Chapter 9

Reconsidering Physics Education: Barriers to Student Learning and Ways to Effective Physics Instruction

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Abstract

This article examines the issues associated with physics education and discusses which barriers affect physics learning and how effective physics teaching is possible. The first part addresses two problems that prevent students from succeeding in physics classes. This section provides an explanation of the underrepresented and female student participation and retention within science, technology, engineering and mathematics related disciplines, especially in the field of physics. The second part emphasizes the importance of knowledge and pedagogy to be used in physics teaching and describes the characteristics of effective physics teaching. The final section makes recommendations for the training and development of physics teachers and instructors, with the aim of increasing the participation and retention of diverse students.

1. Introduction

There have been calls for reform-oriented research and development to restructure science, technology, engineering and mathematics (STEM) teaching. Research in K-20 science education has argued that there are limits to teacher-centered approach and that the advantages of the student-centered approach should be emphasized. Considering the limits of traditional teaching, designs and improvements have been made in the world that will increase the learning gains of students in STEM fields, especially in physics education. Physics education researchers have aimed to increase the participation of diverse students by implementing reform-oriented strategies and to emphasize how physics learning takes place. Despite innovations in the

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field of physics education, to overcome obstacles, it is necessary to recognize the problems in practice and to pay attention to the training and development of physics teachers. From Turkish Science Education perspective, as physics teachers, we should be aware of these barriers to effective physics teaching and learning and understand how to overcome these challenges through the suggestions of research-based curricula and innovations. In this paper, I will review the literature based on barriers to diverse learners' needs in physics learning and effective strategies in teaching physics.

1.1. What filters or supports diverse students' achievement in physics?

Ministries of education in different countries have called for innovative approaches in teaching and learning methods to enhance learners' attendance and retention in science, technology, engineering, and mathematics (STEM) fields (Ministry of Education (MEB), 2011; National Research Council [NRC], 2012, 2013; American Society for Engineering Education [ASEE], 2012; Singer, et al., 2012). In particular, the statement on undergraduate STEM education (NRC, 1996) indicated that 21st century skills emphasized citizens to develop different types of knowledge and abilities that would enable different employment opportunities. Educational institutions emphasized that the responsibilities of science teachers were more about teaching how science was done and how to engage in scientific practices rather than transferring knowledge. These skills encouraged students to have scientific, mathematical and technical literacy to take more meaningful roles in society. It was aimed that 21st century students gained different literacy skills by participating in STEM fields and developed positive attitudes towards science and technology, and scientifically examined and interpreted socioscientific phenomena.

For effective STEM education, Discipline-Based Education Research (DBER) studies examined a particular discipline, such as physics or engineering, with very different methodologies in terms of knowledge and application (NRC, 2012). Research studies in the field of science education began in the early 1900s; however, the real breakthrough came in 1950 when Sputnik was sent into space, recognizing the need for further development in the fields of STEM and more funding opportunities were provided for the research to be done. In these periods, it was aimed to improve education and training by conducting curriculum work in STEM fields; one of them was the Science Curriculum Development Study (SCIS), developed by physicist Robert Karplus in 1962 (Rebello & Zollman, 2005). Especially in the context of the philosophy of John Dewey (1916), Physics Education

Researchers (PER) argued that the development of curriculum materials and teaching methods have focused on increasing the science learning capacity of students by creating learning contexts that include students' interests and scientific discourse practices (Cummings, 2011). The aim was to increase students' continuity in science learning and to facilitate their understanding of physics concepts.

Physics, among other STEM fields, is a science of the most interdisciplinary in nature; however, it has proven to be a science that students have the most difficulty in understanding and lack of interest (Duit et al., 2014). Seventy years ago, there were problems with science teaching and learning, with the education system emphasizing plug-and-chug problem-solving and memorization (e.g. Caswell, 1934; Dewey, 1916). Innovative studies have highlighted that science teaching should be designed around the learning needs of students. Mazur (1997) noted that although teacher-oriented methods of teaching physics have produced many successful scientists, different methods have been needed to facilitate the learning of students with different qualities. Research on physics education has given importance to the development and implementation of new curricula and teaching methods based on a student-centered approach to reduce students' misconceptions and enable them to understand and apply scientific practices.

