Probing students' conceptual knowledge of satellite motion through the use of diagram

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We investigated students' understanding of satellite motion around the Earth. For that purpose, we surveyed high-school and university students from Croatia. With the objective of gaining insight into teachers' understanding of students' abilities, physics teachers were asked to predict students' answers. The results of the study suggest that most students have difficulties with providing physically based explanations. They tend to approach such problems through the use of phenomenological primitives. Specifically, they tend to use the "closer is stronger" p-prim when attempting to identify the satellite orbit which would ensure receiving satellite television signal at a certain location paying no attention to the direction of the gravitational force. We found no statistically significant association between the students' ability to correctly explain the satellite motion and their educational background. The teachers considerably overestimate students' abilities. Generally, the results of this study suggest that diagram-based problem can be useful tool for probing students' understanding of satellite motion.

Keywords: Diagrammatic representation; satellite motion; students' problem solving.

Hemos investigado el entendimiento de los estudiantes del movimiento del satélite alrededor de la Tierra. Con este fin hemos hecho un estudio de los estudiantes de la secundaria y los estudiantes universitarios de Croacia. Con el objetivo de comprender la habilidad de los enseñantes de entender las habilidades estudiantiles, les hemos pedido a los profesores de física prever las respuestas estudiantiles. Los resultados de la investigación sugieren que la mayoría de los estudiantes tiene dificultades a la hora de dar explicaciones físicamente fundamentadas. Ellos tienen la tendencia de abordar estos problemas usando los conceptos fenomenológicamente primitivos. En concreto, tienen la tendencia de usar "p-prim closer is stronger" cuando tratan de identificar la órbita de un satélite que debería asegurar la recepción de señal de televisión por satélite en cierto lugar, sin tener en cuenta la dirección de la fuerza gravitacional. No hemos encontrado una relación estadísticamente significativa entre las habilidades estudiantiles de explicar correctamente el movimiento del satélite y su formación. Los enseñantes estiman mucho más de lo que valen las habilidades estudiantiles. En general, los resultados de esta investigación sugieren que los problemas con los diagramas pueden ser una herramienta útil para investigar el entendimiento estudiantil del movimiento del satélite.

Descriptores: Representación diagramática; movimiento del satélite; solucionamiento estudiantil del problema.

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1. Introduction

We live in the age of navigation, communication and earth observation satellites that are used in communications, weather forecasting, business, and science. Regardless of their widespread use nowadays, they have always aroused curiosity as "mysterious" objects, because e.g. satellites travel in space where most of us have never been or because they cost billions of dollars, which means none of us will ever own one personally. Orbital dynamics can also be mysterious because we cannot easily have our own experience of it. Considering this, developing intuitive understanding of satellite motion is not quite easy.

The dynamics of circular motion is central to a proper understanding of many aspects of physics. However, this topic proves to be conceptually difficult for students. As a matter of fact students enter and leave the physics instruction with a wide variety of explanatory concepts, most of which are - in traditional Newtonian terms - plainly wrong.

Therefore it is very important to identify student misconceptions about circular/satellite motion and to propose possible actions for ensuring conceptual change. Many physics education researchers were aware of the importance of studying this topic which resulted in the identification of many student misconceptions about circular/satellite motion e.g. [1-5] However, some aspects of students' ideas about satellite motion, such as ideas about physically possible shapes and locations of satellite orbits, remained rather unexplored.

In this regard, the aim of our study was to uncover additional students' misconceptions about satellite motion, as well as to investigate teachers' awareness of the existence of these misconceptions. In addition, our research idea emerged from the fact that the results of earlier studies suggest that students [6], as well as pre-service teachers [7-8], and in-service teachers [9-11] have difficulties with concepts related to Earth/space science.

In our study, students were presented a problem which included a visual representation (*i.e.* diagram) of the motion of the Earth satellite in different orbits. Implicitly students were expected to recognize the only possible one, for which the gravitational force directed toward the center. We accentuated the most important features of the diagram, taking into account the importance of directing students' attention to most relevant aspects of the problem [12], and asked the students several questions.

