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Knowledge Elements Used by Pre-Service Primary Teachers to Explain Free Fall

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ABSTRACT
As well as knowledge structures can be complex and coherent, they might be small and disconnected. This study focuses on knowledge elements of pre-service teachers using diSessa's phenomenological primitives (p-prims) framework. Based on group interviews, a test was developed regarding the knowledge fragments used for explaining free fall in three different contexts—the Earth, the Moon, and Mars—for both vertically released and kicked balls. The test was then implemented to 274 pre-service primary teachers. The results indicated that teacher candidates used six different p-prims such as force as a mover, closer means stronger, bigger is greater, overcoming, dynamic balance, and dying away to explain free fall. The use and appropriateness of p-prims differed due to context both qualitatively and statistically.

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Introduction

Knowledge organization is important for providing coherent conceptual frameworks regarding particular concepts. However, individuals may not always have coherent structures in their minds. One theory which draws attention to an individual's fragmented knowledge structures is the "phenomenological primitives (p-prims)" theory of diSessa (1983, 1988, 1993). In contrast to the coherent characteristics of mental models, it proposes that knowledge comprises smaller, more fragmentary structures in the mind (Hammer, 1996; Ueno, 1993).

P-prims are overly abstract, general and oversimplified knowledge elements (Bao, 1999) and operate at a preconscious level (Taber, 2008). They are similar to "conceptual atoms" and form complex cognitive structures (Taber, 2008). P-prims are implicit knowledge elements (Taber, 2014) and they do not need explanation (Ueno, 1993); however, they can explain events and are activated in specific contexts, so they are highly context dependent (diSessa, Gillespie, & Easterly, 2004). When they are obtained in one context, they may be transferred to the other contexts by over-generalizing the events and being socially shared (Ueno, 1993). Therefore, it is also meaningless to classify p-prims as being either correct or wrong. However, it should be discussed whether the use of p-prims is appropriate or not in a specific context. For this reason, diSessa (1993) suggests that instructors helping students should refine their p-prims rather than removing them because learning physics—or development of scientific knowledge—is only possible with the reorganization of intuitive knowledge. With such an epistemological claim, it is possible with the refinement of p-prims because intuitive knowledge lacks systematicities.

diSessa (1983, 1988, 1993, 1996) explains that some p-prims are more frequently used than others. For example, one of them which explains a broad range of phenomena is *Ohm's p-prim*. This p-prim is abstracted by physical experience and used in situations with three interconnected elements.

For example, increased effort implies more results; however, more resistance indicates less results. Another p-prim, which is also used by expert physicists frequently, is *force as a mover*. This p-prim can be considered to be the directed form of Ohm's p-prim and describes the motion of an object by directed force. *Dynamic balancing* is also an example of a p-prim. It is used in situations for explaining the effect of two opposing forces which cancel each other. diSessa (1993) illustrates many other p-prims and how individuals use them to explain both daily and physical events. He considers these resources in helping to make inferences and drawing conclusions to be primary for the construction of physics knowledge and they should be refined in the instruction and used appropriately in specific contexts (diSessa, 1993; Hammer, 1996). When students do not have stable and coherent knowledge structures, they may construct their answers in situ with these fragmented elements. As a result, they can give inconsistent answers influenced by contextual features (Taber, 2008). For example, Wittmann (1998) identified that university students could not have the ability to determine the appropriate p-prims to use for the wave concept and therefore they used them inappropriately. Similarly, Jelicic, Planinic and Planinsic (2017) examined high school students' unscientific mental models of electromagnetic induction including inappropriate use of several p-prims, mostly *force as a mover*. In another study, Tan and Taber (2005) suggested the activation of implicit knowledge elements about electron shells. More recent research also indicated that students could construct their physics knowledge by instructional designs by activating p-prims in appropriate contexts. For example, Young and Meredith (2017) designed instruction and developed tutorials considering students' p-prims about pressure in fluids in an algebra-based introductory physics course. The analyses of videos including students' laboratory work and written materials revealed quite different knowledge elements were activated when the contexts of two problems were quite different. They explained instructors could recognize and encourage progress at all stages of understanding when they focus on "productivity" of ideas instead of their correctness. Wannous and Horváth's (2019) research indicated that 20 students with 15-17 years old performed better in Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992) by activating *force as a mover* (maintaining agency) p-prim appropriately in teaching Newton's laws of motion. Burde and Wilhelm (2020) developed a new curriculum for scientific and coherent mental structures about electric current by considering students' knowledge in pieces gained by daily experiences. They focused on systematically activation of the knowledge elements of students by using the appropriate cues, and designed instruction on directing students' reasoning for scientific understanding by identifying and using productive and intuitive knowledge elements. Volfson, Eshach and Ben-Abu (2020) examined which and how p-prims are responsible with students' misconceptions about circular motion using a daily life context "circus". They identified *balance* and *closer means stronger* p-prims were used by students to explain the speed of spin of a bowl with a full of water. They stated that limited number of p-prims were activated in every context. For the activation of appropriate p-prims in physics classes, the researchers suggested physics teachers' preparation of educational activities such as the use of "circus" interviews or discussions providing daily life contexts about physical events and bringing advanced scientific ideas.

