachers and Professional Associates in Elementary Schools [49]. Importantly, pedagogical-psychological-didactic-methodical education is provided at some universities without involving physics education. This approach is in contrast to the requirements imposed on, for example, Australian science teachers by the heads of school science departments. These requirements imply a high level of discipline-specific science knowledge, which is as important as knowledge in teaching science, with implications for university policies and curricula [27].

The term qualified teacher is problematic and has no specific definition. It refers to a teacher with the appropriate qualifications. Qualifications in Croatia are any academic degree (diploma or formal certification) awarded by a competent registered body confirming successful completion of a study program. It covers a wide range of academic degrees earned at higher education institutions across different levels and in different countries (e.g., bachelor's and master's degrees, doctorates.). It also indicates the level of competencies and the range of knowledge and skills. A qualification can be the equivalent of a license and is often synonymous with a credential (according to the glossary of the Agency for Science and Higher Education). On the other hand, Rumberger believes that a qualified teacher has, in addition to a diploma, the requisite abilities distinguishing him or her as a good teacher, and who continuously undergoes teaching training [25]. Unlike teachers with adequate knowledge in physics who are able to prepare and implement instructional activities to achieve learning outcomes at a higher cognitive level, thus increasing a student's chances of success and academic achievement [38,50,51], unprofessional teachers facilitate the adoption of learning outcomes by heavily utilizing memory and textbooks [52]. While Rumberger's definition of a qualified teacher is beneficial in assessing the shortage in physics teachers, as it allows a more detailed analysis of teacher expertise, it is problematic because no existing evidence has been able to measure teacher shortages in this way [25]. For example, some studies indicate that teaching-oriented students are less able than other students [25,53,54], even though ability seems to be an important component of teacher performance. However, it remains unclear whether this reasoning applies to science and mathematics teachers because perhaps their abilities are generally better than those of other teachers [25].

In the context of this study (see Table 1), professional physics teachers in elementary schools are those teachers who are certified according to the Regulation on the Appropriate Type of Education of Teachers and Professional Associates in Elementary Schools, i.e., those who have adequate education in physics and pedagogical-psychological-didactic-methodical competences. We consider nonprofessional physics teachers those who are not certified (lack an adequate physics education), or who are conditionally certified (have an adequate physics education but lack pedagogical-psychological-didactic-methodical competences, which they must acquire within the given time limit).

Table 1. Professional and nonprofessional physics teachers.

		Adequate Physics Education	Pedagogical-Psychological- Didactic-Methodical Competences
professional physics teachers	certified	+	+
	conditionally certified	+	-
nonprofessional physics teachers	not certified	-	+
		-	-

2. Materials and Methods

This study presents the physics teacher shortage in terms of the number of unfilled positions and positions filled by nonprofessional substitutes, with respect to the total number of physics teaching positions in Croatian elementary schools participating in the study [20,25]. We also analyzed the structure of nonprofessional substitutes according to the type of their education and the shortage of elementary school physics teachers by county.

A nonprofessional teacher is deemed to be a person employed as a physics teacher but without the appropriate education according to the Regulation on the Appropriate Type of Education of Teachers and Professional Associates in Elementary Schools [47] (see the Section 1.2).

Given that data on physics teachers were unavailable or missing at the Ministry of Science and Education, the Education and Teacher Training Agency, the Croatian Bureau of Statistics, and the Institute for Social Research, we used an online descriptive cross-sectional survey [55] as a data source for 2021. We applied the questionnaire (see Appendix A) to a sample of principals of elementary schools in Croatia where physics is taught.

2.1. Questionnaire

The questionnaire consisted of seven items. Item 1 refers to the personal identification code, and the next two items (Item 2 and 3) are demographic items with a choice of options. Item 4 seeks the total number of physics teachers at each school. This is also implicitly included in Item 5, in which the total number of teachers are to be assigned according to appropriate qualifications and pedagogical-psychological-didactic-methodical competencies in the attached table. Item 6 specified the qualifications that were classified under “Other” in the table. Respondents were able to provide additional comments in Item 7 of the questionnaire.

The two demographic items were used to describe the sample of respondents, while Item 2 was additionally used to show the percentage of nonprofessional substitutes by county, relative to the total number of physics teachers at participating elementary schools in the corresponding county. In evaluating Items 4–7, a distinction was made between professionals and nonprofessionals (Items 4 and 5), while nonprofessionals were classified based on the qualifications listed in the answers to Items 6 and 7. Analysis of nonprofessional substitutes by field was made in line with the Regulation on Scientific and Artistic Fields, Areas and Branches [56].

The content validity of the questionnaire has been ensured by including four professionals from universities. They confirmed that the questionnaire contains items which are necessary to obtain information on the number and type of education of elementary school staff employed as physics teachers. They also confirmed that contents, wording, and length of items are appropriate for the sample being targeted, i.e., school principals.