This study addressed the following research questions:

1) Which ideas about satellite motion can be elicited in students by confronting them with the given diagram-based problem?

2) Are physics teacher students more successful when it comes to solving the given physics problem than secondary school students?

3) How well can teachers predict students' answers to the given problem?

Answers to these questions could provide us with feedback regarding students' ability to relate real-life situations to abstract physical concepts. Further, we could gain some insight into students' attitudes towards non-traditional problems and the information regarding teacher competences could additionally improve the process of designing a more effective system of initial education of prospective physics teachers.

2. Review of relevant literature

2.1. Ideas from history of physics

It has been found that many students' misconceptions reflect ideas which can be found in the history of physics [13]. Below, we briefly describe how Galileo and Newton conceptualized circular/satellite motion.

The difficulty to find a logical explanation of the physical phenomenon of inertia that holds as a general principle can be seen even if we consider reasoning of Galileo. In his famous thought-experiment Galileo considered a ball rolling down one side of a double incline and found a tendency of the ball to roll up to the same height on the other side of the incline, regardless of the incline's slope which could be changed. He correctly concluded that, if the incline was horizontal and there was no friction, the ball would continue to move forever. There was no need for a force to keep the ball moving on. This important conclusion was very close to the statement of Newton's first law, except that Galileo thought that in the absence of external forces the ball would continue circular motion following the curvature of the Earth. In the *Dialogues* Galileo distinguishes between naturally-occurring motions which are uniform and circular, and forced ones which are accelerated and rectilinear. He believed that perpetual circular motion is a natural phenomenon [14]

Being aware of conceptual difficulties in understanding the satellite motion, Newton wrote a popular text to explain orbital motion of the Moon, which was published in 1728, the year after his death. In this paper he demonstrated the significance of the velocity for the orbital motion of the satellite. He discussed the trajectory of a cannon ball which, launched horizontally from the top of a very high mountain and, attracted by the Earth gravity, lands at ground level. If the launch speed is increased, the range of the projectile is increased too. If the speed is increased enough, the cannon ball horizontal displacement will become very large, and because of the curvature of the Earth surface the ball will not land at all. It will start orbiting the Earth. In this thought-experiment Newton also established a relationship between the trajectory of the free-falling cannon-ball, travelling with the escape velocity, and the revolution of the Moon around the Earth. Circular motion of the Moon is thus due to its velocity and the attractive gravitational force of the Earth [15]

Finally, we find that crucial for understanding satellite motion was also Newton's proof for the central nature of the gravitational force. In Proposition 1 of the *Principia* he showed that for a body moving under any kind of centripetal force radii drawn to an unmoving center of force sweep out equal areas of the unmoving plane in equal times. Thereby he gave a proof that Kepler's empirical rule is a consequence of a central nature of the gravitational force. In addition, in Proposition 74 Newton showed that the gravitational force exerted by sphere of a homogeneous density to a point outside the sphere is directed to the center of the sphere. We were motivated to test students' and teachers' awareness of these important issues.

2.2. Review of recent literature

McCloskey *et al*. [1] found that a kind of naive belief about the motion of objects is common for many university students even for those who had studied physics. Asked to predict the motions of objects moving in constrained curved paths many of them believed that an object would "remember" the curve after it left the constraint. This is explained by the naive *impetus theory*, common to many students, according to which the act of setting an object in motion imparts to the object an internal force or "impetus" that serves to maintain the motion. As impetus gradually dissipates the object gradually slows down and comes to a stop.

Gardner [2] found an astonishing variety of conceptual frameworks that students use in order to account for the dynamics of circular motion. This includes the Aristotelian idea that forward motion requires a forward force and treating circular motion as a kind of equilibrium. The equilibrium is postulated as a balance between a centripetal force and an equal and opposite centrifugal force, or by considering the constant speed of the object for which the changing direction does not require a dynamic explanation. Some students develop partial Newtonian frameworks, i.e. when faced with corresponding problems they may recognize that an unbalanced, centripetal force is acting but they are not able to describe the nature of that force.