At the beginning of the 1970s, experienced physics educators have studied the efficiency of physics lessons taught with a single teacher in large and crowded classrooms. As a result, they realized that physics was a subject that was not liked and understood by students, that they were unable to reconcile physics topics with everyday life, and that they were unable to acquire the scientific thinking skills necessary for advanced physics courses (Redish, 2003). To understand the students' challenges in detail, physics education researchers have focused on how physics learning takes place and identifying misconceptions or alternative conceptions in specific topics. The detection of students' misconceptions has led to the development of research-based teaching materials and strategies. For example, a multiple-choice test, called Force Concept Inventory (FCI) was developed to investigate students' understanding of basic concepts and misconceptions about mechanics (Halloun & Hestenes, 1985; Hestenes et al., 1992). When Dr. Mazur, a professor of physics, applied the FCI test to large lecture classes, he noticed that students had difficulty in understanding the subject, so he tried to find alternative applications to teaching physics. Mazur (1997) argued that the Peer Instruction (PI) method would be beneficial for students to learn physics. The Peer Instruction (PI) (Mazur, 1997) method was developed as a collaborative learning activity in which students answered multiple choice and concept-oriented physics questions by discussing with their peers with the help of electronic clickers. There were also different curricular materials that aimed to address students' learning difficulties: Physics with Inquiry (McDermott, 1996), Physics Tutorials (McDermott & Shaffer, 1998), Workshop Physics (Laws, 1991), and Interactive Lecture Demonstrations (Sokoloff &Thornton, 1997). For example, Lillian C. McDermott at the University of Washington's Physics Education Group (UWPEG) and colleagues (1998) found that it was necessary to emphasize concept formation in physics through qualitative reasoning based on the conceptual change method; students' ideas were targeted to learn through the stages of "revealing/ confronting/ solving/ reflecting." With the tutorials developed, students were expected to work in groups collaboratively on questions aimed at uncovering misconceptions. These innovations in physics education were supported by the advantages of modern technology, and adaptations could be made to the format and layout of physics courses. Efforts to develop curricula and instructional strategies were catalogued in the study of McDermott and Redish (1999) and on the website of the Physics Education Research (PER)[2] community.

As an alternative to traditional large and crowded lecture halls, teaching and learning environments have been developed in accordance with the constructivist approach. These classrooms are prepared as active learning environments or studio physics classes. In these environments, students are prepared for learning physics by interacting comfortably with the physics teacher and their peers, collaborating, establishing dialogues and actively following the material they have learned. It has been observed that learning in these environments takes place by using and comparing different knowledge structures and by gaining the practice of scientific discourse (Beichner & Saul, 2003). In studio physics learning environments, the lecture and laboratory components of the course were integrated into a single lesson, and the role of the teacher has changed from the role of knowledge transmitter to the role of facilitator to active student thinking and promote collaboration among students (Cumming et al., 1999). As Beichner et al. (2007) reported, innovative teaching methods, classrooms and software in physics education have been instrumental in overcoming the limitations of teacher-centered methods. These developments have significantly improved students' conceptual understanding through students' participation in collaborative work, making evidence-based claims and engaging in critical thinking. In this process, the transition from a teacher-centered approach to

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2 https://www.aapt.org/ComPADRE/

a learner-centered approach was emphasized. Thus, through different types of activities and complex problems, it has been aimed to enable students to develop problem-solving skills and self-regulation through participating in the norms of questioning, argumentation, and communication.

The Physics Education Research (PER) has focused on creating new classroom environments and improving teaching materials and technology, along with investigating misconceptions in students' physics learning. However, one of the most important obstacles to students' learning in physics education is the traditional teaching that is emphasized in the textbooks and the courses prepared through the transmissionist model (Redish, 2003). According to Tobias (1990), in a typical physics course, learners cannot learn a lot of material just by listening or just by numerical manipulation; in turn, physics is not of interest to students, and students are biased toward understanding the bigger picture of what physics is all about. For effective learning, instead of the inadequate transmissionist-based model where knowledge has been defined as absolute, teaching should be learner-oriented to achieve the desired learning outcomes by stimulating students' resources. Knight (2004) described the scientific constructivism model in physics education as a replacement to the transmissionist model. According to constructivism, the role of the teacher is not that of transmitting knowledge, but that of guiding the acquisition of knowledge. In this model, the teacher facilitates the learning process by revealing the students' prior knowledge. Students, too, take an active part in the learning process; they create their own conceptual models by assimilating or accommodating concepts and employing them in new problems or situations. With constructivist approach, knowledge is not defined as absolute and certain; knowledge is formulated and organized by changing and structuring concepts through social cooperation.