We sent an invitation to participate in the survey to the principals of all Croatian elementary schools running a regular program where physics was taught in the 2020/2021 school year. That is a total of 1025 elementary schools covering 7th and 8th grades. The list of these schools along with email addresses can be found on the website [57] of the Ministry of Science and Education. The survey was open for 30 days, from 15 April to 15 May 2021.

The reliability of the questionnaire has been ensured by including a member of the Education and Teacher Training Agency Board as a co-author of the paper. The Education and Teacher Training Agency is directly superior to the schools, and mentioned co-author, as an official on behalf of that agency, invited principals to participate in the survey. They did so voluntarily in order to help solve the physics teacher shortage problem. School principals hire teachers based on appropriate evidence of education in accordance with regulations (see the Sections 1.2 and 4).

2.2. Sample

A total of 260 principals participated in the survey, representing 25.37% of all principals of elementary schools in Croatia where physics is taught. This sample represents a random sample of the relevant population with a confidence level of 95% and a confidence interval of 5.25%. Taking into account that each principal represents a single elementary school, Figure 2 shows the percentage of elementary schools that participated in the survey, by county, in relation to the total number of elementary schools with a regular physics curriculum in the 2020/2021 school year in corresponding counties. Elementary schools from all counties participated in the survey, with the highest response in Karlovac County and the lowest in Krapina-Zagorje County.

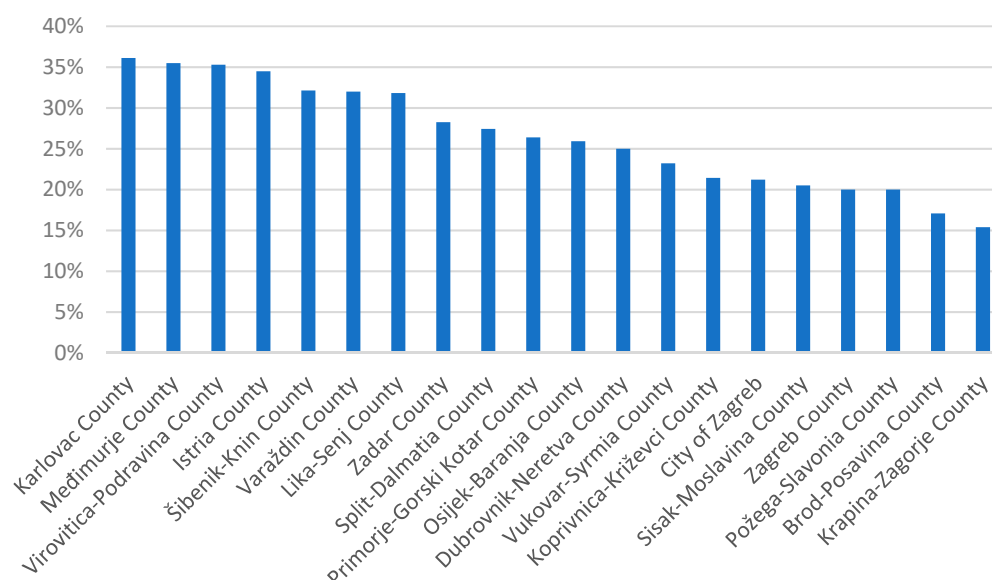


Figure 2. The percentage of elementary schools that participated in the survey, by county, relative to the total number of elementary schools with a regular physics curriculum in the 2020/2021 school year in the corresponding county.

Figure 3 shows the distribution of the number of elementary schools that participated in the survey by the size of the settlement expressed by the number of inhabitants. There is a tendency for principals from smaller settlements to respond more frequently.

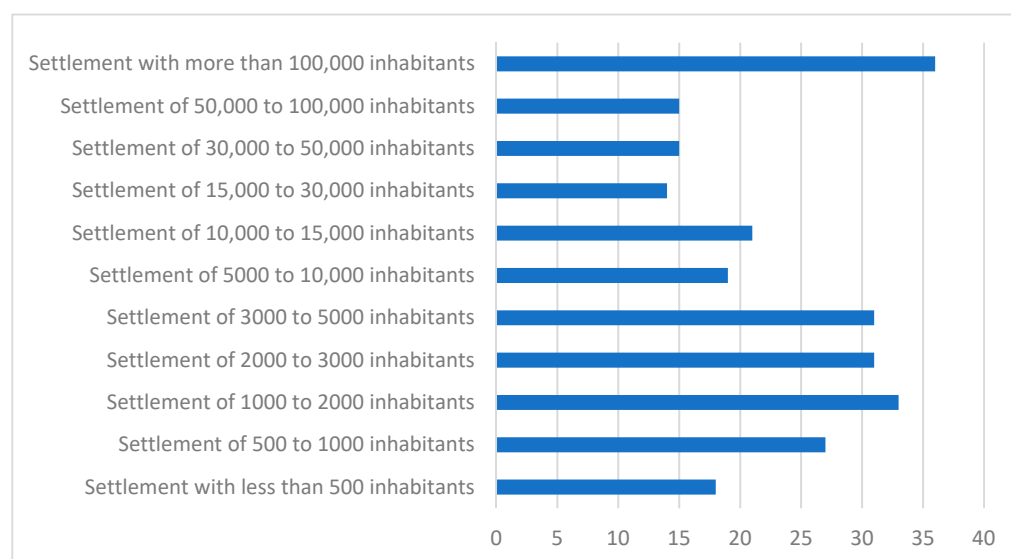


Figure 3. Distribution of the number of elementary schools that participated in the survey by the size of the settlement.

