REPORT ON PHYSICS EDUCATION IN TÜRKİYE: ISSUES, SOLUTIONS, BEST PRACTICES

Series on Fundamental Sciences Education

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PREFACE

The following report provides a summary of the outcomes from the two-day "Workshop on Interdisciplinary Approach in Physics Education at Middle School, High School, and Undergraduate Levels in Turkey." The workshop was organized by the Economic Cooperation Organization Educational Institute (ECOEI) and took place on April 27-28 at the Grand Mercure Hotel in Ankara. The research team responsible for documenting the workshop's insights and recommendations was led by Prof. Dr. Ahmet İlhan Şen from Hacettepe University. The team also included Assoc. Prof. Dr. Özlem Oktay from Atatürk University, Assoc. Prof. Dr. Haki Peşman from Fırat University, Dr. Serkan Ekinci from Hacettepe University, and Head Teacher Arife Parmaksızoğlu from the Ministry of National Education.

This was the fifth and last workshop of the Workshop Series on Fundamental Sciences Education that brings together researchers, educators, administrators, and students in the field of Fundamental Sciences Education. The objective of these workshops is to tackle the challenges, identify the strengths, and highlight the best practices in the respective field. These workshops aim to support the education of upcoming generations in fundamental sciences while also making valuable contributions to the advancement of education in diverse fields such as engineering, economics, and medicine. "Workshop on Interdisciplinary Approach in Physics Education at Middle School, High School, and Undergraduate Levels in Türkiye" explored innovative teaching methods that integrate multiple disciplines into physics education and provided a platform for educators, researchers, and professionals from various fields to come together and discuss the benefits and challenges of interdisciplinary approaches in physics education.

In this workshop, ECO Educational Institute brought together several academicians not only from physics and physics education departments but also from various fields such as faculty of architecture, health, sport, and dentistry etc. On the initial day of the workshop, participants engaged in a comprehensive exploration of the prevailing challenges within the discipline. Subsequently, on the second day, attendees actively shared their insights by presenting exemplary approaches and offering policy recommendations. Each session was followed by an interactive Q&A session, fostering further discussion, encouraging questions from fellow speakers, and facilitating valuable contributions.

I would like to extend my heartfelt gratitude to Prof. Dr. Ahmet İlhan Şen, for his contributions to both the organization of the workshop and reporting its outcomes as well the dedicated research team, Assoc. Prof. Dr. Özlem Oktay, Assoc. Prof. Dr. Haki Peşman, Dr. Serkan Ekinci, and Head Teacher Arife Parmaksızoğlu. Their invaluable efforts in documenting the insights and recommendations have laid a strong foundation for enhancing physics education at various academic levels in Türkiye. ECOEI recognizes the significance of physics education as a cornerstone of fundamental sciences, fostering critical thinking, problem-solving, and scientific literacy. As we reflect on this workshop's achievements, we express our wishes for the promotion and advancement of fundamental sciences education throughout the ECO region and hope that this workshop serves as a catalyst for collaborative initiatives and inspire teachers who will raise the next generation of aspiring scientists and researchers and support them in their pursuit of knowledge and discovery.

Prof. Dr. M. Akif KİREÇCİ
President
ECO Educational Institute

CHALLENGES IN PHYSICS CURRICULUM AND ASSESSMENT AND EVALUATION PROCESSES

Since the foundation of the Republic of Türkiye, there have been continuous efforts in the development and update of the curriculum. Ministry of National Education (MoNE) introduced the implementation of new curricula in middle schools in 2003 and high schools in 2007. In the following years, parts of the curriculum were revised to eliminate substandard aspects. Most recently in 2018, it was updated again, taking the form which is currently being implemented at all grade levels. One of the significant features of this latest curriculum is its clear specification of what and how much will be taught in the classroom environment with explicit written learning outcomes and its definition of limitations.

During the development of the physics curriculum, reliance on mathematical operations are kept to a minimum in the 9th and 10th grades and efforts were made to relate the content to daily life. The objective at these grade levels is for students to recognize the relevance of physics in our lives through interpreting the events they encounter according to the rules of physics, rather than relying heavily on mathematical operations. However, in the 11th and 12th grades, the objective shifts to equipping students with a solid academic foundation by addressing subjects at a more comprehensive and advanced level.

Assessment and evaluation of the physics curriculum and its implementation can be examined at three levels (i) assessment and evaluation within the classroom and school settings, (ii) assessment and evaluation through nation-wide exams, and (iii) assessment and evaluation through international exams.

1.1. Assessment and Evaluation within the Classroom and School Settings

Physics education is implemented according to annual study plans aligned with the outcomes of physics curriculum at each grade level. The annual study plans are prepared and approved prior to the start of the academic year. Generally, the annual plans are consistent nationwide. At the beginning of the academic year, physics teachers in each school start to teach according to the annual plan. However, due to variations in the readiness level of teachers, schools, and grade levels, differences arise in the delivery of lessons.

Physics teachers who possess comprehensive knowledge of the curriculum and its outcomes, understand the misconceptions within the curriculum, conduct experiments in laboratories, know and can apply alternative assessment and evaluation methods, engage in out-of-school applications, have received STEM/STEAM training and apply them, participate in national and international projects, utilize technology and smart boards, willingly participate in in-service trainings, provide guidance to prospective teachers, voluntarily chair school, district and provincial group meetings, and hold master's and doctorate degrees in their respective fields may hold diverse perspectives on physics education. Such variations in teachers' qualifications lead to diversity in educational environments. Teachers with diverse qualifications aspire to apply their knowledge in their teaching.

Attitudinal differences towards the course may arise between students taught by teachers who try to implement their unique programs in line with the curriculum and those under teachers who employ traditional teaching methods. A physics teacher familiar with alternative assessment and evaluation methods can benefit from these approaches during oral and performance assessments. However, since the application of such alternative methods is not feasible in jointly held school-wide written exams, teachers' superior qualifications do not necessarily lead to their students' increased success in such exams.

Indeed, such incongruity can hinder students' motivation to acquire new knowledge and skills. School-wide exams are jointly held to ensure unity, fairness, and solidarity as well as to obtain comparable results. Therefore, they only cover subjects that are commonly taught to all students, focusing on the knowledge and skills they all are supposed to have. Consequently, students in classes where alternative methods are applied may not be able to dedicate extended time periods to solve many questions or practice extensively, leading to deficiencies in exam preparation. In fact, students who regularly practice solving questions of the same type and template, but lack strong problem-solving skills, may attain higher scores in such assessments. Although most students who can come up with alternative solutions when faced with problems perform better academically, they may have lower performance in jointly held exams compared to their peers in traditionally taught classes because they cannot allocate time to memorizing the solution methods or templates of questions nor can they engage in repetitive practice of solving them.

While teachers using traditional methods usually face fewer time constraints, classes implementing alternative learning methods require more time. As such, teachers who wish to apply different methods, conduct experiments and activities, utilize out-of-school learning environments, and even emphasize correcting misconceptions and mistakes in educational resources may opt to overlook the issues they emphasized in the classroom, especially when preparing questions and answer keys for school-wide exams, to avoid conflicts with their colleagues. In other words, they encounter difficulties in assessing the students on the very concepts or topics they emphasized and underlined during their classes.

National regulations stipulate that achievement in physics is assessed through a minimum of at least two exams at each grade level in each academic year. At least one of these exams typically consists of open-ended questions, while the other one includes multiple-choice items and fill-in-the-blank questions. Course teachers usually prepare open-ended questions, while multiple-choice items predominantly feature examples from the available resource materials. This practice stems from the fact that preparation of multiple-choice questions requires specific expertise. When answering multiple choice items, the students are expected to handle the subject matter in a way that conforms to the handling of the subject matter by the item author. If the multiple-choice questions are not properly designed, they are seldom useful in testing misconceptions, which are major obstacles to learning.