The PER community's research is based on how physics learning occurs cognitively; it is also based on scientific research to understand the social and affective factors that influence the methods of physics learning and their effects in different environments and contexts. Through research on students' conceptual challenges, technology-enhanced studio physics classes have been designed to integrate hands-on experiments into lecturing to establish a base for effective physics education. However, the dissemination of constructivist teaching approaches, developed as an alternative to the transmissionist model, is another obstacle to physics learning. A major challenge for PER community is the limited use and dissemination of research-based instructional designs and strategies by other physics teachers since physics teachers tend to use traditional teaching practices. Henderson et al. (2011) stated that although teachers participated in various professional development programs to learn innovative methods, they had an attitude of not using them in the classroom because of the redundancy of subjects in the physics curriculum and their tendency to emphasize memorization. Education reports such as ASEE (2009) and NRC (2012), which highlighted innovative approaches, were also dissatisfied with teachers' understanding, implementation, adoption and adaptation of new teaching materials.

Research on physics education has observed that physics teachers' teacher-centered practices hindered their comprehension and implementation of innovative methods and curricula. Henderson and his colleagues investigated how the products of PER community were understood and used in fidelity; in these studies, it turned out that there were situational and personal limitations and divergent expectations (e.g. Beach et al., 2012; Henderson et al., 2011; Henderson & Dancy, 2009). Individual factors were associated with characteristics of physics teachers, such as their beliefs about teaching and learning science, their values, and their knowledge of teaching methods. Situational factors, unlike individual constraints that affected teachers' teaching methods, consisted of factors such as teaching resources, time constraints, course load or institutional reward system. Inadequate training, time, insufficient incentives, and faculty change were among the most cited situational obstacles (e.g. Brownell & Tanner, 2012; Crawford, 2014; Sunal et al., 2001). They also found divergent factors or expectations that described the interaction between the PER community and physics teachers. For example, physics teachers thought of innovative methods and curriculum as a bad, dogmatic, or short-term need (Henderson & Dancy, 2008).

The PER community have put significant effort on the production of research-based curriculum and teaching methods for undergraduate and high school physics education: they conducted extensive research on how to learn physics more easily and on students' capacity to think and understand physics topics. Findings from the work of Henderson and colleagues were based on other experimental studies (e.g., Brownell & Tanner, 2012; Crawford, 2014; Singer et al., 2012) and the reform documents of national and international committees (NRC, 2012, 2013). These studies showed that traditional physics instruction and limited dissemination of new reform-oriented curricula were two of the most problematic issues and constitued obstacles in physics education. Over the years, the curriculum and lesson plans of physics courses have been mostly content- and results-oriented. This means that physics teachers need to structure knowledge through new learning experiences by actively participating in professional development programs to learn how to implement new strategies. According to the recommendations of national committees (e. g. Singer et al., 2012; NRC, 2013), physics teachers should acquire unique knowledge of research-based teaching methods and enable their students to become active participants and thinkers in meaningful learning processes. In this process, educational research projects should be supported by universities and organizations to ensure the participation of many students in formal and non-formal education institutions for scientific studies. In physics education, although extensive studies have been carried out in cognitive, social and affective dimensions, it has been observed that underrepresented groups such as women, minorities and students with disabilities experience difficulties. Beichner et al. (2007) stated that learning environments prepared by physics educators, such as studio physics, were conducive to increasing student participation for active learning; and that different research studies were still needed to ensure the continuity of participation of underrepresented groups. In their study, Meyer and Crawford (2011) proposed the use of innovative strategies to contribute new science teaching approaches to students with different characteristics, to adapt students to different cultural educational approaches, and to increase their competence in science learning. To emphasize multicultural science education, it has been necessary to reach groups of students with different learning skills and increase their attendance in STEM fields, particularly in physics, with reform-oriented practices.

The recommendations of the Congressional Commission on the Advancement of Women and Minorities in STEM Development emphasized that increased participation of diverse students, women, underrepresented minorities and students with disabilities in STEM fields could only be achieved by thinking of science as a process of knowledge construction (Bordonaro et al., 2000). Science was emphasized by white and masculine images; and science has influenced the participation and active role of women, girls and students from different cultures in STEM fields (Robinson, 2021; Scantlebury et la., 1996). These stereotypical approaches have influenced the learning processes of students from different groups in science classes; therefore, over the years, it has been observed that white men were more successful in participating in and continuing science fields than less represented groups of women students. Practices used in science education have significantly influenced students' interest, participation, and continuity in STEM fields. Science teachers' unconscious acceptance of stereotypes in STEM education might influence the teaching and learning process. One of them was the prejudice by teachers that science or physics was a male-dominated field (Kahle & Meece, 1994; Watt & Eccles, 2008). To ensure and maintain the active participation of teachers and students in STEM education, the following question needs to be addressed: "How do factors such as cultural background, ethnicity, nationality, and gender affect physics learning and teaching?"

