

## Prospective Physics and Science Teachers' Mental Models about the Concept of Work

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**ABSTRACT** Work, as a concept, is often encountered in daily life, but the meaning of work in physics is closely related to power, force, and energy. Studies made about various concepts and subjects have proved that using words in ways different from their scientific meanings has a negative effect on teaching, and causes conceptual complexities and/or generation of alternative mental models. This study aimed to determine the mental models of prospective physics and science teachers about the concept of work. This study was conducted with the participation of 107 prospective teachers in the Physics and Science Teacher Training program. The trainee teachers' understandings were determined by using an achievement test, consisting of three open-ended questions, developed by the researchers. Data obtained were first analyzed according to the level of understanding demonstrated, and then the mental models were determined by using these levels. Four types of mental models about work were identified, specifically the scientific, the scientific synthesis, the initial synthesis, and the initial models. The synthesis model is the dominant mental model, and it has been developed by prospective teachers from two disciplines.

**Keywords** Mental model, Work concept, Prospective teachers

### 1. INTRODUCTION

Conceptual perceptions, learning difficulties, epistemological and pedagogical obstacles all shape teaching and learning and have attracted much attention by researchers for many years. As is known, these factors have a negative impact on teaching activities and student learning, leading to misconceptions, or alternative understandings, about scientific subjects. The fact that a concept is the subject of more than one discipline and/or may have different meanings in the curriculum and daily life is an underlying issue of the above dynamics in teaching (Yıldırım, 1996; Sağlam-Arslan, 2016).

When an individual meets new information, he/she perceives it through the communication channel, and this perception is frequently somewhat different from their existing knowledge on the topic (Sağlam-Arslan, 2016). Theoretical approaches in this field, i.e., the anthropological theory of didactics (Chevallard, 1998), emphasized the importance of the 'first identification/encounter' in mental structures of learners and discussed the effects of this encounter on scientific learning. By the time learners come to school, they have already faced, in their daily lives, much knowledge that will

be taught with scientific meaning in the classroom. For this reason, the meanings assigned to terms in daily life have great importance in the teaching of concepts. As is known, the use of concepts in daily life that are different from their scientific meaning makes them difficult to teach and learn in the right way (Lubben, Netshisaulu, & Campell, 1999; Bennett, Hogarth, & Lubben, 2003). This situation requires the association of daily life meanings with scientific meanings in concept teaching. Giving a meaning to one concept in different forms and in more than one discipline independent from each other has negative effects on learning (Aydın & Balım, 2005). Accordingly, the curricula in Turkey have been redesigned by placing interdisciplinary and context-based teaching at the center.

The concept to be taught, which is difficult because of its epistemological nature, becomes even more difficult when the meaning in daily life is different from its scientific meaning. The concept of work is known in daily life as an activity which is done by spending energy to produce something. It is not defined independently of its scientific

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meaning but is explained within its mathematical relations (Aguiar, Sevian, & El-Hani, 2018; Bächtold, 2018). In scientific statements, work has a meaning in connection with concepts of power, force, and energy. The explanations regarding work within the scope of science and physics courses emphasize the conditions necessary for doing physical work but do not give a specific definition of the concept of work.

A *literature* review reveals that the concept of work is discussed in conjunction with the concepts of power, force, and energy. These studies are grouped under six headings according to their objectives: (a) explaining the correlation between work and energy (Adamczyk & Willson, 1996; Doménech et al., 2015; Gutierrez, Zuza, & Gulsasola, 2015; Hartmann & Priemer, 2018); (b) determining incorrect comprehension levels of students about work, power, and energy (Bahar, Öztürk, & Ateş, 2002; Erduran-Avcı, Ünlü, & Yağbasan, 2009); (c) identifying alternative concepts in work, power and energy subjects; (Küçük, Çepni, & Gökdere, 2005; Pastırmacı, 2011), (d) evaluating students' perception levels about energy and related concepts (Duit, 1984; Goldring & Osborne 1994; Hırça, 2008; Küçük, Çepni, & Gökdere, 2005; Trumper, 1998; Ünal-Çoban, Aktamış, & Ergin, 2007; Watts, 1983), (e) eliminating alternative conceptions about work and energy (İpek Akbulut, Şahin, & Çepni, 2013); and (f) applying new approaches in teaching work, power and energy subjects; (Büyükdede & Tanel, 2018; Cerit Berber, 2008; Cerit Berber & Sari, 2009; Desianna, Nugroho, & Ellianawati, 2019; Ergin, 2011; Mustofa & Asmichatin, 2019). There are a limited number of studies focusing specifically on work, for example, misconceptions about the concept (Erduran Avcı, Kara, & Karaca, 2012) or prospective teachers' skills of distinguishing the difference between negative-positive work (Uzunkavak, 2009).