Furthermore, each school prepares questions based on its own level, or individual teachers tailor questions to suit their own students. Nevertheless, the YKS (Higher Education Institutions Examination) score, which is used for university placement, is also influenced by the secondary education achievement score derived from the diploma grades. Consequently, students with higher end-of-year grades or diploma grades, in addition to test scores, achieve higher cumulative scores in the YKS. This creates an advantage for certain schools and their students in terms of secondary school achievement score for university placement. To address this issue, schools must be assigned with the primary responsibility of imparting knowledge and skills. Moreover, conducting at least one centralized exam simultaneously in all private and public schools during one academic year would contribute to achieving unity and solidarity in assessment and evaluation.

Another significant challenge in physics teaching is the inadequate number of class hours. Consequently, certain topics towards the end of the academic year are either left uncovered or not taught effectively. In comparison to other courses, the learning outcomes of the high school physics curriculum are quite numerous, hence require a considerable amount of course hours. For instance, the curriculum designates only two hours per week for each science course (physics, chemistry, and biology) in 9th and 10th grades, while allocating 4 hours per week in 11th and 12th grades. Table 1 illustrate the ratio between the total number of learning outcomes in the curricula of each course and the total number of course hours in a year.

Table 1. The ratio between the total number of learning outcomes and course hours at secondary level physics, chemistry, and biology classes

Grade	Physics	Chemistry	Biology
9	0,64	0,53	0,15
10	0,54	0,32	0,24
11	0,43	0,24	0,24
12	0,47	0,21	0,20

Table 1 highlights the insufficient number of weekly class hours which is one of the most significant factors contributing to the underachievement in physics education. This limitation greatly hampers physics teachers' ability to deliver effective instruction. The allocated weekly course hours for physics course are inadequate for the acquisition of the knowledge and skill outcomes outlined in the curriculum. Regardless of the teaching method employed, it is evident that the time allotted for high school physics courses is insufficient when considering the learning needs of the students. Teachers simply lack the necessary time to delve deeply into the subject matter, provide real-life examples, deliver context-based lessons, or facilitate experiments and activities in the classrooms. Consequently, due to rushed and incessant delivery of learning outcomes, students often struggle to grasp concepts and establish connections between these concepts. As a result, the lessons become ineffective, taking on a result-oriented style rather than a process-oriented one.

The importance of early field selection becomes apparent when one considers the timing problems experienced in the field selection process for high school students, along with its negative impacts on their motivation and learning pace. 10th grade is too late to choose a field of study. Students who would opt for social sciences in the later grades, experience a decrease in motivation and learning speed in lower grades because they do not consider the physics course as essential for their future studies. Therefore, field selection should ideally be made by the 9th grade at the latest. An additional benefit of early field selection is that it increases the proportion of students' field-specific courses in their weekly schedule. It would also allow them to spend less time in the classroom environment, a favorable outcome for students' physical and mental development.

1.2. Assessment and Evaluation in National Exams

The curriculum is primarily designed with a context-based approach, and textbooks, course outcomes, and assessment and evaluation criteria are planned accordingly. Since 2011, the central university entrance exams conducted by the Center for Assessment, Selection, and Placement (ÖSYM) have been increasingly focusing on skills-based approach and real-life examples. Thus, since 2011, the number of skill-based questions has gradually increased.

Between 2011 and 2018, Turkey had a two-stage system for university entrance exams known as the Transition to Higher Education Examination (*Yükseköğretime Geçiş Sınavı* - YGS) and the Undergraduate Placement Examination (*Lisans Yerleştirme Sınavı* - LYS). The YGS assessed general proficiency, general culture, and basic mathematical knowledge, while the LYS consisted of separate sessions in five different areas: Mathematics, Geometry, Science, Turkish Language and Literature, Geography and Social Sciences.

The introduction of the new curriculum presented challenges for teachers and textbook authors in associating physics course outcomes with real-life contexts and creating skill-based questions, resulting in difficulties in achieving a standardized approach to question writing. This issue was also evident in the YKS questions. Students who were not familiar with life-based questions from classroom lessons and reference books struggled to comprehend these types of questions. Another characteristic of the curriculum is the reduced intensity of mathematical operations in physics questions, which gradually influenced the formulation of physics questions.

An analysis of the distribution of life-based questions over the years, as shown in Table 2, reveals a gradual increase (Parmaksızoğlu, 2019). MoNE supports teachers in developing skill-based questions through resource books distributed in written and printed formats and achievement comprehension tests prepared by the General Directorate of Assessment, Evaluation and Examination Services. Additionally, students are also provided with monthly trial tests for the TYT and the AYT. The MoNE General Directorate of Secondary Education also significantly contributes to physics education through their work on skill-based questions.

However, despite the accessibility of these resources, their impact in classrooms and on students is not at the expected level due to various reasons such as limited class hours, some teachers not utilizing additional resources, private schools being inclined towards their own publications, and certain schools lacking electronic (smart) boards as part of the Movement to Increase Opportunities and Improve Technology (*Fırsatları Arttırma ve Teknolojiyi İyileştirme Hareketi* - FATIH) project. When considering the number of physics questions (see Table 2), the YGS included 14 physics questions, and the LYS included 30 physics questions during the period from 2011 to 2017.

Table 2. Percentage Distribution of Life-Based Physics Questions by Years

Years	YGS	LYS
2011	0,14	0,03
2012	0,21	0,07
2013	0,43	0,20
2014	0,43	0,30
2015	0,29	0,33
2016	0,50	0,27
2017	0,50	0,30
2018	0,29 (TYT)	0,36 (AYT)
2019	0,71 (TYT)	0,50 (AYT)

After 2018, the university entrance exam was renamed the Higher Education Institutions Examination (*Yükseköğretim Kurumları Sınavı* - YKS), which consists of the Basic Proficiency Test (*Temel Yetenek Testi* - TYT) and the Field Proficiency Tests (*Alan Yeterlilik Testi* - AYT). Alongside these changes, the number of questions was also revised. In the new format, the number of physics questions in the TYT was updated to 7 and the number of physics questions in the AYT was updated to 14. However, it appears that the total number of outcomes in the high school curriculum was not taken into consideration when revising the number of questions. In this exam administered by ÖSYM, the total course hours for physics, chemistry, and biology courses, which are similar disciplines, amount to 432 hours over the course of high school education (4 years). Yet, when compared to other courses, the number of outcomes per course hour (Total number of outcomes / Total number of course hours) for physics was 0.49, whereas it remained at 0.21 and 0.29 in biology and chemistry, respectively (see Table 3).

Table 3. Ratio of Total Outcomes to Total Course Hours in Secondary Education Physics, Chemistry, and Biology Lessons

	Physics	Chemistry	Biology
Total Number of Outcomes / Total Number of Course Hours	0,49	0,29	0,21

As a result, the insufficient total number of course hours dedicated to physics in Türkiye is the most significant factor that makes physics a difficult, or even more challenging, subject. This limitation prevents teachers from adopting a life-based approach, applying STEM (Science, Technology, Engineering, Mathematics) or STEAM (Science, Technology, Engineering, Art, Mathematics) approaches, conducting experiments, activities, and projects, as well as utilizing alternative assessment and evaluation methods. Due to the limited time available, teachers are obliged to use traditional teaching methods throughout the academic year in order to cover the required learning outcomes. The primary tools of support in the classroom environment are interactive books and simulations. Easy access to simulations and interactive book resources enables teachers to save time in the classroom. However, the insufficient number of physics course hours in the high school curriculum prevents students from developing authentic problem-solving skills. In such a situation, it is essential to increase the weekly course hours for physics course without wasting any time.