Chinn and Brewer (1998) mentioned that there could be observed a shift from fragmented to more structured knowledge as a global change of knowledge. Redish (2004) and Scherr (2007) stated that it is not necessary but possible to form coherent frameworks by using knowledge pieces such as primitives, facets, and resources by organizing them to construct a coherent framework. That is scientific and unscientific mental structures (misconceptions) can be composed of smaller knowledge pieces. People may construct their stable conceptual structures with primitive elements through repeated use (Taber, 2008). Knowledge might begin in-pieces and could be integrated into more complex systems (Taber, 2014). Many researchers, such as Bao (1999), Burde and Wilhelm (2020), Didiş, Eryılmaz and Erkoç, (2010, 2014), Hrepic (2002, 2004), Hrepic, Zollman and Rebello (2010), Itza-Ortiz, Rebello and Zollman (2004), Jelicic et al. (2017), Wittmann (1998), and Wittmann, Steinberg and Redish (1999) also identified students' mental models, which are coherently organized knowledge structures, consisting of these knowledge elements. For example, Wittmann (1998) defined the term "pattern of associations" between primitive elements and mental models. Pattern of associations could be thought of as “a linked web of primitives and facets associated with a topic” and he considered them more fluid and less precise than mental models. A pattern of associations may be also incomplete and self-contradictory as with mental models; however, Wittmann (1998) stressed its incoherency to distinguish it from a mental model.

Previous Research about Gravity and Free Fall

The gravity phenomenon develops in individuals’ minds with the concept of “things fall down” (Kavanagh & Sneider, 2007) and it evolves in early years before science classes. Free fall is an important concept for understanding the phenomenon of gravity in the explanation of how and why things fall. Aristotle can be considered as the first person to discuss force and motion with common sense beliefs (Halloun & Hestenes, 1985), attempting to explain free-falling objects. He intuitively clarified that heavy items fall because of a tendency seeking a natural position. While speed of fall is proportional to weight of an object, speed increase is achieved by an increase in the force or by an increase in weight as the object gets closer to its natural position in its natural motion – so-called free fall (Halloun & Hestenes, 1985). But physically, the motion of an object being acted upon by only the gravitational force is described as free fall. It is not limited to the motion of an object released from rest, but it covers any motion such as throwing upward from the top of a building or an object thrown with an initial velocity downward.

Free fall is one of the important phenomena emerged from Newton's law of universal gravitation. Because the “fall” concept can be observed, experienced, or intuitively sensed, individuals can provide qualitative explanations about it. Previous research indicates that students also had Aristotelian ideas about falling things. For example, Watts (1982) interviewed children and identified their difficulty applying their knowledge of gravity. In the interviews, some of the students stated that gravity required air and acted on falling objects until they rest on the ground. Palmer (2001) examined elementary and high school students’ ideas about gravity using interviews. After giving students pictorial situations such as a ball is going up or falling down, a person is on a boot, a brick is underground etc., the students discussed whether or not gravity acted on any of these items. They explained that gravity acted only falling objects, but not objects moving upward, stationary objects, or objects underground. Kocakülah and Kenar Açıl (2011) studied how 8th grade elementary students thought about gravity. The researchers both implemented a test with open-ended questions and conducted semi-structured interviews. The findings obtained from 370 students indicated that students had the similar misconceptions about gravity in the literature. They were basically “there is no gravity in space”, “there is no gravity on the Moon”, “there is no air, so no gravity”. Kavanagh and Sneider (2007) explained that high school and physics students at college level had misconceptions which were similar to those of much younger students such as “strength and effort prevent falling”, “gravity is not a force”, “heavier objects fall faster”, “gravity attracts only heavy, slow, or inactive objects”, and “gravity acts upward”, although they could successfully solve numerical problems about gravity. Champagne, Klopfer and Anderson (1980) identified that undergraduate introductory physics students could have inconsistent beliefs about free fall and they even thought that there was no gravity in space. Sharma, Millar, Smith and Sefton (2004) also examined university students’ ideas concerning gravity in a physics course. Similar with previous research, students stated that there was no gravity in space.

In addition to students, previous research also indicated that teachers and teacher candidates had non-Newtonian ideas regarding gravity and these conceptions were similar to those of students. Gönen’s (2008) study with 267 pre-service physics and science teachers identified that teacher candidates had serious misconceptions about gravity, gravitational force, and gravitational acceleration. Some of them previously stated students’ misconceptions such as “no gravity in space, and a body moves continuously in the space because of lack of gravity”. Kaltakçı and Didiş (2006) also examined 30 pre-service physics teachers’ misconceptions about gravity with a Gravity Concept Test including 11-questions which had three-tier in each. The findings indicated pre-service physics teachers' misconceptions such as "no gravity on the Moon", "no gravity in space", "no air, no gravity" etc. Atasoy and Akdeniz (2007) developed a concept test to identify misconceptions about Newton's law of motion. The researchers implemented a validated test including 20-questions to 42 first year pre-service science teachers. Teacher candidates selected a choice and explained their reasons in the "explanation" part below the choices for each question. The results indicated that 45% of the pre-service teachers answered the question asking "the force on the key, whom a man released rest on the Moon" as "there is no gravity on the Moon", and some of them stated that it went upward because of no gravity on the Moon. Similarly, Syuhendri (2017) explored 73 pre-service physics teachers' misconceptions concerning gravity. Nine questions of FCI (Hestenes et al., 1992) corresponding five misconceptions were used in the investigation. Analyses revealed that the pre-service physics teachers had the following misconceptions with different percentages: "air pressure- assisted gravity", "gravity intrinsic to mass", "heavier objects fall faster", "gravity increases as objects fall", "gravity acts after impetus wears down". Ameh (1987) examined four teachers' ideas about gravity in three contexts—a man standing on the Moon, standing on the Earth, and falling from a plane—using interviews. Her study revealed that teachers used unscientific knowledge to answer questions, such as gravity does not act on a person falling from the plane. Kruger, Summers and Palacio (1990) interviewed 20 elementary school teachers and identified that some of the teachers explained that there was no gravity on the Moon and astronauts' heavy clothes and equipment helped them to stand on the Moon. Watts and Zylbersztajn (1981) interviewed five science teachers and asked the same questions to teachers as they had asked students before. The teachers were requested to predict students' misconceptions when they were answering the questions about gravity and free fall. The results indicated that teachers had difficulty in predicting students' misconceptions.