3. Results

Principals who participated in the survey did not report any vacancies for physics teachers in their schools. However, they reported the presence of 45 substitute nonprofessional physics teachers, representing 14.25% of the total ($N = 315.75$) physics teacher positions in the schools that participated in the study. The total number of the mentioned positions is 315.75, with 313 teachers employed full-time and six teachers employed part-time (five were employed on half working time and one was employed on quarter working time). The number $N = 315.75$ covers 45.11% of the total population ($N = 700$) of physics teachers in Croatian elementary schools. The mentioned total number ($N = 700$) of positions for physics teachers in elementary schools in Croatia was obtained upon gaining insight into the system of the Education and Teacher Training Agency, where Croatian teachers apply for in-service training meetings.

All teachers reported as nonprofessional substitutes fall into the “not certified” category (see Table 1, Figures 4 and 5), i.e., they lack an adequate physics education (PE (-)). Among nonprofessional substitutes, regular teachers, i.e., 1st-4th grade elementary school teachers (mag. prim. educ., $N = 10$), are the most represented, followed by mechanical engineers (mag. ing. mech., $N = 4$) and electrical engineers (univ. bacc. ing. el., $N = 4$) (Figure 4). The advantage of regular teachers over engineers is that they have pedagogical-psychological-didactic-methodical competencies (PPDMC (+)). However, overall, there is a higher number of nonprofessional substitutes ($N = 25$) who have neither an adequate physics education (PE (-)) nor pedagogical-psychological-didactic-methodical competencies (PPDMC (-)). The qualification titles of the nonprofessional teachers were taken from the responses of the principals listed in the survey. Abbreviations have been assigned to them according to official documents [58–60].