In the YKS administered by ÖSYM, the number of physics questions is higher compared to other subjects (chemistry and biology), despite having the same total number of course hours. The number of questions presented to students in the Science test in the TYT and the AYT is outlined in Table 4.

Table 4. Number of Questions Asked in the TYT and the AYT Science Test

Science Test	TYT	AYT
Physics	7	14
Chemistry	7	13
Biology	6	13

As a result, having only 7 questions in the TYT and 14 questions in the AYT for the entire 4-year high school curriculum poses issues in terms of content validity and increases the likelihood of chance success. Another problem in the YKS tests is that a single item may cover multiple learning outcomes, possibly due to the limited number of items in the test.

1.3. Assessment and Evaluation through International Exams

There are several international assessment tests, such as the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA), which provide countries with a means to evaluate their education systems.

TIMSS is an achievement monitoring survey conducted every four years by the International Association for the Evaluation of Educational Achievement (IEA). First conducted in 1995, TIMSS is an international study with a history of approximately 25 years. It assesses the academic performance of fourth and eighth grade students in mathematics and science. In TIMSS 2019, 58 countries participated at the 4th grade level and 39 countries participated at the 8th grade level. Türkiye has been participating in TIMSS for a considerable period, joining the study in 1999, 2007, 2011, 2015 and 2019 at the 8th grade level, and in 2011, 2015, 2019 and 2023 at the 4th grade level.

PISA is an educational survey conducted by the Organization for Economic Cooperation and Development (OECD). This research is conducted by the PISA Governing Board, affiliated with the OECD Directorate of Education and Skills. The tests, questionnaires, their analysis, and preparation of the international report are carried out by a consortium determined under the supervision of the PISA Board of Directors. PISA is a survey conducted by the OECD to assess the knowledge and skills acquired by students aged 15 over three-year intervals.

The questions in these exams present problems within real-life contexts. Students are expected to apply their acquired knowledge and skills to solve these problems. Notably, these questions often have a multidisciplinary structure. The supplementary resources provided by the MoNE General Directorate of Assessment, Evaluation and Testing Services, including e-monitoring studies, support this context-based approach. However, due to limited emphasis on the context-based approach in schools, and the mismatch between the style of education and the style of the questions, students encountering different types of questions may struggle to understand and adapt to them.

Incorporating context and real-life situations into questions enables students to engage with the problems, relate to them on a personal level, own the questions, and create their own authentic answers. PISA and TIMMS exams, which evaluate the science literacy of countries, often incorporate real-life contexts that require advanced thinking skills from students. When faced with such questions, students can demonstrate their unique problem-solving skills.

The rubrics used in exams conducted as part of the Monitoring and Evaluation of Academic Skills (ABIDE) Project at the national level, as well as high-level exams like PISA and TIMMS at the international level, are revised based on the answers received from the students after the pilot applications. Unlike multiple-choice tests, these exams require students to apply their authentic solution methods and reach conclusions by questioning the reasons, resulting in lower chance success through guessing. Multiple-choice tests, on the other hand, have a higher likelihood of chance success.

Some studies have shown that students perform equally or even more successfully in assessments with context-based questions compared to traditional assessments (Tekbıyık and Akdeniz, 2010). Moreover, students who receive context-based education tend to be more successful when assessed with context-based questions (Bennett, Lubben, and Hogarth, 2007).

When examining the results of exams conducted with life-based questions, differences between countries can be attributed to specific teaching methods, variations in teachers' resources, disparities in textbooks and materials, and the influence of other learning environments outside of school that affect teaching practices. Especially in our country, teaching both inside and outside the classroom often prioritize result-oriented approaches, which can lead students to comprehend subjects primarily by solving a large number of questions rather than focusing on problem-solving. This approach can result in students becoming accustomed to solving questions based on learned patterns and struggling to adopt when they encounter different situations.

Considering student achievements in PISA and TIMSS exams, as well as examining national exam reports, it becomes evident that students face challenges in effectively using, combining, and transferring knowledge to other areas, rather than lacking knowledge itself. In addition, students often fail to take ownership of problems and instead resort to providing bookish (rote) answers. Recent changes in the curriculum have attempted to address these deficiencies. For example, a STEM-based unit has been included in the secondary school science curriculum.

SUGGESTIONS

- The physics curriculum should be revised to allocate more course hours based on the weight of learning outcomes, and weekly and annual course hours should be increased, considering the difficulty of the subject and its relationship with other disciplines. Insufficient course hours contribute to incomplete coverage of the curriculum curriculum and poor results in evaluation and asssesment of physics subjects, in physics.

- The number of outcomes per unit time should be rearranged to align with the nature of each course and the intensity of the learning outcomes in the high school curriculum. This allows to transfer course hours from courses with fewer outcomes to those with more outcomes.
- Teachers should be provided with academic support on alternative assessment and evaluation methods.
- Textbooks and supplementary resources should be developed that align with the context-based approach, and teacher trainings should be organized on implementing this approach.
- Simulated questions (such as e-monitoring questions prepared by the MoNE General Directorate of Assessment, Evaluation and Examination Services) should be prepared and implemented.
- Methods such as experiments, out-of-school learning environments, and activities should be planned, implemented, and documented throughout the academic year should be planned and recorded in advance, similar to the annual plans.
- At least one centrally and jointly administered exam per course in each semester should be conducted across the country to ensure uniformity in assessment and evaluation and to make the secondary education achievement score more equitable.
- Process-based and interdisciplinary learning approaches should be emphasized.
- The life-based approach should be integrated into curricula and necessary resources and teacher training should be provided to support its implementation.
- Until the curricula are revised, support should be provided for easier and better understanding of the physics course through resources enriched with context-based real-life examples, simulations, videos and animations available on the MoNE Education and Informatics Network (EBA), which is easily accessible to teachers and students. These resources will aid physics course success during the curriculum revision process.

- Textbooks and supplementary resources should be reviewed for misconceptions and physics teachers should be subjected to in-service training on addressing misconceptions in the high school physics curriculum.

- The YKS exams should be administered centrally at the end of the academic year of each grade, taking into account students' physical and mental development, rather than waiting until the last year of high school. The average of these scores should be used for placement into higher education institution.

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CHALLENGES AND SOLUTIONS REGARDING PHYSICS TEACHER TRAINING PROGRAMS

In order for science teachers, especially physics teachers, to be effective in their profession, they need to possess subject matter knowledge (knowledge of physics), teaching professional knowledge (knowledge of educational theories), and pedagogical content knowledge (knowledge of how to teach physics topics in an understandable way). It is crucial for physics teacher training programs to provide opportunities for prospective physics teachers to acquire this knowledge.

Physics Teacher Training Programs follow the guidelines set by the Council of Higher Education (CoHE), similar to other teacher training programs. These programs include courses that cover subject area knowledge and pedagogical content knowledge, which are collectively referred to as Content Knowledge. Additionally, there are courses on teaching profession and general culture. However, the proportion of content knowledge courses in the physics curriculum is considered low at 48%. This includes courses that provide both subject matter knowledge and pedagogical subject matter knowledge, indicating a need for improvement. Numerous scientific publications have highlighted the inadequacy of teacher training programs in delivering subject matter knowledge and pedagogical subject matter knowledge.