The literature also shows that there are some difficulties related to learning and teaching the concept of work. It is important to determine the perceptions of prospective teachers who will be responsible for teaching this concept. As it is known, the cognitive structures of teachers affect student learning. Therefore, it is important to determine the characteristics of the cognitive structures of prospective teachers about work. A multidimensional analysis of cognitive structures is called a mental model in the literature. Mental models are defined as personal and internal presentations created to understand and perceive real phenomena (Franco & Colinviaux, 2000). As cognitive representations, they are used for reasoning, identifying, explaining, estimating, and controlling phenomena (Buckley & Boulter, 2000; Örnek, 2008). Mental models have characteristics such as being individual, changeable, developable, reconfigurable and incomplete (Norman, 1983; Franco & Colinviaux, 2000; Buckley & Boulter, 2000; Harrison & Treagust, 2000; Barquero, 1995, as cited in Greca & Moreira, 2000; Coll & Treagust, 2003; Ünal &

Ergin, 2006, Jalmo & Suwandi, 2018). Accordingly, mental models are structured and arranged by the individual in their learning process (Ünal-Çoban, 2009; Nongkhunsarn, Yuenyong, Tupsai, & Sranamkam, 2019; Chanserm, Tupsai, & Yuenyong, 2018). Due to these characteristics, determining mental models about any subject will reveal important indicators about the learning of individuals (Putri, Samsudin, Nugraha, & Fratiwi, 2019). For these reasons, this study set out to determine the mental models and alternative conceptions about the concept of work held by prospective physics and science teachers.

## 2. METHOD

This descriptive research was carried out with trainee science (n=56) and physics (n=51) teachers who had completed their subject matter knowledge courses and were attending their last term on methods in education in the 2016–2017 academic year.

Trainee science teachers arrive at teacher's college, having followed physics courses throughout at least four years of high school and would have been exposed to the concept of work several times. At the college level, prospective physics teachers attend different physics courses in the teacher training program, including General Physics I in the first semester, and General Physics II in the second semester (both weekly 4 hours theoretical and 2 hours practical).

Data on the mental model held by the college students in this study was compiled in several ways following Kurnaz (2011): determining the mental model by classifying the characteristics of student responses (e.g. Borges & Gilbert, 1999; Lin & Chiu, 2007); referring to models known in the literature (Gökdere & Çalık, 2010; Şengören, 2010); determining the mental model according to predetermined classifications based on the nature of the subject (e.g. Sağlam-Arslan, 2004); and considering the level of understanding of students (e.g., İyibil, 2010).

In the current study, the latter method was followed in order to identify the mental models about work by trainee teachers. An achievement test focussed on three elements of concept knowledge - describing, connecting, and interpreting. The first question on the test required a definition of work, its units, and type designation. The second question necessitated explanations as to whether or not physical work is done in three different systems. The third question demanded a prediction of the relationship between the amount of work done along three different possible paths (see Appendix for details).