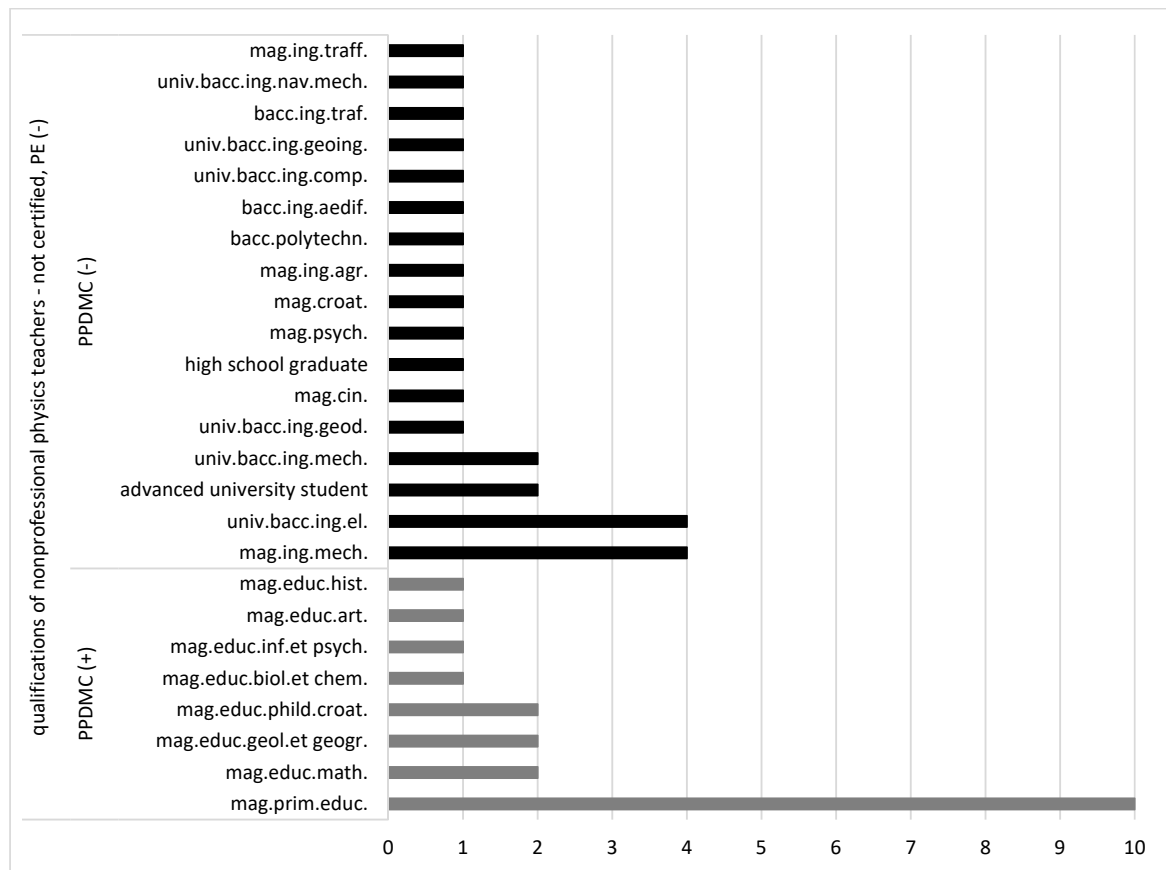


Figure 4. Number of corresponding nonprofessional qualifications of persons employed as physics teachers in the schools that participated in the survey. All nonprofessional substitutes with the appropriate qualifications fall into the “not certified” category (see Table 1). These nonprofessional substitutes lack an adequate physics education (PE (-)). They are divided into those with and those without pedagogical-psychological-didactic-methodical competencies (PPDMC (+) and PPDMC (-)).

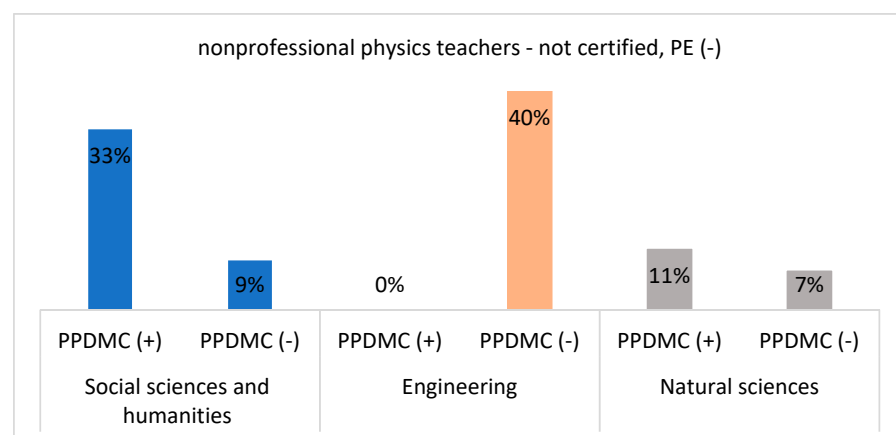


Figure 5. Percentage of nonprofessional substitutes by field (social sciences and humanities, engineering, or natural sciences) relative to the total number of nonprofessional substitutes in physics teacher working positions in schools that participated in the survey. All nonprofessional substitutes fall into the “not certified” category (see Table 1), i.e., lack an adequate physics education (PE (-)). Within each field, they are further divided into those with and those without pedagogical-psychological-didactic-methodical competencies (PPDMC (+) and PPDMC (-)).

In terms of the field (Figure 5), the largest percentage of nonprofessional substitutes in physics teacher working positions comes from the social sciences and humanities (42%), followed by engineering (40%), with the smallest proportion coming from the natural sciences (18%). Figure 5 also shows that most nonprofessional substitutes (40%) who do not have either an adequate physics education (PE (-)) or pedagogical-psychological-didactic-methodical competencies (PPDMC (-)) have engineering qualifications.

The percentage of nonprofessional substitutes, by county, relative to the total number of physics teachers in participating schools in the corresponding county, is highest in Lika-Senj and Dubrovnik-Neretva counties. In contrast, in six counties, there are no nonprofessional substitutes in schools that participated in the survey (Figure 6).