Studies in physics education provided solutions for all students to have a meaningful learning experience (Brookes et al., 2020; Brahmia & Etkina, 2001; Etkina, et al. 1999). One of the most important factors affecting the performance of individuals in a course or learning process was their self-efficacy, which depended on the belief of the students in their own ability (Bandura, 1994). For example, Kost, Pollock and Finkelstein (2009), in their study designed to define the gender difference in physics courses; they found that male and female students' learning from the same physics course differed depending on their beliefs, attitudes, and physics and mathematics background. In another study, Sawtelle (2011) investigated the role of self-efficacy in increasing the participation of students in physics, especially from underrepresented groups, and identified self-efficacy as a necessary indicator for success in physics. With these studies, it shows that innovative reforms are important not only to support the dissemination of new curricula and strategies, but also to focus on examining the academic learning process from a social and cultural point of view and understanding the difficulties that diverse students may experience in the learning process.

In different studies (Beichner, 2008; Brahmia, 2008; Kost et al., 2009; Sawtelle, 2011), the replacement of teacher-centered learning with student-centered methods has enabled different groups of students, such as women or underrepresented groups, to succeed. This, reducing the stereotyped threat, argued that physics learning could take place in cognitive, social, and affective dimensions, and that students could increase their self-efficacy in physics through active learning. Students may not come to physics classes with an academically advantageous background (as a background in mathematics and physics). To create an equal environment of educational opportunity, curricula must address a variety of student needs, cognitive, social, affective, and epistemic development by creating effective learning environments. Therefore, it is important to empower students to understand the definition and application of science by participating in STEM fields. It is also important to emphasize the significance of scientific literacy to restructure physics education and ensure equal opportunity.

1.2. Innovative Approaches to Physics Teaching

The American Association for the Advancement of Science (AAAS, 1993) argued that citizens' understanding and application of the experimental, observable, and inferable characteristics of science could help them solve complex problems involving qualitative and quantitative evidence, logical arguments, and uncertainty based on events in their daily lives. It was noted that citizens needed to have the ability to think critically to believe that scientific knowledge was changeable based on evidence collected in a perseverance way to the point where there was no alternative explanation (NRC, 2012). These statements of national committees on reforming the science education in the United States focus on the main objective of science education in the world. The aim is to equip students with knowledge, beliefs, and abilities that they could practice the work of scientists: exploration of scientific questions, data collection and analysis, engaging in scientific debates to make informed decisions about scientific issues related to their lives. According to Cavagnetto (2010), scientific literacy is related to not only application of scientific concepts through hands-on or minds-on activities to collect and analyze data, but it also requires the interpretation of data to construct evidence-based explanations. The aim to enhance scientific literacy suggests the use of research-based, innovative practices, curriculum materials and academic learning environments to enhance students' participation in dialogic discourse to think critically and understand science in the context of societal issues.

In 1957, the Soviet Union's successful launch of Sputnik into space showed the need for restructuring in STEM fields in different countries, especially in the United States. Therefore, since those years, research projects have been supported with the aim of increasing scientific literacy in K-20 science education (AAAS, 1993; NRC, 2012, 2013). The President's Council of Advisors on Science and Technology (2012) expressed concern on this issue that it has been observed that the teaching methods of undergraduate science and engineering courses did not provide students with quality experiences and did not encourage students' participation in STEM fields. To identify these challenges, discipline-based education research (DBER) has had a critical role to play in developing new instructional strategies and curriculum and to understand how students learn concepts in science disciplines. McDermott (1993) discussed the failure of the traditional teaching approach, emphasizing the accumulation of factual information and learning by rote learning. This was attributed to teachers' experience of learning through didactic methods, from the general to the specific. The expectation of the traditional approach was that students would have the knowledge to quickly solve similar problems in the context of science or physics.

Previous research has found the traditional lecture format to be an ineffective tool as students were in the role of passive receivers of information (e.g. Cuban, 1990; McDermott, 2001; Redish, 2003; Sunal et al., 2001; Van Heuvelen, 1991). Teacher-centered methods led to increased misconceptions in students and developed negative attitudes towards physics: some students disliked physics or thought that physics had no connection to everyday life (Redish, 2003). As McDermott (1990) suggested, the student brain was not a blank slate; students' prior knowledge and experiences could lead to a misunderstanding of the physics concept presented. Physics teachers must uncover students' pre-existing knowledge of the subject not as isolated abstractions, but to build on coherent and meaningful conceptual understanding. In this process, the role of teachers should be to ensure that students are aware of their existing information systems to organize and make connections between real-life events and the previous topics taught in classes.