The studies in the literature indicate that in addition to students, teachers and teacher candidates have unscientific ideas about gravity. Different from the literature, this study aims not to identify teacher candidates' misconceptions regarding gravity, but instead to identify their knowledge elements used as interpretation schemes to explain a physical phenomenon—free fall—. In other words, by considering both scientific and unscientific understanding about physical contexts, this study investigates the implicit knowledge fragments allowing causal explanations and examines the context dependency of the use and appropriateness of knowledge elements. The research questions are as follows:

- Which knowledge elements do pre-service primary teachers use to explain free fall?
- How do the use and appropriateness of p-prims differ with contexts?

Methodology

Pre-service primary teachers' explanations of free fall in three different contexts of two cases were examined qualitatively with interviews first and then quantitatively with a test. Next, the appropriate selection and use of p-prims were identified. Finally, statistical differences were examined after the transformation of qualitative data into quantitative data.

Data Collection and Analysis

Cases

In this study, two cases were considered: The first one is the fundamental explanation of free fall, which is "a ball released vertically from rest". The second case was selected as being slightly more complex for primary teacher candidates to examine their analysis of horizontal and vertical dimensions of motion. Thus, the second case was "a kicked ball", which corresponds to projectile motion.

The second case is important for the analysis of how much the identified knowledge fragments are used as the interpretation schemes by transferring them into different and more complex situations. A projectile is also the motion of an object upon which only gravitational force is acting. Horizontal and vertical dimensions of a projectile motion are independent of each other. While the horizontal dimension of motion corresponds to motion with constant velocity, its vertical dimension is not different than free fall that corresponds to motion with constant acceleration caused by gravity, with no other forces. It has a parabolic trajectory. Although this motion may be physically complex for teacher candidates, it is one of the most familiar types of motion because it can be related to football in daily life.

Contexts

Two cases—a ball released vertically from rest and a kicked ball—were examined in three contexts. Table 1 presents these three contexts: (1) the Earth, (2) the Moon and (3) Mars.

Table 1

The Contexts for Free Fall

Contexts	*Experienced*	*Inexperienced (Hypothetical)*
Familiar	The Earth	The Moon
Unfamiliar	-	Mars

As presented in Table 1, for the examination of two cases for free fall, a familiar-experienced context (the Earth), a familiar-inexperienced context (the Moon), and an unfamiliar-inexperienced context (Mars) were determined. With the identification of variation and transfer of knowledge elements, this allows the examination of context dependency, that is the role of context on p-prims.

Instrument and Participants

Video-recorded group interviews with eight pre-service primary teachers were conducted. After the interviews were transcribed and the data were analyzed, the identified knowledge elements and probable elements were used for development of the test. Finally, necessary validity and reliability precautions were taken, and the test was implemented to a total of 274 pre-service primary teachers (188 females, 86 males), who had also completed a compulsory basic physics course.

As the translated version of the test presented in Appendix I, the questions in the test focusing on free fall in three contexts were presented mostly with visual elements. They did not require algebraic calculations but rather uncovering the pre-service teachers' knowledge fragments. By drawings and verbal explanations, teacher candidates selected the appropriate explanations that fit their reasons when they answered the questions.

Implementation

The test was implemented to the pre-service primary teachers in 30 minutes. When answering the test, teacher candidates were requested to select a choice given in the test that fits their reasoning as well as stating their explanations by drawing or texts.

Analysis

The coding table, presented in Appendix II, was developed and used for the qualitative data analysis. In addition, chi-square analyses were conducted to test the statistical significance of differences in the use and appropriateness of p-prims due to context.

Results

In this study, pre-service primary teachers used six different p-prims to explain free fall in three contexts as on the Earth, Moon and Mars of two cases considering vertically releasing a ball and vertical dimensions of a projectile motion. These were:

(1) force as a mover,
(2) closer means stronger,
(3) bigger is greater,
(4) overcoming,
(5) dynamic balance, and
(6) dying away.

Table 2 presents these p-prims and their abstractions used as interpretation schemes to explain how a vertically released ball and a kicked ball behave in three different contexts.