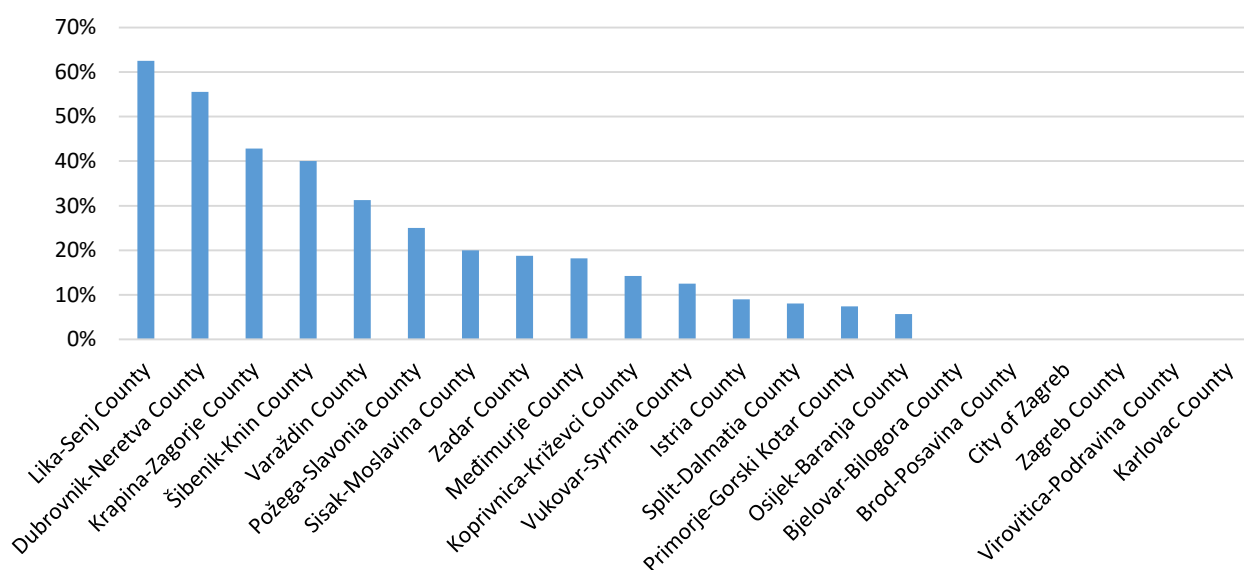


Figure 6. Percentage of nonprofessional substitutes, by county, relative to the total number of physics teachers at participating elementary schools in the corresponding county.

To present information on the development of individual Croatian counties and reveal the possible reasons for physics teacher shortages in each of the Croatian counties, we used several different relevant variables, such as economic strength index, average monthly net salary, demographic indicators (“population change” index), and “cost of living” index. We compared the impact of economic development of individual counties on the percentage of nonprofessional physics teachers in each county (Figure 7). As a measure of the economic development of an individual county, the economic strength index provided by the Croatian Chamber of Economy (CCE) was used [61], which is calculated as the sum of weighted basic economic indicators in three-year averages (GDP per capita, total income of entrepreneurs per employee, average net wages, net profit of entrepreneurs per employee, income on foreign markets of entrepreneurs per employee, unemployment rate) and demographic projections (population growth projection in 2021 compared to 2011) to measure the degree of economic strength and economic potential of counties in comparison to the average of the Republic of Croatia. An economic strength index above 100 means that an individual county is above average in the Republic of Croatia, while a value below 100 means it is below average.

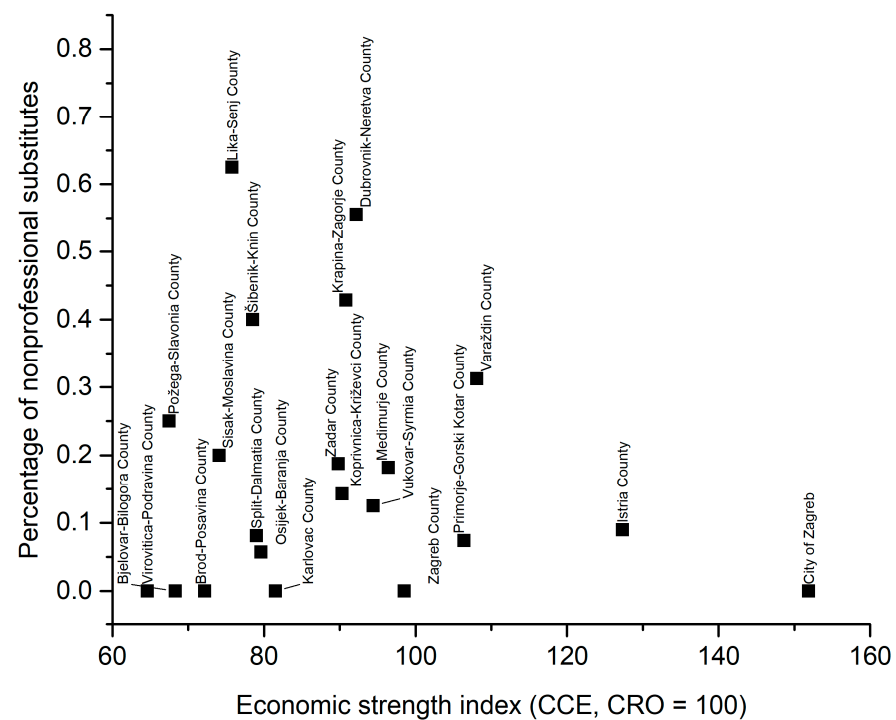


Figure 7. Percentage of nonprofessional substitutes (from Figure 6) as a function of the economic strength index provided by CCE, showing the deviation from the average of the Republic of Croatia (CRO), weighted by 100.

Figure 8 shows how the percentage of nonprofessional substitutes (from Figure 6) depends on the average net salary per county.