Physics teachers should use appropriate strategies and activities to bring alternative concepts or misconceptions to the fore and turn them into scientific concepts. For example, Brown and Clement (1989) and Clement (1993) used the "bridging strategy" in their work and lecture to clarify students' concepts and overcome alternative conceptions by linking similarities or analogous situations to each other. In the study, students were asked whether an upward force acted on a book on a table; many students in the class believed that static objects could not exert an upward force. It was observed that when another physical condition was used, for example when we pushed a spring downwards, the spring was believed to be able to exert an upward force on the hand. Since students interpreted these two physical situations differently, it was emphasized that physics teachers could facilitate learning by making an analogy between the "hand in the spring" and "book on the table" problems. Teachers used the "Socratic teaching" method to guide students to make connections between two similar, but different situations by analogy.

Reform studies in physics education have revealed the necessity of student-centered physics education to create a scientific thinking system by defining the learning needs and knowledge levels of students. The student-centered learning model argues that rather than the absolute and precise transfer of knowledge from person to person, knowledge is socially constructed, and efficient learning requires the active participation of students. According to this model, the social constructivist approach is philosophically emphasized to support the development of students through applications that address the cognitive, social, and epistemic thinking system (Duschl, 2008; Knight, 2004). Rather than emphasizing learning by rote, this approach aims to enable students to experience reflective and independent learning as active participation. According to Van Heuvelen (1991), the role of the teacher in student-centered learning is to guide students to build knowledge through their independent and collaborative work. Teachers should make the lesson interesting by designing new materials and strategies to reveal students' prior knowledge and misconceptions; students should take an active part in the construction of concepts, solving problems and evaluating thoughts in discussions. Classrooms conducive to group work can help students actively engage in physics, doing, thinking, and speaking, rather than being passive (Laws, Sokoloff, & Thornton, 1999). Curriculum materials for guided inquiry enable students to build knowledge by taking responsibility and discussing in collaboration with their peers.

Students need to develop diverse literacy skills such as mathematical, scientific, and reading literacies to be able to utilize the language of science in physics classes. A coherent physics understanding demands the construction of content and practical knowledge in various forms: the use and development of visual or mathematical models, the manipulation of materials necessary to design experiments, the collection and analysis of data, the making of explanations using scientific language, and so on (Airey, 2009). To this end, students are able to actively think, apply and explain about various forms of knowledge related to scientific, cultural and social issues in society. The physics course does not only include subject knowledge; it also requires students to develop knowledge of how to adopt various representations: oral and written language, mathematics, tables, graphs and diagrams, or experimental tools, laboratory equipment, or any physical object. Using the language of science is necessary to make the learning process a more meaningful one, to make sense of doing science and to connect with everyday situations. Learning physics is about more than rote memorization of definitions and formulas; students need to relate physics concepts to the physical world and understand their theoretical and experimental applications to construct coherent physical models. This requires teachers to prepare different formative assessment forms to support learning. Teaching materials including curriculum and assessments should enhance students' engagement to explain their ideas, make comparisons among diverse thinking patterns, and reconceptualize the concepts through participating in a group work, developing and using different forms of models of physical phenomena (Black & Atkin, 2014). Studio or workshop physics classes can support students' participation in the discourse of science to solve a problem toward a common goal through conceptual or representational models or mathematical models (Prince, 2004). Therefore, teachers should also have effective classroom management strategies to monitor discussions and group work to reveal students' existing conceptions and assimilate or accommodate the new knowledge through scientific structuring.

Considering the limitations of traditional physics teaching, research on curriculum development has produced new teaching materials to guide learners in developing their understanding of science concepts (Beichner et al., 2007). Through replacing lectures with active learning strategies such as Peer Instruction (Mazur, 1987), Interactive Lecture Demonstrations (Sokoloff & Thornton, 2004) or Just-in-Time-Teaching (Novak, et al., 1999), the learning process allows students to participate in scientific research activities that enable them to acquire and develop knowledge by doing and experiencing (Handelsman et al., 2004). For example, Dr. Mazur (1997) noticed the conceptual difficulties of students in physics classes and developed Peer Instruction, which allowed students to answer multiple choice questions through electronic communication system by discussing in pairs with their peers during the course. In this method, responses can be recorded electronically, students' conceptual thinking system can be followed, and the effectiveness of teaching can be evaluated. Interactive Lecture Demonstrations (ILD) was another effective strategy developed to engage students in physics classes and for conceptual thinking-oriented lectures (Sokoloff & Thornton, 1997; Thornton & Sokoloff, 1997). This strategy starts with a demonstration: a collision between two cars while a heavy car moves toward a stationary light car. After the demonstration, the teacher directs the student to make a prediction about the physical event: which of the cars will exert the greater force? After the prediction section, students perform the experiment to reconceptualize the phenomenon and receive evidence-based feedback of their predictions. Besides, for physics lessons, traditional classrooms were replaced by studio or workshop classes such as SCALE-UP (Student-Centered Activities for Large-Enrollment Undergraduate Programs) (Beichner et al., 2007) at North Caroline State University where students worked collaboratively to solve a problem. SCALE-UP classrooms are designed to help teachers move around desks, interact with groups to provide immediate help, and identify learning difficulties. These studio or workshop classes allow teachers to do the lecture and laboratory part of the lesson together including hands-on activities hands-on activities, simulations or Microcomputer-Based Laboratory (MBL) into lecturing (Thornton & Sokoloff, 1998).