Table 2

P-Prims and Their Abstractions Used as Interpretation Schemes for Three Contexts of a Vertically Released Ball and a Kicked Ball

Letter Code	P-prims	Abstraction	Explanation	Pictorial Schema	Interpretation Schemes
A1	*Closer means stronger*	Proximity and effect are directly proportional	Falling downward	⬇	Motion of the ball is towards *the Earth/ Moon/Mars* because *the Earth/ Moon/Mars* is closer than the others.
A2	*Force as a mover*	An object's motion is by directed a force applied	Falling downward	⬇	Motion of the ball is towards *the Earth/ Moon/Mars/Sun* because *the Earth/Moon/Mars/Sun* forces the ball for moving.
B2			Toward…	⬈	
B1	*Bigger is greater*	Dimension and effect are directly proportional	Toward…	⬈	Motion of the ball is towards *the Sun/Moon/Earth* because *the Sun/Moon/Earth* is bigger.
B3	*Overcoming*	The influence wins over the others	Toward…	⬈	Motion of the ball is towards *the Sun* because *the Sun* overcomes others.
C	*Dynamic balance*	Two opposing forces cancel each other	Suspension	⬌	The ball suspends in the air because of dynamic balance of the forces by celestial bodies.
D	*Dying away*	Motion is gradually stopped	Fall and suspend	↘	Motion of the ball is falling downward and then it suspend in the air, because force dies away.

Note. The p-prims in this table are adapted from diSessa (1983, 1988, 1993, 1996) and Hammer (1996).

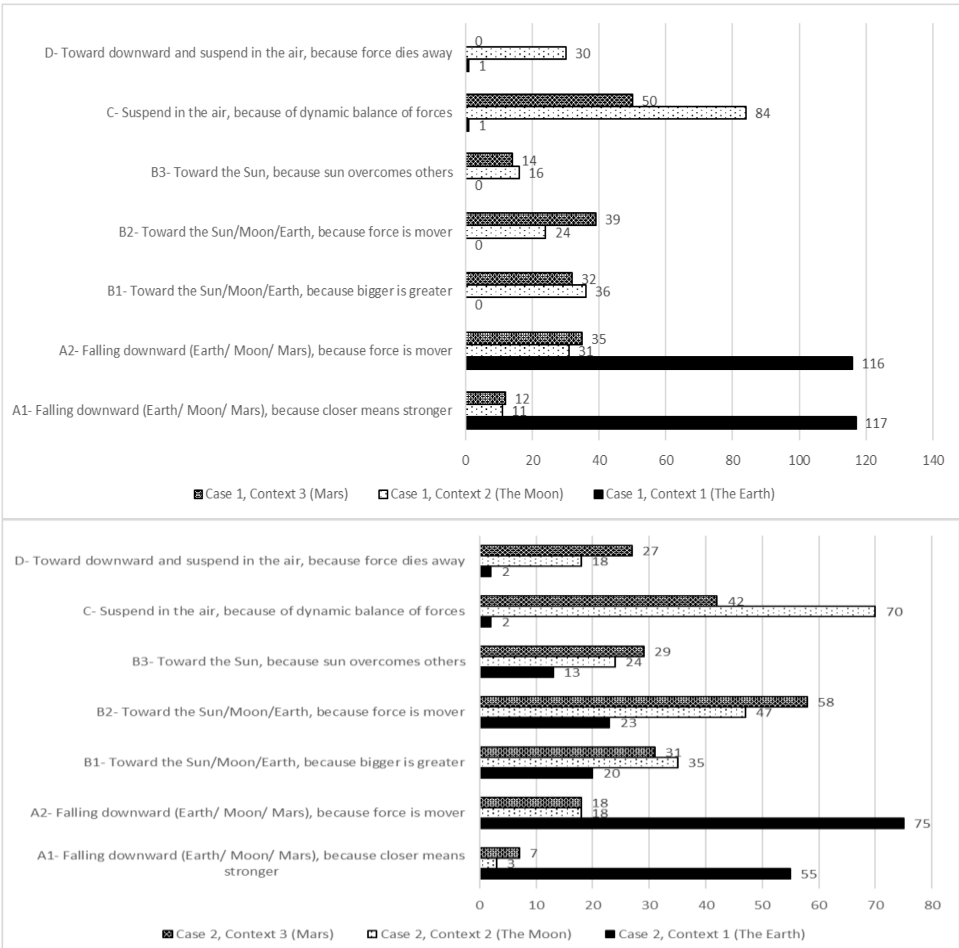
As Table 2 presented the p-prims and their use, in total six p-prims for four ways explaining free fall in three contexts for a vertically released ball and a kicked ball were used by teacher candidates. They explained the motion of the released and kicked balls as;

(1) falling downward (⬇),
(2) moving toward another celestial body (the Sun, the Moon) (⬈),
(3) suspending in the air (⬌),
(4) falling and then suspending in the air (↘) .

Pre-service primary teachers used different p-prims as an interpretation scheme to explain each motion. For the first motion "falling downward" which is considered the scientific explanation for each context of each case, pre-service teachers used the *closer means stronger* p-prim by relating "proximity and effect"; and *force as a mover* by considering the "direction" of applied gravitational force. The second explanation for the released and kicked balls is movement of the ball toward another celestial body by leaving the place kept free. Teacher candidates explained it with three different reasoning schemes. These were, *force as a mover* by considering the "direction" of gravitational force applied by another celestial body; and *bigger is greater* by relating the "dimension and effect". Although these two p-prims were used by considering the different celestial bodies such as for the Sun and Moon, the final p-prim was used only for the Sun. It was *overcoming* by considering the "influence" of the gravitational force winning over the influences of other celestial bodies. The third explanation was the motion of the ball suspended in the air after it was released or kicked. Teacher candidates' interpretation scheme for this explanation was *dynamic balance* among the gravitational effect applied to the ball by the celestial bodies. The last explanation for the motion of the ball was falling of the ball slightly after being kicked or released and then suspending in the air. Teacher candidates used the *dying away* p-prim for this explanation by considering the "disappear" of the gravitational force applied to the ball. Figure 1 shows the variation of these p-prims for a vertically released ball (case 1) and a kicked ball (case 2) over the contexts - on the Earth (context 1), on the Moon (context 2), and on Mars (context 3).