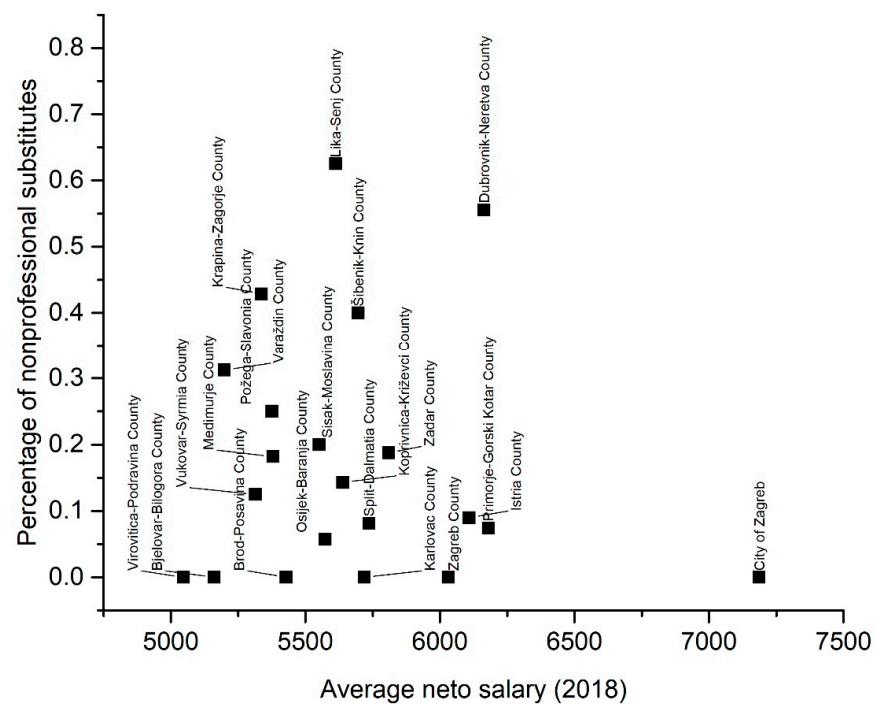


Figure 8. Percentage of nonprofessional substitutes (from Figure 6) as a function of average net salary per county (source: CCE).

4. Discussion

The expectation is that there will be no vacancies because any lack of certified teachers for positions is filled by noncertified teachers in line with the relevant legislative acts [25]. For example, in North Carolina teachers are required by law to teach only 50% of their work time in the area for which they are certified, and for the rest of the time they can work in other areas [62]. Moreover, many states in the United States do not have laws restricting employing nonprofessional teachers [62]; hence, their numbers are of great value. For example, in the United States in the 1980s, about one-quarter of teachers who taught mathematics and science were not certified [25], while in 1981, only 44% of full-time teachers were certified in science and mathematics [63]. In the 1960s, a significant number of mathematics and science teachers lacked proper preparation to teach in these fields [25]. In any case, one should keep in mind that teacher hiring occurs in waves. Thus, vacancies would certainly have been reported if we had conducted the survey in the first or last month of the school year.

The percentage of 14.25% of nonprofessional physics teachers from the total number of physics teachers employed in Croatian elementary schools and participating in the survey is lower than in the previously mentioned examples. Their employment is prescribed by the Act on Education in Elementary and Secondary Schools [48]. In Croatia, a non-certified person can be employed for a period of 5 months if there is no person to meet the relevant requirements among candidates for a vacant position. If a person lacks pedagogical-psychological-didactic-methodical competences, he or she is obliged to acquire them within one year of gaining employment. In addition, those hired as teachers for the first time must complete a one-year internship and pass the professional state examination within one year of completing the internship.

The representation of nonprofessional physics teachers with qualifications in social sciences and humanities (42%), as the most numerous regular teachers ($N = 10$), primarily indicates the problem of an inadequate physics education. On the other hand, nonprofessional teachers with qualifications in a technical field (40%), such as mechanical and electrical engineers ($N = 8$), lack pedagogical-psychological-didactic-methodical competencies (unless they subsequently completed an appropriate lifelong learning program) and/or knowledge of fundamental physics which they have not acquired in the courses of their completed degree programs. Nonprofessional teachers with science qualifications, such as engineers or bachelor graduates in physics, lack pedagogical-psychological-didactic-methodical competencies (unless they subsequently completed an appropriate lifelong learning program). For example, the last group includes biology professors who lack knowledge of fundamental physics.

Regardless of the type of missing competencies, nonprofessional physics teachers have a negative impact on students. For example, despite promoting modern methods in physics education, nonprofessional teachers [16] rely heavily on textbooks and use traditional lecture teaching methods [64–67]. This approach prevents students from receiving a quality education [42,66]. In addition, poor initial experiences with the subject or teachers can lead to negative student attitudes toward physics [21,68] and a lack of knowledge in physics [21,69–71], ultimately resulting in fewer students enrolling in and completing university physics courses and programs [21,27,72,73], especially for the teaching profession [63]. We also know from experience that in Croatian elementary schools, students have a negative attitude towards physics. As a result, about 50% of students do not continue physics as a subject after elementary school. Consequently, they will not be able to develop a scientific worldview necessary for the development of modern society, especially if professional physics teachers have never taught them (even in elementary school). Other students who continue to study physics at higher levels of education face serious difficulties in their future learning, as they lack a basic knowledge in physics, which cannot be subsequently supplemented. This is supported, for example, by the data on student grades in the State Matura (final high school exam) in the subject of Physics, which are regularly scored below average [74], or below-average results by Croatian students in the Programme

for International Student Assessment (PISA) test, which assesses student knowledge and skills in science [75]. The described consequences of the shortage of professional physics teachers are at odds with the goals of educational reforms based on creating an increasingly competitive global and high technology economy, which dictates high-quality education in physics and other natural sciences and mathematics [76–78]. The global economy and high technology also place greater demands on students in these fields [79] to successfully prepare the STEM workforce for the challenges and demands of the 21st century [80].