In addition, researchers from the PER community researchers from the PER community or physics education have developed valid and reliable survey tools to assess factors affecting learning process. David Hestenes and his colleagues developed Force Concept Inventory (FCI) to examine students' conceptual understanding of Newtonian dynamics through exploring conceptual challenges, naïve concepts and confusions about the topic (Hestenes, et al., 1992). The survey results provided information about the learning gains of their students[3]. In another study, the study, led by Richard Hake, used both traditional and interactive methods, comparing the FCI test scores of 6,000 introductory physics students at the beginning of the semester and at the end of the semester. The results showed that traditional courses failed to convey students' basic conceptual understanding, with learning outcomes being only 23%; however, it was claimed that students' learning gains were 48% at developing conceptual understanding in courses that included active teaching activities (Hake, 1998, 2001). The results of the study emphasized that rather than result-oriented courses in which students were passive, methods that enable students to take active responsibility in the learning process would facilitate students' learning, increase interest in science and enhance their retention in physics (Hake, 2001). Cummings and colleagues (1999) showed that there might be lower learning gains as a result of interactive engagement courses due to the implementation problems. In the study, the interactive course included the use of Interactive Lecture Demonstrations (Sokoloff & Thornton, 1997) and Cooperative Group Problem Solving (Heller & Hollabaugh, 1992) in five experimental classes. The control group included seven standard studio classes taught with traditional course materials. Each class had 30-45 students. The control group at a studio class was taught with traditional methods, and learning gains were similar to Hake (1998) results. The experimental group's learning gain was smaller ($< g_{FCI} >= 0.35$) than Hake (1998, 2001) for interactive classes.

Studies have shown that the application of research-based curriculum materials in studio or workshop classes or interactive learning environments was more effective than the lecturing method (Hake, 1998; Cummings et al., 1999). However, in the teaching of physics, problems have been observed in the dissemination of reform teaching practices; it turned out that teachers continued to use lecturing practices since there were situational, personal obstacles and divergent expectations that prevented teachers from applying new methods (Henderson & Dancy, 2008). To make the learning

3 Learning Gain = (Posttest average- Pretest average)/ (100- Pretest average)

process more effective, physics teachers need to understand, implement or adapt innovative teaching strategies. Physics teachers or instructors should be aware of these alternative teaching strategies and develop knowledge of instructional strategies, curriculum, and assessment to empower students' scientific discourse practices. Physics teachers should experience learning with innovative methods to advance their understanding and practices.

Shulman (1986, 1987) argued that knowledge base of teaching was defined as pedagogical content knowledge (PCK) beyond the knowledge of content and general pedagogical knowledge. According to Shulman (1986), the intellectual work of teachers was related to knowledge of diverse modes of instructional strategies including analogies, models, and explanations to make the content explicit and coherent for students. PCK was defined as teachers' professional knowledge addressing content, pedagogy for teaching and learning of a specific topic (Kind, 2009). Bransford et al. (1999) stated that effective teachers had the knowledge to use strategies, assessments, and curriculum to create an imbalance in students' misconceptions to develop more plausible and fruitful conceptions. Therefore, physics teachers need to guide students to take an active part in the practice of scientific inquiry. In this process, students should be encouraged to participate in activities such as asking questions, defining problems, collecting and analyzing data, comparing different situations and explanations, and solving complex problems (Etkina et al., 2006; Zohar & Schwartzer, 2005). Teachers who embrace these aspects of PCK define that learning is a holistic process, considering the diversity or needs of the students in their classrooms, rather than directly adapting the prescriptions of textbooks or curriculum.