Figure 1

Variation of Used P-Prims over Three Contexts of Two Cases. Numbers on the Graphs Represent the Frequency of Used P-Prims by 274 Teacher Candidates



As Figure 1 illustrates, for the first case—a vertically released ball—*force as a mover* and *closer means stronger* were the most commonly used p-prims for falling downward (A1, A2) towards the Earth. Their frequencies were almost the same. In the second case—a kicked ball—for falling downward, they were still the most used p-prims in the context of the Earth; however, their frequencies decreased in the second case due to the complexity of the projectile motion. For moving toward another celestial body (B1, B2, B3) explanation, in the first case, the p-prims *force as a mover*, *bigger is greater*, and *overcoming* were used with different amounts for the contexts of the Moon and Mars, however they were never used for the Earth. Teacher candidates seem being sure on falling downward explanation with *closer means stronger* p-prim and *force as a mover* p-prim for the Earth context. But for the second case, the use of these p-prims increased for all contexts, even for the Earth. For suspending in the air (C) explanations, *dynamic balance* was observed a few times in the Earth context. This p-prim was used most frequently for the Moon for both cases—released and kicked balls—however, its use decreased for the second case. *Dynamic balance* was also one of the most used p-prims in overall for both cases. For falling and then suspending in the air (D), the *dying away* p-prim was never used for Mars and it was used only once for the Earth in the first case. Its use increased for Mars and decreased for the Moon in the second case.

To summarize the graphs in Figure 1 by considering the cases, falling downward was mostly used to explain free fall for a vertically released ball (case 1). To do this, the *closer means stronger* and *force as a mover* p-prims for the Earth (context 1) were used as interpretation schemes. In this case, the most used explanation for the Moon (context 2) was suspension in the air. With this explanation, mostly *dynamic balance* was used for the Moon. It is seen the most frequently used explanation for Mars (context 3) was to move toward another celestial body with the use of different p-prims. For a kicked ball (case 2), falling downward was still the most given explanation for the Earth; however, for the Moon and Mars, moving toward another celestial body with the use of different p-prims was dominant.

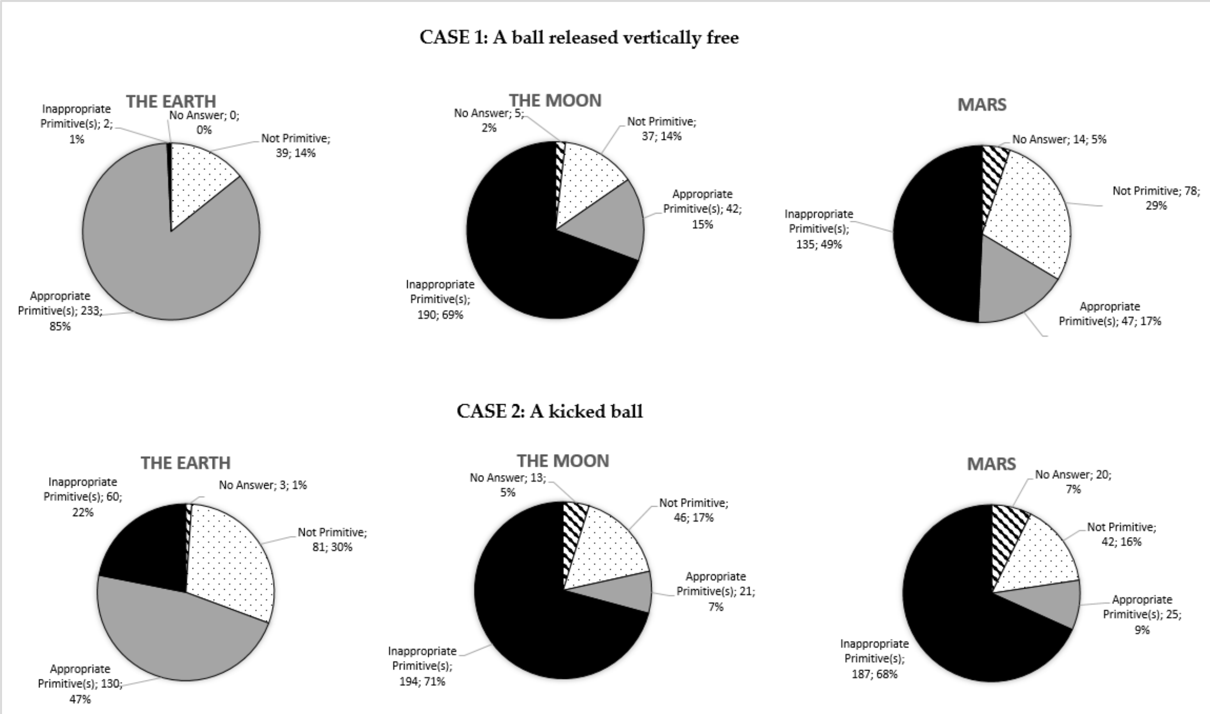
When focusing on the contexts (without considering different cases) of free fall on the graphs in Figure 1, the qualitative findings about p-prim use on the Earth, on the Moon and on Mars contexts also indicated the differences. For example, falling downward explanation was mostly used for the Earth- familiar and experienced context- with *force as a mover* and *closer means stronger* p-prims. Moving toward another celestial body was mostly used for the Moon and Mars with different p-prims such as *bigger is greater*, *force as a mover* and *overcoming*. In addition, to explain suspension of the vertically released and kicked balls, *dynamic balance* p-prim was also used in these inexperienced contexts. These findings indicated the role of experience on the abstractions from daily life. In addition, a chi-square test of independence was performed to examine the differences in the use of p-prims in different contexts. Depending on the diversity in the use of p-prims, a significant difference was identified throughout the contexts [X^2 (df= 12, N= 1266) = 629.150, p= .000].