Given the possible negative consequences of the shortage of professional physics teachers and the fact that every child has the right to an effective elementary school education [81], the above percentage of 14.25% is exceptionally high. Based on this percentage, we estimate that the number of students who are not professionally taught physics is about 40,000 in only one school year. Specifically, we can read on the website [57] of the Ministry of Science and Education that there were 68,711 students in Croatian elementary schools running a regular program in the 2020/2021 school year where physics was taught (7th and 8th grade). Overall, 14.25% of this number of students is equivalent to 9791. If we assume that the survey covers 25.37% of schools, the calculated number of students is about four times higher, corresponding to about 40,000.

The differences in the representation of nonprofessional physics teachers by county (Figure 6) suggest that there are different causes for physics teacher shortages that cannot be generalized for any particular geographic area. We can verify this due to the fact that the Pearson correlation coefficient of the percentage of nonprofessional substitutes and economic strength index, shown in Figure 7, is -0.12 , which indicates a weak negative linear relationship, is not statistically significant. Therefore, the link to economic development is not the only factor affecting the percentage of unprofessional substitutes in schools. As can be seen in Figures 6 and 7, the Lika-Senj (62.5%) and Dubrovnik-Neretva (55.6%) counties indicate the highest percentage of nonprofessional substitutes. At first, this seems very unusual because a high percentage occurs for one of the most economically underdeveloped counties (Lika-Senj County), as well as for one of the most developed tourist counties in Croatia (Dubrovnik-Neretva County), where the economic strength index gravitates towards the Croatian average (see Figure 7). However, things become clearer when other factors are discussed, such as the average net salary by county, the “cost of living” index or demographic projections (population growth projections in 2021 compared to 2011). Dubrovnik, the capital city of Dubrovnik-Neretva county, shows the highest “cost of living” index in Croatia [82], which obviously affects the emigration of professional physics teachers, or their employment to better-paid positions, given that the monthly salary of a physics teacher in an elementary school is not sufficient to cover the imposed standard. Namely, the salary depends on many factors, such as years of service, successfully passing the professional state exam, professional education, and promotion. The starting salary is about 690 EUR, which is among the lowest average salaries in Croatia (see Figure 8) in the economically least developed counties of Croatia, such as the Virovitica-Podravina County and Bjelovar-Bilogora County (see Figure 7). Therefore, it is very likely that young physics teachers do not have the motivation to stay in this environment, or they choose to develop for better-paid positions. On the other hand, it is possible that a small number of high school students from the Dubrovnik-Neretva county are interested in enrolling into physics education programs at university, given that Dubrovnik is more than 200 km from Split, where the closest faculty offering physics programs is located. In all other parts of Croatia, students are able to choose up to two universities at shorter distances from their place of residence.

The ranking of the Lika-Senj County among counties with the highest percentage of nonprofessionals is because its area is mountainous and economically and demographically devastated. This all affects the growing emigration of the able-bodied younger population. This situation is supported by the fact that Lika-Senj is the worst ranked county in terms of demographic indicators of CCE (almost 15% of the population emigrated in 2011–2021 period) [61].

The positioning of the Virovitica-Podravina County and Bjelovar-Bilogora County among counties where only professionals have been noted in schools is, very possibly, due to the fact that these two counties are the least economically developed and have the lowest average salaries in Croatia (Figure 8). The salaries are comparable to the initial (minimum) salaries of physics teachers in primary schools and therefore are sufficient to support the local standard of living. Furthermore, with increased length of employment in the education system, teaching salaries also increase and exceed the average salary of these areas, thus motivating teachers residing in these areas to stay and work in the locality.

Our conclusions are consistent with those of Sparkes' research [11], who compared situations in different regions of the United Kingdom with different needs for physics teachers. He found that causes such as demographics, cost of living, employment opportunities for physicists in other, better-paying jobs, gender prejudices, low morale, and demanding university programs in physics resulted in a shortage of physics teachers in some regions and not in others. This partly explains the unresolved and widespread problem of physics teacher shortages around the world [83], and the fact that good practices of some countries cannot be easily imitated in other countries. Along these lines of thought, in the next phase of the research, we want to contribute and provide an effective solution to this global problem by finding the underlying cause of physics teacher shortages in Croatia and suggest possible solutions. This will further assist the government, universities, and schools in devising appropriate educational policies.

5. Conclusions

The shortage of physics teachers is a global and persistent problem. It stems from the insufficient number of graduating physics teachers relative to the number of available positions and from the abandonment of the physics teaching profession by experts who move to other more lucrative professions. As a result, nonprofessional physics teachers are hired to do the job of qualified physics teachers. Nonprofessional physics teachers lack knowledge of the specific content (syllabus), i.e., knowledge of physics and/or pedagogics. This means they cannot provide high-quality and effective student-centered physics instruction. This hampers student interest in learning physics, negatively affects enrolments into university programs in physics and choosing a career in physics, ultimately jeopardizing the survival of the entire physics education and physics engineering profession.