To understand the satellite motion the concept of action at distance is important The concept of gravitational force has been explored by a number of physics education researchers; see the review by Gönen [16] Bar *et al*. [3] investigated pupils' pre-instruction ideas about action at a distance, in contexts such as gravitation. Within that study, pupils stressed the need for air as a conducting medium for forces acting from afar. Further, in the same study it has been shown that many students believe "action at a distance needs support which can be supplied by gravity" [3].

These findings have been supported by a recent study of students understanding of gravity in introductory college Astronomy by Williamson and Willoughby [4]. They found three main alternative mental models of gravity: the boundary model, the orbital indicator model, and the mixing of forces model.

The article by Kavanagh and Sneider [5] picks up the trail of research studies that address children's and adults' understanding of the ideas about satellites' orbits. These studies revealed several common misconceptions about gravity related to orbital motion: that gravity needs air; that there is no gravity in space; that objects in orbit are weightless, so gravity does not affect them; that the force of gravity diminishes rapidly with increasing altitude; that force is needed to keep an object in orbit; that planets closer to the Sun or that spin faster have more gravity; and that gravitational forces between objects are not equal and opposite. Ideas are probably resulting from general presuppositions [17], and can be traced to the developmental schemes of common sense theory [18] which assume that children's ideas are formed at a young age. Research findings showed that such concepts hardly change during regular instruction [19], thus a special instructional effort is needed. For example, one instructional method that includes considering the Moon as satellite which is held in orbit by gravity, elicited in pupils the preconception, that gravity needs air as a conducting medium, and caused a conceptual change in the ideas of some other pupils [20].

3. Methods and research

3.1. Sample

High-school and university students. This study included 276 high-school and university students from different counties in Croatia. The students were selected by non-random convenience sampling [21]. We surveyed those students who voluntarily applied to participate in the research, and who obtained the necessary consent from their school principals and subject teachers. The sample structure is presented in Table I. Additionally, it should be noted that there was an approximately equal share of students from different grades within the sample of high-school students. Similarly, there was an approximately equal share of students from different study years, within the sample of university students.

It could be useful to point out that compulsory education in Croatia lasts for eight years and the secondary education is optional. The admittance criteria for secondary education are based on the students' achievement at the primary school level. We basically distinguish between two types of secondary education – gymnasiums and vocational schools. Gymnasiums are intended to prepare the students for further education and vocational schools offer professional qualifications. They are attended by students aged 15-19. Further, note that Croatian gymnasiums are secondary schools that are comparable to English grammar schools or U.S. high-schools. The gymnasium curriculum in of Croatia foresees the following subjects: mathematics, the natural sciences, the native language, one to three foreign languages (including Latin), geography, information-technology (IT), history, history of art, music, philosophy, logic. There are different types of gymnasiums with respect to the focus on certain subject areas. For example, in science gymnasiums focus is on mathematics and science, whereby in information-technology gymnasiums the focus is on information-technology. On the other side, in vocational schools students are prepared for a particular job. The gymnasium type of education lasts four years and ends with the "matura" examination (monitored by the state) which is an entrance qualification for further education. The students who attend vocational schools (lasting 3-5 years) are also allowed to take the "matura" examination in order to acquire the access to university education. Finally, prospective physics teacher acquire their (5-year lasting) initial education at the faculty of science. These students graduate with masters' degree in science education which makes them fully qualified for teaching physics and the other subject they studied (which is usually mathematics, chemistry and informational technology) at the elementary/high-school level. In the practice, these students also often find their employment in other sectors that require expertise in science and technology.

The sampling procedures were implemented with the objective of obtaining a sample which is representative of "hypothetical populations" [21] of students from certain schools/

TABLE I. Description of sample characteristics.

School type	Science gymnasiums and information technology gymnasium from Rijeka and Split (grades: 1.-3.) (**SG&ITG**)	General Gymnasium from Rijeka and Zagreb (grades: 1.-3.) (**GG**)	Vocational School from Rijeka (grades: 1.-3.) (**VS**)	University of Rijeka / University of Zagreb – Physics teacher students (years: 1.,2.,3.,5.) (**PT**)
Sample size	72	139	24	41

universities. In our study, we also tended to draw comparisons between high-school and university students. All high-school students, regardless of grade, have been taught the physics concepts which were relevant for our study. On the other side, the included university students have been taught the relevant concepts twice. The first time they learned the corresponding subject matter during their high-school education, and the second time they learned it, on a higher level, during their university education. Furthermore, we made comparisons between high-school students from different school types, in order to estimate the effectiveness of different curricula.