One of the aspects criticized about teacher training programs is its classification of courses into field education and educational sciences. According to the literature, professional knowledge courses should focus on educational sciences theories, such as educational psychology, philosophy of education, sociology of education, and theories of teaching. On the other hand, courses like instructional technologies, material development, and teaching methods are specific to field education and should be taught by field educators. Physics teacher training programs have faced significant criticism in this regard.

Another issue relates to the staff structure in faculties of education. In many faculties, courses that should be taught by experts in the field of physics education are instead taught by physics department faculty members. This lack of awareness or consensus regarding which courses should be considered field courses and which ones should be classified as field education courses poses a problem. Furthermore, the fact that some physics teaching programs have physics departments teaching field courses can lead to additional challenges. It is advisable to examine the conceptual aspects of the courses in the teaching program, even for field courses, and address issues such as misconceptions. Faculty members teaching these courses should take these concerns into consideration.

One pathway to becoming a physics teacher is through studying at physics programs. Students or graduates of these programs undergo two semesters of pedagogical formation training, which grants them the right to become physics teachers. The curriculum for pedagogical formation education is also determined by the CoHE. However, the limited number of courses in this program diminishes the quality of physics education, as individuals who complete the program may not be adequately equipped for the teaching profession. Furthermore, teachers who initially have no interest in teaching or are unable to enter the physics teaching department because of not having enough scores may not respect their profession and may perceive their profession as temporary until they spend a certain period of time in the field, which can be called the period of acceptance of the profession. Furthermore, there are significant differences between the perspectives of prospective teachers studying at the faculty of education and those who come from other faculties receiving pedagogic formation training. The opportunity to become a teacher through pedagogical formation training has caused the teaching profession to lose its status and be considered a fallback option, that can be summarized with the common phrase saying, "If I can do nothing else, I will teach." It is essential to recognize that knowing physics and teaching physics are distinct roles. The teaching profession, which plays a crucial role in shaping the future of the country, should be carried out by teachers who are passionate, well-equipped, and graduates of education faculties.

Extending the duration of teaching practice (internship) for prospective teachers in faculties of education and increasing their time spent in schools will have positive effects on their perspectives on school, students, and increase their professional motivation. Enhancing communication between practice schools, supervisor teachers, pre-service teachers, and universities will facilitate a smoother transition into the working environment and profession upon appointment.

In Türkiye, the opportunity for prospective teachers to become teachers in public institutions depends on their performance in the Public Personnel Selection

Examination (KPSS). The performance of prospective physics teachers in the KPSS serves as evidence of the challenges in training qualified teachers, as mentioned above.

The Specialized Field Knowledge Test for Teaching (ÖABT) is particularly crucial in teacher appointments. This exam consists of 75 questions, including 45 subject area knowledge questions and 30 field education questions. In 2022, pre-service physics teachers averaged 36 correct answers out of 75, indicating that 39 questions were answered incorrectly or left unanswered. Similar data exists for pre-service science teachers in the ÖABT, where they averaged approximately 32 correct answers, implying 43 incorrect or unanswered questions. According to the numerical data available for previous years, pre-service science teachers had difficulty especially in physics questions in ÖABT. These data indicate that the physics content knowledge of both physics and science teachers in Türkiye is not at the desired level. To address this issue, the duration of teaching practice courses in faculties of education should be extended, the practical experience of pre-service teachers in classrooms should be increased, the entire curriculum should be thoroughly examined, and efforts should be made to ensure that pre-service teachers graduate with a solid command of the curriculum's outcomes and subjects at each grade level. Meticulous consideration should be given to the selection of supervisor teachers during these endeavors.

In 2017, Türkiye ranked 103rd out of 140 countries in terms of the quality of mathematics and science education, according to the World Economic Forum. One of the primary factors explaining this result is the insufficient subject matter and pedagogical content knowledge of mathematics and science teachers, particularly in physics.

In light of this information, it can be concluded that improvements are necessary in physics teacher training programs to equip physics teacher candidates with the required subject matter knowledge, teaching professional knowledge, and pedagogical subject matter knowledge. Teacher training programs should be revised to fully incorporate the subjects covered in the physics curriculum in schools. Measures should be taken to address misconceptions, which present significant obstacles to learning and applying physics concepts.

SUGGESTIONS

- The proportion of field courses in Physics Teacher Training programs should be increased, focusing on the conceptual aspects specific to the subjects and addressing misconceptions.

- It should be ensured that the lecturers teaching field courses in Physics Teacher Training programs complete pedagogical courses as part of their training as educators. The Training of Trainers program, as the prerequisite in the appointment of faculty members other than the members of the Faculty of Education, applied at Hacettepe University can serve as an example. (https://yasamboyu.hacettepe.edu.tr/egitimler/egiticilerin-egitimi-sertifika-programi-2022).
- Teacher training is the primary responsibility of Faculties of Education, except in some special cases, and should remain as such. Instead of pedagogic formation training programs, students of physics departments/ physics engineering departments should be offered and provided with the opportunity to pursue double majors and/or minors in physics teaching programs. In addition, active master's programs with thesis or non-thesis options should be opened within the institutes, inactive ones should be activated, and their curricula should be updated.
- The development of elective courses should be enhanced, and their availability should be increased.

CHALLENGES AND SOLUTIONS REGARDING PHYSICS TEACHERS' PROFESSIONAL DEVELOPMENT

Good teachers play a crucial role in students' educational journeys, and research has consistently shown a correlation between teacher quality and student achievement. Therefore, professional development activities are essential in enhancing teachers' self-efficacy and job satisfaction. It is crucial to prioritize professional development with the same level of importance as undergraduate education.

For physics teachers to progress in terms of quality and succeed in their profession, their participation in professional development activities is vital. As science and technology rapidly advance, physics teachers need to stay updated with these developments and adapt to them quickly. In Türkiye, physics teachers enter the profession with a university education (Physics Teacher Training Undergraduate Program, 2018). However, this education alone becomes insufficient over time, as physics teachers require additional knowledge, skills, and expertise to keep up with developments in their field. The following sections discuss current problems and potential solutions for professional development training for physics teachers.

3.1. Dearth of Subject-Specific Content

One significant issue in compulsory or special trainings under professional development programs is the lack of subject-specific content tailored to specific fields, including physics. It is crucial for physics teachers to spark their students' interest in the subject. One effective approach is for physics teachers to utilize active teaching methods and techniques that place the student at the center of learning. The teaching methods employed should establish a connection between physics and everyday life. Physics teachers should be able to integrate effective learning methods from academic literature into their lessons to make physics education engaging and meaningful. Organizers of professional development activities should take this into consideration.

In addition to active teaching methods and techniques, addressing misconceptions and common mistakes is a crucial aspect of physics education. Individuals often develop non-scientific knowledge that is strongly held and resistant to change. Misconceptions can be found in almost every physics subject, from force and motion to electricity and magnetism, work, power, energy, heat and temperature, optics, waves, and modern physics. Misconceptions exist among students, pre-service teachers, practicing teachers, and academics across all age groups. Physics teachers should continually improve their understanding of misconceptions in physics and incorporate rich examples into their lessons. Field-specific training provided by experts in the field will enhance the subject area knowledge of physics teachers. By identifying and addressing student misconceptions and teaching to improve misconceptions, physics teachers can promote a more conceptual understanding of physics.