The aim of this study is to identify the shortage of elementary school physics teachers in Croatia and thus contribute to devising educational policies by the government, universities, and schools. Accordingly, it is advantageous to monitor future trends, identify the causes and take appropriate measures to address this shortage and provide quality education for students.

Using an online survey for elementary school principals, we conducted the first survey to identify a shortage of elementary school physics teachers in Croatia. We asked them about the number and type of education of the staff working as physics teachers. In all, 260 school principals participated in the survey, i.e., 25% of the total population of principals of Croatian elementary schools where physics education was provided in line with the regular program run in the 2020/2021 school year.

The principals who participated in the survey did not report the existence of physics teacher vacancies in their schools. They did, however, report the presence of nonprofessional substitute physics teachers in 14% of the total number of physics teacher positions in the schools that participated in the survey. Among them, a greater number of nonprofessional substitute teachers came from the social sciences and humanities (42%), such as regular teachers, followed by technically qualified persons (40%), such as mechanical and electrical engineers, with the fewest coming from the natural sciences (18%), such as biology teachers.

Differences in the representation of nonprofessional substitutes for physics teachers by county were also found (e.g., the highest percentage of nonprofessional substitutes was found in the Lika-Senj County and Dubrovnik-Neretva County), indicating different causes

for physics teacher shortages in different geographical regions. Moreover, the teacher salary, and its correlation to the average net salary of a particular county, seems to be one of the main factors in deciding whether a teacher will stay and work in a particular county, emigrate, or look for a better paid job. We plan to investigate these causes in more detail in the next phase of research and propose possible solutions to the problem of the physics teacher shortage in Croatia.

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Informed Consent Statement: All respondents were informed about the nature of our study and they voluntarily participated in the study. The participants were assured that the principles of confidentiality and anonymity would be adhered to in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Questionnaire for Elementary School Principals in Croatia

This survey is part of a study to help solve the problem of the physics teacher shortage.

The survey investigates the representation of physics teachers with appropriate qualifications in elementary schools in Croatia.

The survey results will be used for scientific research, and the researchers are obliged to maintain the confidentiality and anonymity of the respondent data.

Completing the questionnaire takes only a few minutes.

We thank you in advance for your cooperation and time.

1. Enter a 10-character personal identification code

— — — — —
composed as follows:

1st character: your gender—female (F) or male (M).

2nd and 3rd characters: the last two digits of your year of birth (e.g., 98 for 1998).

4th and 5th characters: the first two letters of your mother's name (e.g., AN for Ana).

6th and 7th characters: the first two letters of the name of the place where you work (e.g., ZA for Zagreb).

8th, 9th and 10th characters: your house number (e.g., 016 for house number 16).

Example: The person is a man, born in 2000, his mother's name is Sandra, he works in Rijeka, he lives in house number 12. His code is: M00SARI012.

2. In which county is the institution you manage located? Choose one of the options provided.

- (a) Zagreb County
- (b) Krapina-Zagorje County
- (c) Sisak-Moslavina County
- (d) Karlovac County
- (e) Varaždin County
- (f) Koprivnica-Križevci County

- (g) Bjelovar-Bilogora County
- (h) Primorje-Gorski Kotar County
- (i) Lika-Senj County
- (j) Virovitica-Podravina County
- (k) Požega-Slavonia County
- (l) Brod-Posavina County
- (m) Zadar County
- (n) Osijek-Baranja County
- (o) Šibenik-Knin County
- (p) Vukovar-Syrmia County
- (q) Split-Dalmatia County
- (r) Istria County
- (s) Dubrovnik-Neretva County
- (t) Međimurje County
- (u) City of Zagreb

3. What is the size of the settlement where the institution you manage is located? *Choose one of the options provided.*

- (a) Settlement with less than 500 inhabitants.
- (b) Settlement of 500 to 1000 inhabitants.
- (c) Settlement of 1000 to 2000 inhabitants.
- (d) Settlement of 2000 to 3000 inhabitants.
- (e) Settlement of 3000 to 5000 inhabitants.
- (f) Settlement of 5000 to 10,000 inhabitants.
- (g) Settlement of 10,000 to 15,000 inhabitants.
- (h) Settlement of 15,000 to 30,000 inhabitants.
- (i) Settlement of 30,000 to 50,000 inhabitants.
- (j) Settlement of 50,000 to 100,000 inhabitants.
- (k) Settlement with more than 100,000 inhabitants.

4. What is the total number of physics teachers at your school? _____

5. In the table below, check the boxes indicating the number of physics teachers employed at your school with the appropriate qualifications. The abbreviation PPDMC stands for pedagogical-psychological-didactic-methodical competences.

	0	1	2	3	4
mag. educ. phys.					
mag. phys. (with PPDMC)					
univ. bacc. phys. (with PPDMC)					
other					

6. If you have classified physics teachers in the previous table under “other”, indicate their qualifications;

7. Provide any additional comments you may have;

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