Teachers. We surveyed all 48 high-school physics teachers who participated in the "Split-dalmatian County Physics Teacher Symposium", which was held in Split (Croatia) in September 2011. Teachers were selected by one-stage cluster sampling [21].

3.2. Students' task

The students were given a sheet with the problem statement and the corresponding questions, as well as a blank sheet where they were supposed to write down their answers to questions 1.1, 1.2 and 1.3. Problem-solving time was not limited. The problem was read:

1. Figure 1 shows the Earth globe, whereby the position of Croatia, the equator and axis of rotation are highlighted. The satellite in Earth's orbit transmits the television signal. This is the so called geostationary satellite which appears to be stationary (motionless) when viewed from the Earth's surface, because its period of rotation equals the Earth's period of rotation.

1.1 *If we want to receive satellite channels in Croatia, which of the marked paths of motion (A, B, C, D) would most adequately represent the orbit of the corresponding satellite?*

1.2 *Please, explain your choice.*

1.3 *What is causing such motion of the satellite?*

We can see that this relatively simple problem requires the analysis of a diagram in which the most relevant parts are highlighted. The position of Croatia, Earth's axis of rotation and the equator are marked in the diagram, and the satellite orbits are designated by letters A, B, C, D. Thereby, the orbits can be approximately considered as circles whose centers lie on Earth's axis of rotation. For the purpose of determining which of the provided paths of motion is physically feasible, it is necessary to understand the concepts of gravity and circular motion. In order for circular motion to take place, a centripetal force must be present. The centripetal force which causes satellite motion around the Earth is the gravitational force. Concretely, the force of gravitational attraction is directed along the line connecting the satellite with the center of the Earth. Therefore, the plane of satellite's motion must

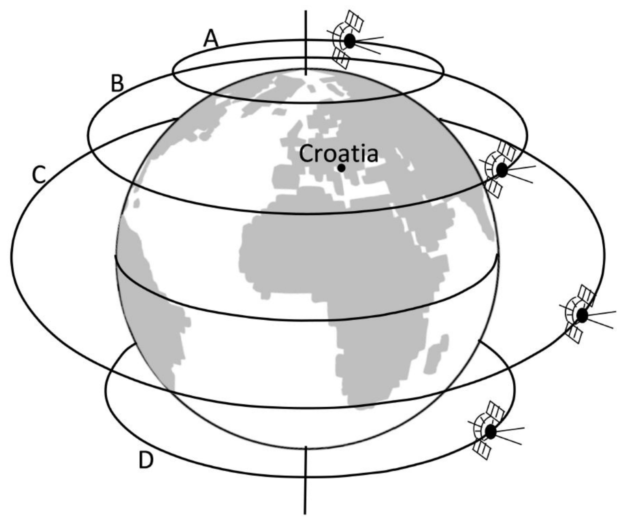

FIGURE 1.

pass through the center of Earth, from which it follows that orbit C is the only possible, correct path of satellite motion. The motion of the geostationary satellite is additionally affected by its exactly adjusted circumferential speed at the distance of $r = 42200$ km from the center of the Earth. As a result of the appropriate speed which the satellite, launched horizontally near the Earth, must have, the satellite does not fall back to the ground, but is kept in a circular orbit under the influence of gravitational force. This is in accordance with Newton's discussion [22] about the transition from parabolic to circular orbits, when the launch speed approaches the value of the first cosmic speed $\nu_1 = \sqrt{gR_E} = 7903.5$ m/s, where g is gravitational acceleration on the Earth's surface and $R_E = 6370$ km is Earth's radius. Of course, launch speed for geostationary satellite $v = \sqrt{GM\left(\frac{2}{R_E} - \frac{1}{r}\right)} = 10759.3$ m / s is much larger than v_1 and approaches to second cosmic speed (escape velocity) because the orbit is far from Earth surface $(r \gg R_E)$. Here G is universal gravitational constant, M is Earth's mass and r is the radius of the geostationary orbit.