Another area often neglected by teachers and not emphasized much in laboratory studies is topics related to assessment, assessment tools, units, and error calculations, which are unique to physics. However, these topics play a crucial role in developing a sense of physics and fostering students' love for the subject as well as in diligent implementation of laboratory lessons. Professional development programs should include content focused on these specific areas (Oktay and Eryılmaz, 2022).

Improving communication skills between physics teachers and students leads to increased student motivation and interest in physics. Restricting teaching to the classroom without real-life connections can detach the subject from practical application. Professional development activities should provide training on practices that enhance communication between physics teachers and their students, making the subject more enjoyable and relevant to students' active lives.

Physics, although intertwined with daily life and encompassing various disciplines, can be challenging to connect with other fields due to time constraints and program intensity. Expressing the relevance of physics concepts in other disciplines and making connections between them promotes meaningful learning for students. Teaching lessons with interdisciplinary connections fosters collaboration between physics teachers and colleagues in different disciplines. Including interdisciplinary physics teaching in professional development programs enriches the field knowledge of physics teachers and makes physics more meaningful and practical.

SUGGESTIONS

- Professional development trainings that cover effective methods in physics education, such as peer teaching, problem-solving approach, inquiry-based learning, project-based learning, technology-supported learning, demonstrations, analogies, modeling, virtual laboratory applications, digital physics content creation, simulations, animations, software, and argumentation, which are effective methods in the field of physics education, should be provided for teachers.

- In-service trainings consisting of up-to-date information on misunderstandings and misconceptions in physics and teaching environments can be organized to address these misconceptions.

- Professional development training packages that solely focus on teachers' understanding of physics concepts can be developed.

- Practical courses can be provided within professional development trainings on subjects such as assessment, error in assessment, error concepts, significant figures, and units, incorporating commonly used experiments at high school and secondary school level. Such trainings will enhance the effectiveness of physics laboratory lessons.

- Before professional development trainings, a comprehensive needs analysis can be conducted to determine the topics and content of the specific needs, demands, and opinions of physics teachers (Oktay and Eryılmaz, 2020a). Relevant thesis studies conducted at universities (Oktay, 2015) and academic publications can serve as valuable guidance.

- Professional development trainings can be organized to address the topics such as physics clubs, projects, physics olympiads, exhibitions, out-of-school physics practices that will increase the communication between physics teachers and students.

- Interdisciplinary professional development programs can be organized that integrate fields such as geography, chemistry, biology, music, physics, medicine, and engineering, which are intertwined with physics.

3.2. Exclusivel Reliance on MoNE for Trainings

MoNE is responsible for teacher professional development in Türkiye, organizing national-level trainings through the Department of Education under the General Directorate of Teacher Training and Development, with the trainings organized by governorships at the local level (https://oygm.meb.gov.tr/). However, the burden on MoNE is substantial, considering the extensive efforts required for professional development in various teaching fields.

Research indicates that professional development trainings, including physics, are often composed of theoretical knowledge and lack depth in subject-specific knowledge, fail to address specific field needs, and lack a comprehensive approach encompassing feedback, monitoring, evaluation, continuity, and implementation. To enhance the effectiveness of professional development programs, it is crucial to involve different institutions and organizations beyond MoNE in teachers' professional development. Universities, especially faculties of education well-equipped in physics education, should take an active role and responsibility in professional development of teachers. Collaboration with research institutions can contribute to professional development studies and address the specific needs of physics teachers.

SUGGESTIONS

- Professional development organizations such as physics education centers in faculties of education within universities can be established. These centers can offer courses and resources to volunteer physics teachers.
- Professional development trainings can be organized for physics teachers during summer periods, conducted by universities and subject matter expert in the field.
- The number and variety of professional development activities can be increased through non-governmental organizations, associations, foundations, private institutions, congresses dedicated to physics/science education, and dedicated social platforms and communication networks specifically for physics teachers.
- Institutions such as the Scientific and Technological Research Council of Türkiye (TUBITAK) or the Turkish National Agency can support projects with special calls towards professional development of teachers.

3.3. Lack of Incentives for Voluntary Participation

In-service trainings organized for teachers should encourage participation. As part of the lifelong learning process, these trainings can also be categorized under adult education and focus on professional development. One of the most important features of adult education is that the more voluntary and enthusiastic the participation in these trainings, the higher the rate of efficiency from these trainings. Therefore, professional development programs should be designed to be interesting, tailored to participants' needs, and include motivational elements. Offering rewards to encourage individual participation in these programs is an effective way to enhance their value.

SUGGESTIONS

- The participation of physics teachers who successfully complete trainings, organized either by MoNE or private institutions, can be considered a factor in performance evaluations and salary increases for professional promotion.
- When physics teachers demand to participate in paid trainings that they think will improve their skills, they can be encouraged by providing additional resources from their institutions.
- Physics teachers can be provided with opportunities to pursue master's degrees (with or without a thesis) and this process can be counted as at least 2 years of professional development training. These educational opportunities can also be considered for physics teachers to gain the status of expert teacher and/or head teacher.
- A system can be established to enable physics teachers to conduct research in collaboration with universities.
- Teachers can be encouraged to conduct concrete academic studies with their students in their schools and to publish these studies in scientific journals.

3.4. Monotonous Nature of the Programs

Professional development programs often consist of short-term seminars or symposia, with a focus on theoretical content while neglecting practical elements. To meet comprehensive needs analyses specific to physics education and address the specific requirements of physics teachers, professional development programs should offer a variety of types and characteristics. Initiatives are being taken by MoNE to enhance teachers' personal and professional development. For example, the School Based Professional Development (SBPD) model (https://oygm.meb.gov.tr/www/okul-temelli-mesleki-gelisim/icerik/65) was updated and implemented by MoNE in 2010. Similar initiatives can be adapted and utilized by physics teachers, ensuring continuous on-the-job development.

SUGGESTIONS

- Trainings can be organized in schools on a regular basis with the learning communities that would include physics teachers.
- In addition to communication within the schools, professional development programs can be developed to bring together physics teachers from nearby schools or districts to foster collaboration and knowledge sharing.
- Professional development models such as peer learning, action research, mentoring, and lesson study, in which the teacher is active can be applied, where physics teachers actively participate.
- In schools, practices such as co-teaching can be developed to enable newly appointed physics teachers and experienced teachers to work together.
- In addition to face-to-face trainings, online or hybrid professional development trainings can also be organized to eliminate time and space constraints.

3.5. Absence of a Monitoring Mechanism

As important as the planning and organization of a professional development program is the monitoring of the effectiveness of the program, i.e., the evaluation of the program and the creation of continuity in the program. This process is dynamic, with feedback mechanisms identifying the strengths and weaknesses of the professional development program and thus enabling making revisions to the implemented model. Evaluation is often overlooked or undervalued in professional development programs. Support for physics teachers should extend beyond the training itself, ensuring that the knowledge gained is effectively implemented in the field. A multidimensional approach should be adopted to monitor physics teachers' progress (Oktay and Eryılmaz, 2020b).

SUGGESTIONS

- Physics teachers can be evaluated by training developers and trainers using various assessment tools (tests, observations, interviews, etc.) to assess the changes in them after the implementation of professional development programs.
- In addition to monitoring the physics teachers participating in professional development programs, changes in their students can also be monitored. It is crucial to remember that the ultimate goal of these trainings is to

facilitate effective and accurate physics learning for students. Therefore, it is recommended to also track the changes in students' learning outcomes.