### 2.1. Validity and Reliability

For the validity and reliability of the data collection tool, expert opinion on the research question, and then a pilot application was performed. In this context, the data collection instrument was examined by a group of two faculty members and two physics teachers with ten years of experience. After the necessary arrangement of the data

**Table 1** Mental models and their characteristics

Mental model	Properties of model	Relation between model and understanding level
<b>Scientific</b>	A model consisting of conceptions exactly compatible with scientific knowledge.	All responses to different types of questions are in level [3] or [4].
<b>Scientific Synthesis</b>	A model consisting of conceptions based on daily life and experience, resembling scientific knowledge.	Two of the responses to different types of questions are in level [3] or [4] and the other is in level [0], [1] or [2].
<b>Initial Synthesis</b>	A model consisting of alternative conceptions based on daily life and experiences, and/or where false knowledge is dominant.	Two of the responses to different types of questions are in level [0], [1] or [2] and the other is in level [3] or [4].
<b>Initial</b>	A model type consisting of alternative conceptions irrelevant to scientific knowledge, and/or involving false information.	All responses to different types of questions are in level [0], [1] or [2].

[0]: No Understanding (NU), [1]: Alternative Conception (AC), [2]: Partial Understanding with Specific Alternative Conceptions (PU/AC), [3]: Partial Understanding (PU), [4]: Sound Understanding (SU).

collection instrument, the pilot application was carried out with 70 freshmen who had taken the general physics course. Thus the conformity of the data collection instrument with the aim of the study and its comprehensibility was established.

## 2.2. Data Analysis

The data obtained from the study were analyzed in two stages. Firstly according to the *level of understanding* and secondly according to the *mental model*. The following scale, developed by Abraham, Williamson & Wetsbrook (1994), was used in the comparative analysis to analyze the responses according to the *level of understanding* of the concept of work by prospective teachers.

[0]: No Understanding (NU): Blank, rewriting the question, irrelevant or unclear response.

[1]: Alternative Conception (AC): Scientifically incorrect responses containing illogical or incorrect information.

[2]: Partial Understanding with a Specific Alternative Conception (PU/AC): Responses showing that the concept is understood but also containing an alternative conception.

[3]: Partial Understanding (PU): Responses containing some components of the scientifically accepted response.

[4]: Sound Understanding (SU): Responses containing all components of the scientifically accepted response.

The mental models related to work were identified by conducting an individual holistic analysis of the level of understanding. Understanding levels are associated with mental models (initial, synthesis, and scientific) in the literature (Vosniadou, 1994). The synthesis model is divided into scientific synthesis and initial synthesis. Accordingly, in this study, four types of mental models were identified: the scientific, the scientific synthesis, the initial synthesis, and the initial models. The relationship between the general characteristics of these models, and their levels of understanding, are presented in Table 1.

## 3. RESULT AND DISCUSSION

Findings are discussed using two themes: prospective teachers' understanding level and their mental model related to the concept of work.

**Table 2** Distribution of understanding levels according to the responses

Question type	Level	Physics		Science		Total
		F	%	f	%	f
<b>Describing</b>	[0]	-	-	1	2	1
	[1]	2	4	14	25	16
	[2]	19	37	22	39	<b>41</b>
	[3]	19	37	18	32	37
	[4]	11	22	1	2	12
<b>Connecting</b>	[0]	-	-	1	2	1
	[1]	5	10	22	39	27
	[2]	30	59	11	20	<b>41</b>
	[3]	10	20	12	21	22
	[4]	6	12	4	7	10
<b>Interpreting</b>	[0]	1	2	2	4	3
	[1]	1	2	9	16	10
	[2]	5	10	26	46	31
	[3]	43	84	13	23	<b>56</b>
	[4]	1	2	-	-	1

### 3.1 Prospective Teachers' Understanding Level

The distribution, according to understanding levels of the responses given to the questions, has been summarized in Table 2.

The results on connecting questions in Table 2 show that more than half (59%) of physics prospective teachers' responses in this category were at level [2], while other responses were at levels [1], [3] and [4] with respective ratios of 10%, 20%, and 12%. No responses were recorded at level [0].

The responses of prospective science teachers in the connecting category demonstrated 39% at level [1], followed by similar ratios 20% and 21% at levels [2] and [3]. The remaining responses of trainee science teachers were located at levels [0] and [4] (2% and 7%, respectively).