In other words, for keeping the satellite in a circular orbit, its speed is as equally responsible as the gravitational force acting on it. This can be easily understood if we consider an example of the Moon as the Earth's satellite in the following speculative situation. If the Moon would be stopped, then under the influence of the gravity it would fall down to the Earth, just like all other objects would. On the other hand if the gravitational pull would disappear, the Moon would drift far away to the space. It is also important to note that the satellite (tangential) speed is not caused by the gravitational (central) force of the Earth. Wee and Goh [23]created an Easy Java Simulation model to allow students to visualize the satellites' orbits near Earth.

TABLE II. The closed-ended questionnaire prepared for purposes of the teacher survey.

1. *Figure 1 shows the Earth globe, whereby the position of Croatia, the equator and axis of rotation are highlighted. The satellite in Earth's orbit transmits the television signal. This is the so called geostationary satellite which appears to be stationary (motionless) when viewed from the Earth's surface, because its period of rotation equals the Earth's period of rotation.*
Please answer the question by choosing one of the offered response options. You are not necessarily required to choose the correct answer – we ask you to choose the option which you think most of your students would choose.
1.1.2. *If we want to receive satellite channels in Croatia, which of the marked paths of motion would most adequately represent the orbit of the corresponding satellite?* **a)** Path A, because it allows optimum signal reception for all places on Earth, whereby the signal propagates from the top to the bottom of the Earth. **b)** Path B, because it is nearest to Croatia and consequently ensures optimum signal reception. **c)** Path C, because the center of the motion plane coincides with the center of the Earth. **d)** Path D, because the geostationary satellite has to be in front of the horizon in order to make the signal transmission to all parts of the Earth possible.
1.3. *What is causing such motion of the satellite?* **a)** Earth's rotation. **b)** Gravitational force and the velocity of the satellite. **c)** First cosmic velocity. **d)** Software which is built into the satellite. **e)** Gravitational force.

3.3. Teachers' Predictions

High-school teachers were administered a closed-ended questionnaire (Table II). Thereby, questions 1.1 and 1.2 from the students' questionnaire were integrated and presented in the form of question 1.1.2. The question 1.3 remained unchanged. Furthermore, the provided answering options were formulated based on empirically obtained students' answers (Table III).

We asked the teachers to choose the option which they think most of their students would choose when faced with the same question. Thereby, the offered response options were based on empirically obtained students' answers. Similar research has been conducted by Lightman and Sadler [24]. They were interested in the extent to which teachers are able to predict the difficulty index (*i.e.* percentage of correct answers) of exam questions. Viiri [25] also designed a questionnaire based on empirically obtained students' answers and used it for purposes of studying the ability of the teachers to accurately estimate the competences of their students.

3.4. Procedures

For purposes of identifying students ideas about satellite motion (research question 1), we categorized students' answers into three categories with respect to the three questions 1.1, 1.2 and 1.3. For purposes of scoring questions 1.1 and 1.2, we distinguished three different answering behaviors: correct answer, incorrect answer and missing response. Answers to question 1.3 are classified in a different way, *i.e.*, we have assigned them one of four answering behaviors: complete answer, partially complete answer, alternative answer and missing response. In this way we tried to find percentage of those respondents who fully perceive the physical situation.

Further, we aimed to investigate whether the differences in the rate of correct/complete answers between high-school and university students, were statistically significant (research question 2). In order to accomplish this task, we firstly had to create two variables – the "Nature of the response" variable, and the "Educational level" variable. The former variable consisted of the levels "Correct answer" and "Other", and the latter variable consisted of the levels "High-school students" and "University students". For the purposes of investigating whether these two variables were associated with each other, we decided to calculate the Fisher's exact test [26]. For purposes of calculating the necessary statistics, we used the SPSS 17.0 software.

Finally, we estimated the extent to which teachers were able to predict students' answers to the given problem (research question 3). To this end, we decided to compare the expected distribution of student answers to the observed distribution of student answers, whereby the expected distribution was derived from the results of the teacher survey.