Atkin and Brown (2002) have presented teaching as a challenging task with its complex and intellectual meaning, including values, beliefs, and conceptual perceptions, the learning environment, teacher epistemology, student epistemology, and other contextual factors that shape instruction. Teaching requires more specialized knowledge than mere subject knowledge. Teachers can select and tailor strategies and assessment methods to address students' learning needs. Experienced physics professors have an important role in shaping physics education to improve teaching and learning processes. Physics teachers need to be informed, trained, and involved in physics education research and to understand findings and address them in teaching specific content and assessing students' learning. Teachers need to be not only aware of the diverse and unique needs of their students, but also adapt pedagogical approaches to serve those needs. Instructors can make student thinking visible to communicate with and stimulate their thinking. Instructors should plan the instruction to create a comfortable classroom climate in engaging students in nature, practices and discourses of science. Epistemic, conceptual, and social learning should be harmonized into the instructional process through curriculum, instruction and assessment (Duschl, 2008). This helps instructors monitor students' thinking and learning to develop and evaluate scientific reasoning and participate in scientific discussions.

Effective teaching includes successful instructional strategies in the context of students' prior knowledge, beliefs, and values. Effective teachers must have professional knowledge of how to teach a specific topic besides general teaching strategies to recognize students' conceptual difficulties. Physics instruction should empower students with diverse backgrounds and abilities through designing an active learning environment and using innovative strategies. When physics classrooms involve hands-on group activities, students can engage in doing science through data collection and analysis and communication to understand real-world physics and learn through self-regulation. Interactive learning can help students be aware of their existing conceptions and compare differences between their own and others' thinking processes to make decisions continually. Physics education researchers should work with physics teachers to develop consciousness about research-based curricula and innovative strategies. Physics teachers should be part of professional development programs to raise awareness of how to address diverse students' needs, to overcome situational barriers and engage in practices of scientists. In this way, physics teachers can make students understand nature of science, how real science is conducted and how culture and society influence the construction of scientific knowledge.

2. Discussion and Concluding Remarks

From the previous discussion, we can conclude that teachers need to adapt their level of knowledge and practices from the traditional approach (teacher-centered) to the constructivist approach (student-centered). Despite research-based curriculum design and the development of instructional strategies, research studies have proven that physics teachers continue to use traditional approaches (e.g. Cuban, 1990; Henderson et al., 2011; McDermott, 2001; NRC, 2013; Redish, 2003; Sunal et al., 2001). The traditional method tends to discourage students from developing comprehensive scientific knowledge through the application of scientific practices. Waxman, Padron, and Garcia (2007) describe the practices of the lecturing method as "poverty of pedagogy": with this method, students engage in a competitive inquiry through memorization. Teacher-centered teaching, based on a positivist view of knowledge, holds that knowledge is absolute, that expertise in knowledge occurs through the accumulation of factual knowledge, and that learning takes place by transferring from the knowledgeable.

According to Singer et al. (2012), science education should provide students with opportunities to understand and apply the nature of science and scientific practices, as well as basic subject matter knowledge of the core theory and laws of a discipline in the STEM field. It should be ensured that students learn theoretical and practical knowledge in an active and interactive way through interconnected practice. Students should be able to make persuasive explanations by acquiring the skills of critical thinking in solving complex problems. Teaching and learning should be planned and implemented in accordance with the constructivist approach of science, considering cognitive, social and affective contexts. Innes (2004) asserts that theory and practice are not independent of each other; in teaching methods where theory and practice are intertwined, students have the experience of solving complex problems in cooperation to utilize quantitative and qualitative reasoning and modeling practices and assessing their self-efficacy. In this way, students can have the ability to make statements based on scientific evidence, to make connections between scientific processes and science-related issues in society.

Traditional physics courses are based on memorizing topic-oriented formulas and solving questions with the plug-and-chug method. In these courses, the laboratory portion includes experiments in a "cookbook" format with step-by-step procedures to prove a law taught in the course (Redish, 2003). This approach minimizes student interaction and student engagement and includes solving assessment questions in the textbook. Science teachers, especially physics teachers, can learn and develop strategies to create a student-centered learning environment where students are more active. Instead of outcome-oriented rhetorical questions, teachers can guide classroom discussion by creating authentic questions and activities that encourage students to participate and explain. Context-oriented problems can provide problem solving related to daily life to enhance students' interest in physics. Student-centered learning can also be created by incorporating web-based simulations (Phet Simulations) (Wieman, Adams, & Perkins, 2008) and classroom response systems (Peer Instruction) (Mazur, 1997) into the teaching of the lesson, using educational technologies in the regular classrooms.