When pre-service primary teachers' given explanations with different p-prims were examined, the distribution of the appropriateness of p-prims over three contexts of two cases was presented in Figure 2.

As presented in Figure 2, pre-service primary teachers' four kind of explanations (falling downward, moving toward another celestial body, suspending in the air, falling and then suspending in the air) about the motion of a vertically released ball and a kicked ball included the elements that were not p-prim as well as including appropriately and inappropriately used elements. In addition, in most of the contexts of two cases, teacher candidates did not give any answer to the question. Different proportions for different categories of appropriateness of p-prims (appropriate p-prims, inappropriate p-prims, not p-prim, no answer) were identified over three contexts of two cases. By considering the findings in Figure 2, when the complexity of the case increased, that means the complexity of the motion increased from one dimensional motion (a vertically released ball) to two-dimensional motion (a kicked ball), the appropriate use of p-prims for each context decreased (from 85% to 47% for the Earth, from 15% to 7% for the Moon, and from 17% to 9% for Mars). So, the inappropriate use increased for each of them. In addition, being familiar but inexperienced influenced the appropriate use negatively more than being unfamiliar and inexperienced. While familiarity and experience provided the more scientific and

Figure 2

The Appropriateness of P-Prims over Three Contexts of Two Cases



Appropriate use of p-prims for the Earth, with the lack of both familiarity and experience for Mars, the percentage of appropriately use of p-prims decreased. However, for the Moon, with familiarity of the context, teacher candidates may make overgeneralizations to hypothetical or inexperienced context, so their inappropriate use may be observed more than in unfamiliar and inexperienced Mars context for both cases (69% and 71% for two cases of the Moon, 49% and 68% for two cases of Mars). In addition, it can be observed in the graphs that the lowest percentage of unanswered questions was in familiar and experienced context—the Earth—and the highest percentage of unanswered questions was associated with unfamiliar and inexperienced context—Mars—for the both cases. Hence, teacher candidates answered the questions more when they were familiar and experienced in those areas. Finally, a chi-square test of independence was performed to examine the differences in the appropriateness of p-prims in different contexts. Depending on the diversity in the appropriateness of p-prims (appropriate, inappropriate, not use, no answer), a significant difference was identified throughout the contexts [X^2 (df= 6, N= 1644) = 613.654, p= .000].

Discussion and Conclusion

P-prims are implicit knowledge fragments derived from experience or intuition. They allow individuals to explain events on the spot, and also construct coherent knowledge structures with a good organization. Identification of p-prims is difficult because individuals do not report them. So, "inferring" is needed with indirect evidences (Taber, 2014). In this study, the following conclusions were deduced about the p-prims used to explain free fall:

1. Pre-service primary teachers used different p-prims in their explanations over the contexts of the vertically released and kicked balls. Teacher candidates used four kinds of explanations for free fall of a vertically released and a kicked ball. While the first explanation, falling downward, represents a scientific Newtonian understanding, the rest three (moving toward another celestial body such as the Sun, the Moon etc., suspending in the air, and falling and then suspending in the air) can be considered as misconceptions with non-Newtonian ideas (Ameh, 1987; Atasoy & Akdeniz, 2007; Champagne et al., 1980; Gönen, 2008; Kavanagh & Sneider, 2007; Kocakülah & Kenar Açıl, 2011; Kruger et al. 1990; Palmer, 2001; Sharma et al., 2004; Syuhendri, 2017; Watts, 1982). Teacher candidates used six different p-prims such as *force as a mover*, *closer means stronger*, *bigger is greater*, *overcoming*, *dynamic balance* and *dying away* for these four kinds of explanations with some abstractions (proximity, dimension, direction, cancellation etc.) from daily life.