4. Results

We can gain some insight into student's ideas about satellite motion (research question 1) by analyzing their answers to

TABLE III. The classification of students' answers to questions from problem 1 and their corresponding share.

Questions and answers	Percentage
1.1. *If we want to receive satellite channels in Croatia, which of the marked paths of motion would most adequately represent the orbit of the corresponding satellite?*	
Correct answer: Path C.	9 %
Incorrect answers:	91 %
Path B. (79.63 %)	
Path A. (5.46 %)	
None or all of the paths. (5.46 %)	
Path D. (0.45 %)	
1.2. *Please, explain your choice.*	
Correct answer: Because the center of the plane of motion coincides with the center of the Earth.	1 %
Incorrect answers:	88 %
Because of the orbit's proximity to Croatia or Europe, *i.e.* because of the opportunity for signal coverage in Croatia or Europe (71.28 %).	
By example:	
-I think that C is the correct option, because the Earth doesn't rotate around its own axis, but it is slightly tilted to the right. For that reason, Croatia is placed closer to the satellite orbit C compared to B.	
-The angle of coverage of orbits A and B is sufficiently large to ensure signal coverage in Croatia. But, in order to receive the signal Croatia has to be positioned within the angle which defines the area of waves emitted by the satellite B (theoretically A is also possible). Thus, it follows that the satellites must be approximately located at the left half of the right hemisphere.	
Because of the nature of motion/position of the satellite. (4.4 %)	
By example:	
-Because the satellite's period of rotation equals the Earth's period of rotation.	
-The line connecting Croatia and satellite B doesn't pass through the Earth.	
Because of accomplishing signal coverage for as many as possible locations on planet Earth (3.52 %)	
By example:	
-B covers a much larger area compared to A. One further evidence is that we are receiving the signal for many German-language channels, whereby we know that Germany is located northwards.	
Because of satellite's distance from Earth, *i.e.* because of its distance from certain locations on Earth (2.64 %)	
By example:	
-The orbit C satellite is equally distant from all locations which are equally distant from the equator.	
Because of latitude and/or longitude. (2.64 %)	
By example:	
-Path B, because the latitude of Croatia is 45°N.	
Because of Earth's motion. (1.76 %)	
By example:	
-Path C, because Earth is rotating around its axis, and its widest latitude is the equator.	

Responses which include the gravitational force concept. (0.88 %)	
By example:	
-Path C, because it reflects the state of equilibrium – for this orbit the gravitational force cancels out the effects of the centripetal force.	
Other incorrect responses. (0.88 %)	
By example:	
-Path B, because I liked it most.	
-I tried to relate it to characterizing different areas of the hemisphere with different climatic zones. Thereby, the orbit B corresponds to the area of temperate climate where Croatia is located. I want to point out that the climate is not connected in any way with this question, but it facilitated my reasoning about the given problem.	
Missing responses	11 %
1.3. What is causing such motion of the satellite?	
Complete answer: Gravitational force and the velocity of the satellite.	4 %
Partially complete answers:	34 %
Gravitational force. (31.62 %)	
Velocity of the satellite. (2.38 %)	
Alternative answers:	
Some other force or force, in general. (12.09 %)	
By example:	
-The cause of such motion lies in the satellites association with Earth's force of gravitational attraction, in a state characterized by zero gravity, whereby it is rotating around the Earth in a similar manner as the Moon.	
-The force of Sun's attraction, around which it orbits together with the Earth.	
Motion, position, composition and other characteristics of the Earth. (19.11 %)	
By example:	
-Because areas of the Earth which are closer to the poles rotate faster than the areas in the vicinity of the equator.	
-Because of tilt of the Earth.	
-The cause lies in the axis of Earth's rotation.	
-Earth's gravitational potential energy	
Motion, position, composition or other characteristics of the satellite. (7.8 %)	
By example:	
-Satellite is in circular motion and it includes 4 additional satellites in order to ensure TV signal coverage for all parts of the world (north, south, poles, center). Croatia is closest to it.	
-Software built in by NASA or the like which is controlled from Earth.	
-The satellite's gravitational potential energy relative to the Earth is equivalent to the centrifugal force within the non-inertial frame of the satellite which results in the fact that the satellite doesn't change its distance from the Earth.	
Missing responses	23 %

the given task. The typical, as well as original students' answers and their share are given in Table III.