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CHALLENGES AND SOLUTIONS REGARDING THE USE OF MATERIALS, TOOLS AND EQUIPMENT IN PHYSICS EDUCATION

The effective use of teaching materials is essential to create engaging and meaningful educational environments. Enriching lessons with materials and tools is emphasized in curricula to promote lasting and effective learning. To keep up with the rapid advancements in information and technology, the integration of alternative resources, diverse methods, and technology-based materials is becoming increasingly important. The use of materials and tools in teaching environments, reaching a wide range of students, also promotes equal opportunities in education.

In basic physics/science education, it is crucial to have materials that support learning, make abstract concepts more tangible, facilitate practical application during teaching, place students at the center of learning, and make physics enjoyable and interactive. Various materials used in and outside the classroom can capture students' interest in physics and positively enhance their motivation for the subject. Teaching materials promote students' creativity, problem-solving skills, and their ability to access information and collect data. The following sections discuss the challenges related to the use of materials and equipment in physics education, along with possible solutions:

4.1. Limited Time and Opportunities for Material Use

In high schools, physics courses are allocated 2 hours per week for 9th and 10th grade levels and 4 hours per week for 11th and 12th grade levels. At the current physics curriculum, there are 44 outcomes at 9th grade, 39 at 10th grade, 62 at 11th grade and 68 at 12th grade (Physics curriculum, 2018). As a result of the low number of lessons and the fact that the concepts are quite comprehensive, teachers often struggle to cover the required topics within the limited class time. Consequently, the use of materials to reinforce the subjects is either very limited or completely overlooked. Moreover, financial constraints (e.g., lack of funds for purchasing paid software) and technical limitations (e.g., insufficient access to computers and the internet) in schools further impede the integration of physics-related materials into teaching environments.

SUGGESTIONS

- As a result of the arrangements of school administrations and teachers, additional courses or free time outside the classroom can be created and activities related to the subject area of physics can be organized with materials and tools that support learning in the classroom.

- In cases where school facilities and physical conditions are limited, online materials can be utilized.

- Physics materials that are free of charge or quite cheap and can be purchased with the financial support provided by the school can be researched by the physics teachers in schools by creating a list of resources, which can be more widely available within and outside the school.

4.2. Lack of Pedagogical Knowledge on Material Use and Design

As in every branch, the physics curriculum emphasizes the importance of teachers using materials in their lessons. In the current curriculum, the following statements are used under the heading of matters to be considered:

> It should not be forgotten that preparing teaching materials and coming to class prepared are among the main duties of the teacher. Teachers should not rely solely on textbooks to help their students acquire the knowledge, skills, values, and attitudes related to physics. They should structure and use teaching materials (information notes, presentations, activities, worksheets, worksheets, projects, reading passages, etc.) in a way that is consistent with the learning outcomes, taking into account factors such as grade level, students' interest, readiness levels, and learning styles (Physics Course Curriculum 2018, p. 12).

To fulfill these expectations, teachers need continuous training on material use and design. During their pre-service education, physics teachers should receive training on basic computer skills, digital literacy, and effective internet use to equip them with the ability to develop and utilize materials. However, the current pre-service programs lack specific content related to material identification, development, design, and use for physics teachers (Oktay and Şen, 2012). MoNE also emphasizes the importance of developing and using materials in lessons with the FATIH project (The MoNE General Directorate of Educational Technologies, 2010). This project, called the "Movement for Increasing Opportunities and Improving Technology" (FATIH), was launched in 2010 with the integration of technology. With this project, it is aimed to enhance technological infrastructure in schools and utilize information technologies efficiently.

Laboratories are one of the environments where tools and equipment are frequently used in physics lessons. Laboratories play a vital role in physics education, allow students to experience the concepts in physics, offering opportunities for hands-on experiences and increasing their interest and motivation towards physics lessons. However, the limited weekly class hours compared to the extensive curriculum outcomes in physics courses pose challenges for teachers to utilize laboratories effectively. Additionally, deficiencies in school laboratory equipment and concerns related to exam systems can discourage teachers from using laboratories. As a result, many laboratories become unused over time and are converted into classrooms. These problems hinder teachers' experience in using laboratory equipment and developing the necessary pedagogical knowledge.

SUGGESTIONS

- During their undergraduate education, physics teachers should be given the opportunity to the extent possible to recognize teaching materials specific to physics courses, to have the skills to develop them and to use them. In this way, their attitudes, and abilities towards the use of materials prior to their professional career can develop positively. In this context, it is recommended that courses such as instructional technologies and material design, instructional technologies, teaching practice 1 and 2 should be completely oriented towards physics subject content.

- First of all, in-service trainings can be organized to encourage teachers to use materials in physics lessons. In these trainings, first of all, teachers should be trained on how to access accurate and reliable information and resources. Following the trainings encouraging the use of materials, in-service trainings can be organized for material development by considering the needs at different levels.

- Multidimensional in-service trainings should be developed that cover a range of materials, from simple tools and materials easily found in daily life to advanced software and technology integration.

- During in-service trainings, the teacher should not only be a learner, but should also be encouraged to create user manuals for the materials they develop, enabling them to guide other teachers.

- In-service trainings can cover topics such as on robotic coding (e.g., Arduino), artificial intelligence STEM, Web 2.0, animation, graphics programs, concept and mind maps (Şen and Oktay, 2018), simulation, augmented and virtual reality, podcasts, virtual laboratory, digital games and videos, modeling, 3D printers and mobile applications.

- In-service trainings should continue to develop the scope of the FATIH project and emphasize the effective use of interactive whiteboards and tablet computers for all subjects in physics courses with practical examples.

- In-service trainings should also be organized in laboratory environments, which have an important place in physics courses, to provide the teachers with the opportunity to use experimental tools and equipment concretely. For experiments that cannot be conducted in laboratory environments, online professional development environments should be created for teachers to utilize technologies like interactive whiteboards and computers. In addition, in cases where laboratory environments are unavailable, simple interfaces can be introduced in the classroom environment so allow students to experience the use of tools and equipment in physics lessons, so that the learning process can be enriched in a way that students can achieve both cognitive and affective gains. In this context, demonstration experiments can be utilized.

4.3. Lack of Teaching Materials Specific to the Field of Physics in Turkish

Physics, characterized by its abstract nature, can be conceptually challenging to understand. The accurate understanding of concepts relies on information obtained from reliable sources. In this context, one of the most effective materials is books. Unfortunately, many physics resources are written in foreign languages, leading to translation issues and inaccuracies.

Textbooks and resource books, which play a crucial role in reflecting the curriculum, are also limited in terms of physics content. The MoNE Board of Education is responsible for evaluating and examining textbooks. Common criteria and guidelines are established for reviewing draft textbooks and educational materials, including their electronic contents (MoNE, 2022).

The scarcity of visual and auditory materials in the Turkish language is as significant as the lack of written materials. To address this issue, the "Education Informatics Network (EBA)," an online social education platform provided free of charge by the General Directorate of Innovation and Educational Technologies under MoNE, offers class and subject-based e-content (MoNE, 2016).

SUGGESTIONS

- The physics contents within the scope of EBA can be enhanced and expanded.
- Projects and studies for translating foreign and reliable contents (e.g., *Interactive Physics, PhET interactive simulations* etc.) into Turkish can be initiated. These studies should involve specialists such as academicians, informatics experts, software developers, computer engineers, teachers, and translators. In the process of translating the contents into Turkish, attention should be paid on the accurate representation of physics concepts with the collaboration between field experts, teachers, and translators.
- Integration of media tools into physics courses should be increased. The free use of scientific documentaries, films, magazines, and books with physics content from Discovery Channel, BBC, TUBITAK should be promoted in educational environments. The production of radio and television programs focused on physics education should be encouraged.
- Specific selection criteria should be elaborated for physics textbooks that align with the curricula. Interactive contents (e.g., CDs, supplementary materials, experiment guides, etc.) that reflect real-life applications and offer more opportunities for student assessment can be added. Considering the growing prevalence of mobile devices in our lives, podcast contents that sparks students' interest and curiosity by discussing physics concepts and showcasing current research can be created with the participation of field experts, tailored to students' age and level.
- The number of master's and doctoral thesis studies focusing on material development and use in the field of physics education at universities can be increased. Dissemination activities can be organized to effectively implement the findings obtained from these studies in educational materials and education-teaching process.