Existing literature indicated both students' misconceptions as "gravity needs air" (Watts, 1982), "gravity does not act objects moving upward" (Palmer, 2001), "strength and effort prevent falling" (Kavanagh & Sneider, 2007), "no gravity on the Moon, "no air, no gravity" (Kocakülah & Kenar Açıl, 2011), "no gravity in space" (Champagne et al., 1980; Kocakülah & Kenar Açıl, 2011; Sharma et al., 2004), and also teachers' and teacher candidates' misconceptions as "no gravity in space" (Gönen, 2008; Kaltakçı & Didiş, 2006), "air pressure- assisted gravity", "gravity acts after impetus wears down", "no gravity on the Moon" (Atasoy & Akdeniz, 2007; Kaltakçı & Didiş, 2006; Kruger et al., 1990) and "no air, no gravity" (Kaltakçı & Didiş, 2006). The explanations of teacher candidates in this study as "moving toward another celestial body such as the Sun, the Moon etc.", "suspending in the air", and "falling and then suspending in the air" are comparable with the misconceptions identified in previous studies. Pre-service primary teachers used *force as a mover*, *bigger is greater* and *overcoming* p-prims to explain how a vertically released ball and a kicked ball could move toward another celestial body. In addition, teacher candidates used *dynamic balance* p-prim to explain how a vertically released and a kicked ball could suspend in the air; and *dying away* p-prim to explain how a vertically released and a kicked ball could first fall and then suspend in the air. Increase of the use of these inappropriate p-prims for the Moon and Mars contexts of the second case (a kicked ball) may explain "gravity does not act objects moving upward", "strength and effort prevent falling", "gravity needs air" or "no air, no gravity", "no gravity in space", "air pressure- assisted gravity", "gravity acts after impetus wears down", and "no gravity on the Moon" misconceptions identified in previous studies (Atasoy & Akdeniz, 2007; Champagne et al., 1980; Gönen, 2008; Kaltakçı & Didiş, 2006; Kavanagh & Sneider, 2007; Kocakülah & Kenar Açıl, 2011; Kruger et al., 1990; Palmer, 2001; Sharma et al., 2004; Syuhendri, 2017; Watts, 1982). By this way, individuals may try to explain "not falling" of a vertically released and kicked ball on the surface of the Earth, the Moon and Mars for many different ways caused by smaller knowledge elements.

For a scientific understanding of free fall, teacher candidates displayed the use of two different p-prims. These were *force as a mover* and *closer means stronger*. For the appropriate selection of these p-prims, teacher candidates considered the "proximity and effect" and "direction" of applied gravitational force. For example, some of them considered the "direction" of a force by *force as a mover*, the others considered the variables changing "proximity and effect" of a gravitational force by *closer means stronger*. Teacher candidates used these two p-prims to explain free fall mostly for the Earth context, but they used the other p-prims inappropriately allowing unscientific explanations. These implicit knowledge fragments might allow scientific and unscientific explanations for "why" questions especially asked on the spot. When there are no coherent mental structures in one's mind constructed with the relevant concepts, these implicit elements that are gained experience or intuition, might be responsible for the unscientific explanations as called misconceptions in the framework theory. In other words, when students do not have stable and coherent knowledge structures, they may construct their answers in situ with these fragmented elements.

Pre-service primary teachers are not aware of their p-prims, there is also no need to be aware of their knowledge elements (Taber, 2014) providing causal explanations implicitly. However; to facilitate the scientific understanding for the Moon and Mars contexts, the development of curricular materials providing explicit activation of appropriate p-prims are needed. In physics instructions, nature of gravitational attraction should be stressed not only for familiar and experienced context the

Earth, but also for the others. With their new curriculum focusing on the systematically activation of knowledge elements, Burde and Wilhelm (2020) shifted students' activation priority from a p-prim to another p-prim to engage a deeper causality in students' thinking of electric circuits. Similarly, in Wannous and Horváth's (2019) research, students performed better in FCI by the activating *force as a mover* p-prim appropriately in teaching Newton's laws of motion. Volfson et al. (2020) concluded the importance of providing students daily life contexts that bring advanced scientific ideas about physical events with interviews or discussions.

As well as correct selection and appropriate use of knowledge fragments in science contexts providing individuals explanations about events, they are also important for the construction of coherent scientific knowledge. Because learning physics including scientific and coherent mental structures can be achieved by construction, transformation and reorganization of p-prims (Burde & Wilhelm, 2020). In physics instructions, to explain physical phenomena, students may use both coherent but incorrect knowledge like misconceptions, and knowledge pieces inappropriately. Teachers should consider that students hold different kind of knowledge such as coherent or in pieces. Before removing them, knowledge elements of misconceptions should be examined clearly if any. By providing the contexts to students for appropriately use of knowledge elements, then scientific understanding could be achieved by not exchange but re-organization of the schemes. In conclusion, the appropriate selection and use of p-prims can be achieved by the activation of p-prims providing many different physical contexts allowing inference, comparison and conclusion.

2. The use and appropriateness of the p-prims to explain free fall differed over the contexts both qualitatively and statistically. Previous research indicated the context dependency of the use of knowledge elements for different physics concepts (Burde & Wilhelm, 2020; diSessa, 1993; diSessa et al., 2004; Jelicic et al., 2017; Volfson et al., 2020; Wannous & Horváth, 2019; Young & Meredith, 2017). In this study, most scientific explanations and appropriate use of p-prims were observed with respect to free fall for the Earth context in each case. However, inappropriate use of p-prims for unscientific explanations were mostly observed for the Moon and Mars contexts. Chi-square analyses conducted to examine the differences for the use and appropriateness of p-prims also indicated the statistically significant differences due to context. These findings imply the context dependency of knowledge elements (diSessa, 1993; diSessa et al., 2004) used for the explanation of a scientific phenomenon. Different contexts can easily cue different responses because the different knowledge pieces may tend to be weakly connected. However, a particular piece can be robust and activated with a high probability in a variety of situations (Bao & Redish, 2006). This conclusion is also comparable with Young and Meredith's (2017) research, since their analyses revealed that quite different knowledge elements were activated when two problems were quite different.