Examination of the responses of prospective teachers in interpreting questions showed that 56% of responses were at level [3], and 31% were at level [2]. The majority

(84%) of trainee physics teachers' responses in this category were at level [3], followed by 10% at level [2]. While nearly half (46%) of prospective science teachers' responses in this category were at level [2], there were no level [4] responses. The other responses were distributed at levels [3], [1] and [0] with ratios 23%, 16% and 4% respectively.

Table 2 shows that a majority of the prospective teachers have some alternative conceptions about the concept of work. A detailed analysis of responses in level [2] revealed various alternative conceptions about work, and are summarized in Table 3.

Based on Table 3, the most common alternative conceptions displayed by prospective teachers were as follows. AC1: Work is a vector quantity as it depends on the vector quantities force and displacement. AC2: In order to do work, there must be a force other than the force of gravity and displacement. AC3: Work done changes according to the path taken. Two additional alternative

**Table 3** Prospective teachers' alternative conceptions related to 'work'

Alternative Concepts	Sample Answers	Frequency		
		P	S	T
<b>AC1.</b> Work is a vector quantity as it depends on the vector quantities force and displacement	-The displacement in the direction of the force is called work. It is a vector quantity (F19). -It is the displacement of an object in the direction of the applied force. They are vector quantities (FB22).	14	6	20
<b>AC2.</b> In order to have work there must be a force other than the force of gravity and displacement.	- A child walking on an inclined path moves in the direction of the movement, but not work is done physically because there is not force acting on the child (F40). - As a free falling object does not use any force, it doesn't do any work (F6). - No work. Because there is no force applied to the object (F7).	8	1	9
<b>AC3.</b> Work done changes according to the path taken	- $W_C > W_A > W_B$ , because the work done is proportional to the distance. $W = F \cdot x$ , The path taken at C is the maximum (F39). - C is in the opposite direction to gravity, but more energy is consumed, because of the curved path (FB50).	1	7	8
<b>AC4.</b> Work done only changes according to displacement	- $W = F \cdot x$ , A and C are the same but bigger than B, stairs are not important. The path having hypotenuse is the same as A, the path of B is small (F41). -Work is done more in objects A and C due to the distance of the path, it is less in B than them (F16).	4	4	8
<b>AC5.</b> Work done is directly proportional to displacement, inversely proportional to the slope of the path	- $B > A = C$ , work is done in B, directly, because the taken path is the shortest (FB24). - $W_B > W_A = W_C$ , Because as the B path itself is in the direction of force (inverse), maximum work is done there. Since the displacements of the A and B paths are equal and the vertical components are in the direction of the force, work is less (F50).	2	6	8
<b>AC6.</b> The work done depends on the difficulty of the path	-A is the most difficult to take out, B is the easiest; C is the medium difficulty (FB15). - One who gets out of the A path uses less energy. One who gets out of the C path uses less energy, the path is long, B path is short, spends more energy (FB34).	-	7	7
<b>AC7.</b> If force acting on an object and the displacement of the object are in a horizontal direction, the work is done.	- Since the displacement of a free falling object in the horizontal plane is 0, there is no work done (F11, F24).	3	3	6
<b>AC8.</b> Work is done if energy is spent.	-The child walking on the inclined path did work. He had difficulty to go upwards. He loses energy (FB30).	-	2	2



conceptions closely followed these three. AC4: Work done only changes according to displacement. AC5: Work done is directly proportional to the displacement and inversely proportional to the slope of the path.

It has been seen that the alternative conceptions of trainee physics and science teachers differ. According to Table 3, the physics group mostly demonstrate AC1 and AC2, while the prospective science teachers mostly show AC3 and AC6 coded alternative conceptions. While the prospective teachers in both branches are equivalent in terms of the AC4 coded alternative conception, AC6 and AC8 coded alternative concepts were only seen in trainee science teachers.

### 3.2. Prospective Teachers' Mental Models about the Concept of Work

The mental models on the concept of work held by the trainee teachers in this study and analyzed by integral evaluation of levels of responses to the questions in the achievement test are summarized in Table 4.

When Table 4 is examined, it can be seen that most of the prospective teachers hold an initial synthetic model (42%), followed by 35% with a synthetic scientific model, 15% with a scientific model, and 9% holding an initial model.