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LOW LEVEL OF MOTIVATION FOR AND NEGATIVE ATTITUDE TOWARDS PHYSICS LESSONS

Physics plays a significant role in various aspects of daily life, including technology, transportation, energy, health, social security, and environmental issues. Since physics knowledge is required in several fields, attainment in physics courses equips students with knowledge applicable to these fields and opens up career opportunities in engineering, science, medicine, technology, and space research. Moreover, physics courses enhance problem-solving skills and scientific reasoning abilities. Therefore, succeeding in physics courses has wide-ranging benefits that extend beyond understanding the subject matter; it also involves reinforcing problem-solving skills, scientific reasoning skills, and physics literacy.

Studies have shown that a positive attitude and high motivation toward physics courses are important factors for success. Positive attitudes encourage student interest, active participation, and time allocation for physics lessons. Similarly, high motivation leads to greater effort and engagement in physics courses. However, in Türkiye, and many other countries, students often exhibit negative attitudes and low interest in physics courses. Various reasons contribute to this, including the perception of physics as difficult, challenges in comprehending course materials, and the high difficulty level of exams. Additionally, there may be issues in the teaching of physics courses, such as teachers' insufficient subject matter knowledge and pedagogical content knowledge, limited emphasis on constructivist and inquiry-based teaching approaches, that makes student active, such as problem and project-based learning, as well as a focus on exam-oriented problem-solving rather than conceptual learning, and a lack of adequate laboratory activities.

SUGGESTIONS

To support positive attitudes and motivation towards physics courses, the following suggestions can be implemented:

- *Reviewing and improving the physics curriculum:* We witness frequent changes in curricula in Türkiye. At this point, the physics curriculum has strong features to enhance students' attitudes and motivation towards physics courses. Therefore, instead of radical changes, the curriculum should be continually improved based on scientific research and new information to enhance students' attitudes and motivation.

- *Training and motivation of teachers*: Teachers should be trained and motivated to increase students' attitudes and motivation towards physics lessons. In this context, teacher training programs should be improved, and in-service trainings can be offered for existing teachers.

- *Improvement of laboratory facilities*: Laboratories are crucial in physics lessons as they allow experiments and observations. By improving laboratory facilities and incorporating more hands-on activities, students' attitudes and motivation towards physics lessons can be enhanced. Considering the current state of technology, physics courses can be moved to the virtual environment and students can be supported to understand physics subjects more easily.

- *Emphasizing the relevance of physics in daily life*: Physics is a science used in all areas of everyday life. In this context, life-based physics teaching and life-based assessment and evaluation can be emphasized more. There are many studies indicating that students' attitudes and motivation towards physics courses can increase in this way.

- *Promoting active learning in physics courses*: Physics lessons can be made interactive to encourage students' active participation. Likewise, in student-centered activities, it is extremely important that not only the limbs of the students (*hands-on activities*) but also their minds (*minds-on activities*) are activated.

CHALLENGES AND SOLUTIONS REGARDING THE USE OF OUT-OF-SCHOOL ENVIRONMENTS IN PHYSICS TEACHING

Physics concepts and phenomena can be observed and experienced concretely in various aspects of everyday life. Many examples from everyday life can be utilized in physics teaching. In the context of this reality, it would not be a correct approach to limit physics teaching only to the school environment within four walls. For this reason, it is crucial to go beyond the physical boundaries of the school in physics teaching and to establish meaningful connections between what is learnt in school and experiences gained outside of school obtained through concrete experiences. Therefore, incorporating out-of-school environments in education-teaching processes complements the reality of physics education. Planned, systematic, and structured visits to out-of-school learning environments can be integrated into physics teaching.

Although some steps have been taken toward the use of out-of-school environments in physics teaching, desired outcomes have not yet been achieved in the physics curricula and teacher training undergraduate programs for different age groups and educational levels. For example, in 2018, while, with the decision of the CoHE, the undergraduate physics teaching programs now include an elective course titled "Out-of-School Learning Environments," under the professional knowledge courses for the first time in the undergraduate physics teaching programs of all universities, as a positive development, the secondary education physics curricula published by the MoNE Board of Education and Instruction lack sufficient guidance on utilizing out-of-school learning environments. This omission hinders pre-service teachers from using out-of-school environments in their future teaching practices and reflecting their experiences gained in this course to formal education practices. Moreover, the fact that practicing physics teachers currently working in educational institutions often lack such an experience in utilizing out-of-school environments in physics teaching emerges as another issue.

In addition to curriculum-related challenges, the quality of visits to out-of-school environments is a crucial aspect to support learning at school. The quality of visits depends on pre-visit, during-visit, and post-visit activities. Teachers should select appropriate out-of-school environments, plan activities aligned with visit objectives by contacting the guides in the relevant institution, ensure student readiness for the environment and activities, collaborate with families and school administration regarding security, cost, and transportation, and organize post-visit activities to establish connections between what students have learned in school and what they have experienced outside the classroom, taking into account the learning outcomes specified in the curriculum. Considering all the roles and responsibilities of the teacher mentioned above, utilizing out-of-school environments in physics teaching may pose challenges an become a handicap for teachers lacking experience in this area.

Furthermore, visits to out-of-school environments involve guides in these environments, school administrators, and families as common stakeholders. Cost and transportation issues, as well as ensuring students' safety and meeting their food and beverage needs during visits, and the safe completion of the trip, are important concerns for school administrators and families. These factors can also discourage other stakeholders, including teachers, from organizing visits to out-of-school environments.

SUGGESTIONS

To address these challenges, the following suggestions are proposed:

- The "Out-of-School Learning Environments" course in the physics teaching undergraduate programme should not only increase pre-service teachers' knowledge and awareness of such environments but also provide more opportunities for practical training to experience the theoretical knowledge acquired in the course. In this framework, a new and detailed course content should be designed to enable sufficient observations and practices in out-of-school environments, similar to the "Teaching Practice 1" and "Teaching Practice 2" courses. With the changes to be made in the course content, pre-service teachers can better gain first-hand experience, understand their roles and responsibilities before, during, and after their visits to out-of-school settings, increase their awareness of potential challenges they will encounter in the process, and gain the skills to develop solutions to these problems. The experiences gained during their undergraduate education will enhance physics teachers' willingness to make visits to out-of-school learning environments and incorporate them in their teaching process.

- In parallel with the improvements to be made in the teacher training undergraduate program, it is suggested that necessary improvements should be made in the high school physics curricula to allow prospective teachers to apply the experiences gained during their undergraduate education regarding out-of-school learning environments to their future teaching processes. In this respect, more references can be made to the use of out-of-school environments in the curricula in order to enable students to create meaningful connections between physics and everyday life. Considering that the curriculum is the main determinant of formal education, this emphasis on visiting out-of-school environments in curricula will provide a driving force for not only teachers but also all other stakeholders to take an active role in the whole process.