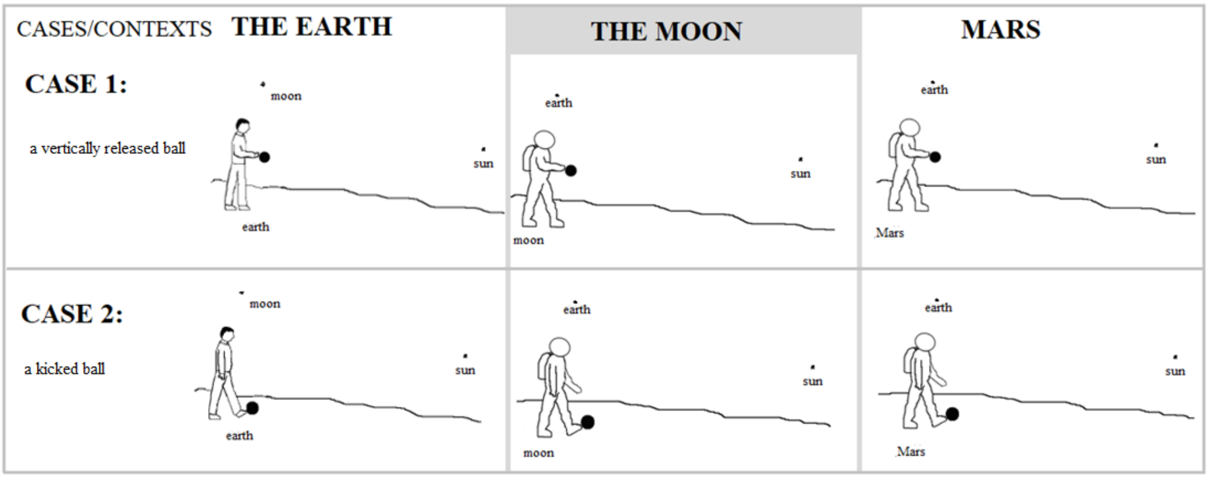
In this study, while familiarity and having experience increased the number of provided answers and the appropriate p-prims, on the contrary, familiarity without experience increased the inappropriate use of p-prims. These findings also pointed out the role of experience on making abstractions from daily life. In addition, discussion of free fall in two cases such as one-dimensional motion (a vertically released ball) and two-dimensional motion (a projectile motion of a kicked ball) pointed some differences in pre-service teachers' use and appropriateness of p-prims. Complexity of the motion decreased the appropriate use of p-prims because of the difficulty in the recognition of free fall in the second dimension (vertical) of projectile motion.

Implications

To conclude, this study indicated which implicit and smaller knowledge elements were used to explain free fall in different contexts by pre-service primary teachers, and the context dependency of the p-prims both qualitatively and statically. For further research, it might be useful to employ diSessa's "p-prims" framework for different science concepts. Examination of the knowledge elements behind students' explanations might provide the activation of appropriate p-prims. By this way, scientific understanding might be constructed in science classes by the activation of appropriate p-prims. It should be noted that the scientific explanations of physical concepts cannot be induced only by intuition or experience, and therefore students, teacher candidates, as well as teachers should interpret the theoretical constructs and organize their knowledge accordingly (diSessa, 1993; Hammer, 1994, 2000, 1996; Hammer & Elby, 2003; Reif, 1995, 1997). Hence, in physics classes, careful discussion of a physical phenomenon in the contexts with different types and complexities may help learners in the refinement of p-prims for scientific understanding.

Appendices

Appendix I. The translated version of the test



Please draw the direction of motion of the ball after released (in Case 1) and after kicked (in Case 2). Explain your reason if it fits the choices below and state the letter of explanation into the appropriate context.

Letter	Reasoning
A1	Falling downward, because the Earth/Moon/Mars is closer
A2	Falling downward, because the Earth/Moon/Mars forces the ball moving
B1	Toward the Sun/Moon/Earth, because the Sun/Moon/Earth is bigger
B2	Toward the Sun/Moon/Earth, because the Sun/Moon/Earth forces the ball moving
B3	Toward the Sun, because the Sun overcomes others
C	Suspend in the air, because of dynamic balance of forces by celestial bodies
D	Falling downward and suspend in the air, because force dies away

Appendix II. Coding table for data analysis

Letter	Code	Answer	P-Prim If Exist
	0	No Answer	no answer
	10	Falling downward (Earth/Moon/Mars)	not primitive
A1	11	Falling downward (Earth/Moon/Mars)	closer means stronger
A2	12	Falling downward (Earth/Moon/Mars)	force as a mover
	20	Toward the Sun/Moon/Earth	not primitive
B1	21	Toward the Sun/Moon/Earth	bigger is greater
B2	22	Toward the Sun/Moon/Earth	force as a mover
B3	23	Toward the Sun	overcoming
	30	Suspend in the air	not primitive
C	31	Suspend in the air	dynamic balance
	40	Falling downward and suspend	not primitive
D	41	Falling downward and suspend	dying away
E	51	Another way	

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