The trainee teachers holding an initial synthetic model (physics 31%; science 56%) were not able to scientifically explain the conceptual structure of work and displayed various alternative conceptions. A typical response given by a trainee science teacher holding an initial synthetic model is illustrated below:

*Describing:* It is the type of energy that occurs in unit time.

*Its' unit is J, which is a scalar quantity.  $W=F \cdot x$ .*

*Connecting:* He doesn't do work. With the effect of gravity, it already falls by itself. He does work, and it is in a horizontal plane and weight on his shoulder.

*Interpreting:*  $C > A > B$ . In the path C, it is in the opposite direction to gravity, but a curved path, more energy is spent. (FB50)

The synthetic scientific model was the second most frequently displayed mental model among the participants (physics 51%, science 16%). It can be seen that the prospective teachers who have this model have explained the conceptual structure of work scientifically, and have answered at least two of the questions about work in a scientific way, but they also displayed various alternative conceptions. The characteristics of synthetic scientific

model responses given by a trainee physics teacher are illustrated below:

*Describing:* The displacement on the direction of the force is called work.  $W=F \cdot x$ , it is a scalar quantity.

*Connecting:* The object doesn't do work. Gravity does work on the object. It has done work as the multiplication of the force is applied to the load, and the distance the load was carried. The child has done work against gravity.

*Interpreting:* The important thing in the work done against gravity is how high it arises (in equal mass). Since the heights are equivalent, the work is equivalent, too (F9).

The scientific model was demonstrated by a limited number of prospective teachers (physics: 18%, science: 10%). These trainee teachers were able to explain work scientifically (definition, units, and magnitude) and transfer their knowledge to real cases and interpret different physical events. A typical response by a prospective physics teacher with a scientific model is illustrated below:

*Describing:* When a force is applied to an object if the object displaces in the direction of the applied force, work is done.  $W = F \cdot x$ , the unit is the joule (N. m), it is a scalar quantity

*Connecting:* When released, a falling object has done work physically. Because of the weight of the object, and its displacement is in the same direction. A man who carries a load on his shoulders on a horizontal plane is not regarded as doing work physically. Because of the weight of the load and the man's direction of movement is not in the same direction. A child walking on a sloping path is regarded to have done work because its weight's horizontal element and direction of movement are in the same direction.

*Interpreting:* The work done by all of them is equivalent to each other because the displacement of all three objects is equal to each other (F44).

Table 4 shows that the initial mental model is held only by trainee science teachers. Prospective teachers holding this model responded without demonstrating scientific knowledge about work, were not able to scientifically explain the concept, and displayed various alternative conceptions. The responses given by a trainee teacher identified as holding the initial model are illustrated below:

*Describing:* It is said to change the way and direction of an object by the result of an applied force.

*Connecting:* Work has been done because there is a displacement. Work is not done unless the load carried contacts the ground. It did work because there is a displacement.

**Table 4** Mental models of prospective teachers

Subject Area	Mental model type							
	Scientific		Scientific synthetic		Initial synthetic		Initial	
	f	%	f	%	f	%	F	%
Physics	9	18	28	51	14	31	-	-
Science	6	10	7	16	28	56	9	18
Total	15		35		42		9	

*Interpreting:  $C > A > B$ . In C, the work done against gravity is highest because we consume a lot of energy while climbing a ladder. Since there is a slope in A, it is a lot too. However, it will be less in B if we directly put it upstairs (FB26).*

The results indicate that prospective physics teachers generally hold the synthetic scientific model, and none of the prospective physics teachers hold the initial model. While prospective science teachers mostly adopted the initial synthetic or initial models, over a third of this group were held to the synthetic scientific or scientific models as well.