- Worldwide, science centers are commonly used for out-of-school learning environments for teaching physics concepts. It can be expected that the problems experienced by all stakeholders, especially the problems related to cost and transportation, will decrease with the spread of science centers, which have been established with the support of TUBITAK. The number of such centers has been increasing in recent years. However, out-of-school environments suitable for physics teaching are not limited to science centers. When considered in terms of these problems, physics teachers can benefit from various out-of-school learning environments (e.g., open spaces, aquariums, science museums, various health institutions, industrial establishments) that are close to the school environment in alignment with the learning outcomes of the course.

CHALLENGES RELATED TO INTERDISCIPLINARY APPROACH

The traces of physics can be observed both in our everyday experiences and in scientific and technological advancements. As a science discipline, physics also interacts with various branches of science and applied to a broad spectrum of fields, ranging from astronomy to engineering and from health to art. To effectively capture this interdisciplinary nature, physics education should incorporate numerous examples of physics applications in different domains, adopting a life-based approach. However, the lack of concrete application examples from various fields that can be used in physics teaching often leads many students to perceive physics as a course consisting of abstract concepts that challenging to comprehend, thus fostering negative attitudes towards the subject.

During the workshop organized with the theme of interdisciplinary physics education, experts from diverse fields and scientists gathered to extensively discuss concrete application examples of physics in various discipline. The workshop covered a wide range of examples, spanning from art to engineering, architecture to mathematics, music to audiology. The common conclusion drawn from the workshop was that the interdisciplinary approach in physics education has been overlooked, and concrete examples of physics applications in other fields have not been adequately utilized. In order to address this matter in more detail, it is beneficial to briefly outline some of the application examples in different areas of physics discussed during the workshop.

Firstly, the workshop emphasized the significance of the laws of physics in sports sciences. By focusing on the physics of motion in sports sciences, participants examined human movement and the acculturation of movement with illustrative examples. The workshop emphasized the relevance of the laws of physics in the study of movement, particularly highlighting concepts such as energy, speed, and force encountered in mechanics. Instead of relying on generic examples like “the movement of an object from point A to point B,” which are frequently encountered in physics courses, the workshop proposed the adaptation of context-based approaches using application examples from the field of sports sciences. Similarly, another field where mechanics concepts find application is dentistry. The workshop showcased visual examples illustrating practices for dental health. One of the striking points in these visuals is the frequent utilization of the concept of force in physics.

Another session of the workshop explored applications in audiology. Participants emphasized the importance of basic concepts in sound physics (e.g., frequency, vibration, sound wave properties) in audiology. Music, another field in which concepts in sound physics are used, was also highlighted in a session, where properties of sound, sound sources, and the characteristics of sound in different materials were discussed, with the emphasis on the close relationship between physics and music.

One of the interesting topics of discussion during the workshop was the interaction between physics and the arts. Specifically, the participants showed great interest in how Leonardo Colletti (Colletti, 2017) incorporates the works of renowned painters into his high school physics classes. The examples used in this context aroused curiosity and interest among the workshop participants.

These aforementioned examples demonstrate that physics directly interacts with numerous application areas, even those that may not be immediately apparent. Unfortunately, the integration of this interaction into physics lessons across various age and grade levels cannot be observed.

It is possible to examine the interdisciplinary nature of physics from a unique perspective by referring to the expressions used in the presentation of the Nobel Prize in Chemistry ceremony in 1908, honoring Ernest Rutherford, professor of physics at Victoria University:

> Though Rutherford's work has been carried out by a physicist and with the aid of physical methods, its importance for chemical investigation is so far-reaching and self-evident, that the Royal Academy of Sciences has not hesitated to award to its progenitor the Nobel Prize designed for original work in the domain of chemistry – thus affording a new proof to be added to the numerous existing ones, of the intimate interplay one upon another of the various branches of natural science in modern times (NobelPrize.org Web Page).

As anticipated, this interdisciplinary nature of physics is directly manifested in the process of physics education. For instance, concepts and topics from diverse fields of physics and chemistry, such as atomic and molecular structures, matter and its properties, nuclear physics, radioactivity, and thermodynamics, are taught in high school physics and chemistry courses in Turkey, as well as in other countries.

When teaching interdisciplinary subjects, the knowledge acquired by students in one course and the experiences they gain can serve as prior knowledge for the gains in subsequent courses and significantly affect the construction of new knowledge. psychologist David Paul Ausubel, known for his studies in the field of educational psychology, revealed in his theory of meaningful learning that the learning process of individuals is closely connected to their prior knowledge, emphasizing the crucial and decisive role that prior knowledge plays in acquiring new knowledge. In this respect, the theory of meaningful learning emphasizes the necessity of considering students' prior knowledge in the educational process. As curricula serve as a guide in this process, it is desirable to adopt a similar approach during curriculum development studies.

Within the context of teaching interdisciplinary subjects, aspects such as the scope and sequence of objectives to be included in the curricula of different courses, establishing connections between prior knowledge and new knowledge to be acquired, and fostering intra- and inter-curricular associations in relevant objectives gain significance.

Considering the above information, one of the challenges encountered when examining the curricula of the courses taught at the secondary education level is related to teaching interdisciplinary subjects in physics. For instance, the "modern atomic theory" is incorporated in the physics and chemistry curricula for secondary education, implemented since the 2018-2019 academic year. This theory, which describes the quantum model of the atom, is introduced for the first time in the 9th grade chemistry curriculum and extensively covered in a unit of the same title in the 11th grade chemistry curriculum. In the physics curriculum, the modern atomic theory is addressed in the 12th grade. Upon evaluating all the outcomes and explanations provided in the curricula collectively, it becomes apparent that there is an inconsistency in the teaching of modern atomic theory. A notable example of this is the teaching of the concept of "orbital". Essential topics like wave-particle duality and the uncertainty principle, crucial for understanding the concept of orbital in the behavior of electrons within atoms according to the modern atomic theory, are solely addressed in the 12th grade physics curriculum. However, the concept of orbital is introduced in the 11th grade chemistry curriculum, in the previous grade, with the aim of students comprehending this concept without prior knowledge of the aforementioned topics. This inconsistency in the curricula across different courses can cause difficulties in understanding interdisciplinary topics, such as the modern atomic theory.

SUGGESTIONS

In recent years, the process of updating the curricula in our country has been characterized by dynamism. Building upon the motivation of this dynamic process and the information provided above, the following suggestions can be put forward for future curriculum updates:

- The physics curriculum can be enhanced by incorporating concrete application examples from various fields of physics into the educational process. In this respect, including examples from diverse fields into the curriculum can serves as a guidance for teachers. This approach will stimulate students' interest and curiosity, actively engage students with different interests and types of intelligence into the education process, enable them to evaluate the world around them through a physics lens, and potentially foster positive changes in their attitudes towards physics.

- When teaching interdisciplinary topics, it is necessary to develop the curricula of different courses collaboratively. At the earlier stages of curriculum development process, interdisciplinary topics in physics courses can be identified and how these topics intersect with other subjects can be determined.

- All stakeholders, particularly curriculum development specialists, field educators, and teachers in the relevant field, should work together to update the curricula. In this process, it is crucial for all stakeholders to prioritize consistency in the curricula not only within a course across different grade levels but also between different courses when teaching interdisciplinary subjects.

- Teachers have a vital role in the successful implementation of curricula. When teaching interdisciplinary subjects, teachers can adopt an "interdisciplinary approach" and direct the teaching process by considering the connections between courses within the limits specified in the curricula.

- The quality of textbooks has a special importance in students' acquisition of new knowledge. Therefore, it is expected that textbook authors explicitly incorporate the connections between courses when dealing with interdisciplinary issues in their course materials.

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