Moreover, physics teachers should plan lessons and organize formative assessments that encourage students to focus on the process rather than the outcome. Effective physics teaching and learning requires students to focus on the "how" and "why" along with the "what" questions, and to generate their own questions and recognize problems. Teacher development is continuous. Teachers must identify problematic situations in their current practice and develop theoretical and practical knowledge for better implementation. After identifying the problem, teachers make the lesson plan by determining the research-based strategy to solve the problems. In this process, they can make changes and adaptations to the strategies chosen according to the needs of the students and the learning environment. Physics teachers or instructors can work with physics education researchers or the PER community to understand and experience the implementation of innovative strategies. To make the dissemination process more practical and easier, physics education researchers can support physics teachers by developing guidebooks for using reform-oriented practices including written and technological resources.

Physics teachers or instructors are responsible for changing the quality of teaching and learning to increase the participation of students from different cognitive, social, and cultural backgrounds. Physics education researchers must overcome strong stereotypes and strive for equitable instruction to increase the participation of both women and underrepresented minorities in physics education. Many students (especially women) think that physics lessons are based on rote learning and are not connected to life; they leave the physics or physics related fields and find the science of physics alienating (Handelsman et al., 2007). Teachers should implement strategies that create a more inclusive classroom by considering student differences and encouraging intellectual and scientific dialogue. For example, Florida International University (FIU) implemented Modeling Instruction (MI) as a reform-based strategy in introductory physics courses for five years (Brewe et al., 2010). They used the Modeling Instruction as a participatory framework to support the participation of diverse students—women, students with disability or underrepresented groups. In this study, it was aimed to evaluate the effect of research-based curriculum and strategies on equitable and encouraging participation in the teaching and learning process. Ultimately, it was shown that the practice of Modeling Instruction significantly influenced the participation of underrepresented students with higher FCI scores. Even though underrepresented students had lower overall conceptual understanding scores than most students, continuing physics courses with Modeling Instruction reduced the learning gap between students. Women started with lower conceptual understanding, and having better conceptual understanding at the end of Modeling Instruction increased their learning outcomes. The authors argued that research-based instructional designs, methods or curricula played a valuable role in creating a supportive learning environment with the aim of improving conceptual development for all students.

In another study, Espinosa (2011) examined the factors affecting women students' retention, especially of black women in STEM fields. Participants were 2141 women from 135 institutions. The results showed that precollege characteristics, college experiences, and institutional setting were indicators of their retention in STEM fields. Their understanding of scientific practices and their application in the community could increase their recognition in the STEM field and their confidence to continue (Carlone & Johnson, 2007). Undergraduate research programs could enable female students to become intrinsically motivated by participating in scientific activities in STEM fields: It could give opportunities to practice or follow others' practices, it could give opportunities to report and present by attending scientific conferences or organizations. The women in the study were successful in math and science classes, enabling them to continue in STEM fields. When science was not made accessible to all students, it could cause students to move away from STEM fields. Physics teachers should address the contribution of science in society and daily life. The study claimed that physics or science teachers in STEM fields should ensure the retention of all students by implementing research-based pedagogical strategies.

Docktor and Mestre (2014) also suggested that alternate forms of surveys were needed to measure a variety of outcomes. The authors argued that research-based surveys were developed to evaluate students' conceptual understanding such as "Force and Motion Conceptual Evaluation (FMCE)" (Thornton & Sokoloff, 1998) or to probe their beliefs about learning physics such as "Views about Science Survey (VASS)" (Halloun & Hestenes, 1996). These instruments aimed to assess self-regulation, content mastery, problem-solving skills, and use and interpretation of models in the context of physics courses. For the learning environment to form an equitable teaching and learning framework, cognitive, emotional, and social factors must be investigated and markers of success such as self-efficacy must be carefully examined.

As a community, Physics Education Research (PER) in United States and around the world, conducted research studies and developed evidence-based and inquiry-oriented curricula to enhance learners' active engagement in physical sciences. These resources should be developed and adapted to be utilized in different contexts to increase scientific literacy for all. Teacher change requires time and occurs through guided experience through professional development programs (Sengul, 2018). Physics teachers should be encouraged and guided to adapt the existing reform-oriented strategies or curricula or construct new innovative methods to enhance students' active participation and make sense of science content and process skills. In different countries like Turkey, physics teachers need to adopt new instructional approaches to move beyond preparing students for standardized testing. They should utilize the suggested methodologies and become part of change agents including curriculum developers, education researchers etc. to develop and enhance the use of scientific inquiry. Professional development programs should facilitate the enactment of research-oriented strategies to uncover and improve teachers' beliefs, knowledge, and practices and their students' learning outcomes.

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