The findings show that the level of knowledge of trainee teachers about work varies according to the type of question. In general, they demonstrated a partial understanding of specific alternative conceptions. In the describing and interpreting categories, they showed a partial understanding. Also, it was determined that they had a partial understanding of specific alternative conceptions in the connecting category. It may be that this is caused by the education system, which includes teaching practices that only require cognitive knowledge and skills towards lower levels of the cognitive learning area. For this reason, it seems that participants' responses to the type of associative questions, requiring high-level cognitive skills, are below current scientific knowledge levels. The results of some studies (Sağlam-Arslan, 2004; Kurnaz, 2007; Kurnaz & Sağlam-Arslan, 2009), showing that student learning is shaped according to teaching practices, also supports this idea.

The prospective teachers' responses reflecting their level of understanding revealed alternative conceptions about the concept of work. This analysis showed that prospective teachers developed common alternative conceptions related to work, and the incidence of these concepts differs according to the participant group. Some of the alternative conceptions in this study have also been revealed in previous studies. For example, the alternative conception, 'work depends on displacement', is found by Erduran Avcı (2019) and Erduran Avcı, Kara, & Karaca (2012) in studies with trainee science teachers and students. Aydoğmuş (2008), with 6th-grade students, Palmer (2001), with 6th and 10th-grade students, and Pastırmacı (2011), with the 7th-grade students, identified students holding the alternative conception 'if work should be done, a force other than gravitation and displacement should be present.' On the other hand, Madanoğlu found an alternative conception held by 9th-grade students of 'more or less work is done if the inclination is more or less,' was similar to the alternative conception of 'work done is inversely proportional to the slope of the path' exhibited by prospective science teachers (Madanoğlu, 2015). It can be argued that, in general, the insufficient use of interdisciplinary approaches in concept teaching may affect the development of alternative conceptions. The difficulty of holding in one's mind a holistic structure of common

concepts that have been attributed to different meanings in separate courses necessitates the use of a better approach.

The analysis conducted to determine the mental models of the participants about the work concept identified four different models: the scientific, the scientific synthesis, the initial synthesis, and the initial. It was found that prospective physics teachers mainly displayed scientific synthesis and initial synthesis models, while prospective science teachers displayed initial synthesis and initial models about work. The characteristics of these types of models indicate that prospective teachers have mental structures that are not fully aligned with the scientific concept of work. Synthesis models (initial synthesis and scientific synthesis) based on the knowledge structures in which learners combine scientific knowledge with their experiences are the most common types of mental models (e.g., Kikas, 2005; Hannust & Kikas, 2007). This situation suggests that the mental schemas of learners are structured according to knowledge obtained as a result of ordinary, or daily life processes, as well as scientific information (Greca & Moreira, 2001).

It is seen that the mental models about work by trainee science and physics teachers differ. Accordingly, prospective physics teachers developed mental models more compatible with scientific knowledge compared to prospective science teachers. This situation can be accounted for by the fact that work is a common subject in different courses of the science teacher training program (mechanics, electricity and magnetism, modern physics, thermodynamics, etc.).

When the results of this study on comprehension levels, alternative concepts and mental models are evaluated within the framework of the postulates of the anthropological theory of Chevallard (1989), deficiencies related to learning by the individual can be defined as a reflection of educational reality. For this reason, learning environments to promote scientifically accurate mental models should be designed by taking into consideration these results, and the effects of, for example, written course resources used during teaching, teachers' knowledge, as well as students' daily life experiences. We suggest that learning environments and activities should include multiple and frequent representations of concepts and be based on interdisciplinary approaches.

#### 4. CONCLUSION

This study revealed that prospective science teachers have various alternative conceptions and different mental models about work that are more or less compatible with scientific knowledge. Because students first meet with formal meanings of basic science concepts in science courses at school, the science teachers' mental models about these concepts are very important. For this reason, it is recommended that some courses, including special teaching techniques and laboratory

approaches/applications, be designed to address this issue in science teacher training programs.

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## APPENDIX

1. Define the work concept? Explain if it is scalar or vector quantity and its unit.
2. Explain with reasons whether or not work has been done physically in the given situations below?
  - a) A free falling object
  - b) Man carrying a load on his shoulder in the horizontal plane
  - c) A child walking on an inclined path
3. What are the relations among the works done against gravity when three bodies with identical mass are removed from the A, B and C paths to the point M? Explain your answer.