The bar-charts given in Fig. 2, allow us to perform group comparisons with respect to competences assessed by means of the problem 1. The height of the bars within the charts corresponds to the proportions of different answering behaviors (correct/complete, partially complete, incorrect/alternative and missing response) Each of the bars corresponds to exactly one of the questions.

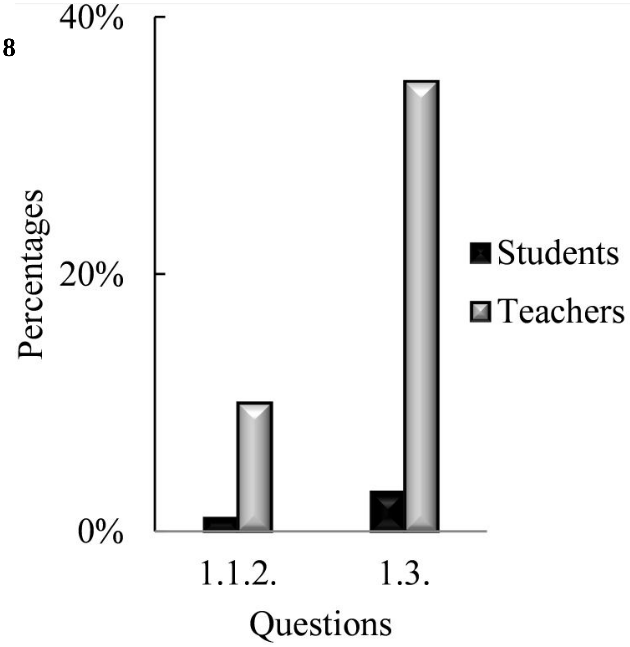

FIGURE 2. The distribution of students' answers to questions from the problem 1.

TABLE IV. The contingency table for the question 1.1 from the students' survey.

	Nature of response		
Educational level	Correct	Other	Total
High-school	12	223	235
University	14	27	41
Total	26	250	

TABLE V. The contingency table for the question 1.2 from the students' survey.

	Nature of response		
Educational level	Correct	Other	Total
High-school	2	233	235
University	2	39	41
Total	4	272	

For purposes of exploring the relationship between student achievement and student educational level (research question 2), we decided to calculate the Fischer's exact test.

In order to calculate the Fischer's exact test for task 1.1, we firstly had to create the corresponding contingency table (Table IV).

For question 1.1, the Fisher's exact test proved to be highly statistically significant ($p < 0.001$). In other words, the results show that there is a statistically significant association between the nature of students' responses to question 1.1 and their educational level. Specifically, this seems to represent the fact that, based on the odds-ratio, the odds of students correctly solving the question 1.1 (choosing the correct orbit) is 9.6 times higher if they are physics teacher students than if they are high school students. Thereby, the rate of correct answers is 46 % higher in the group of physics teacher students.

In order to investigate, whether the university students were significantly more successful (compared to high-school students) at providing an adequate explanation for their answer to question 1.1, we decided to create a contingency table for question 1.2 (Table V).

This time, the Fisher's exact test showed no statistically significant ($p = 0.106$) association between the correctness of students' explanations and their level of education.

Finally, we were interested in the effect of educational level on students' ability to provide complete answers regarding the causes of motion of geostationary satellites. Therefore, we created a contingency table for question 1.3 (Table VI).

By calculating the Fisher's test, it has been shown that there is a statistically significant ($p = 0.045$) association between the students' educational level and their ability to completely specify the causes of the motion of geostationary satellites. However, we can say that the corresponding effect size is relatively low, because the percentage of complete answers is only 7 % higher for physics teacher students compared to the high-school students.

TABLE VI. The contingency table for the question 1.3 from the students' survey.

	Nature of response		
Educational level	Complete	Other	Total
High-school	6	229	235
University	4	37	41
Total	10	266	

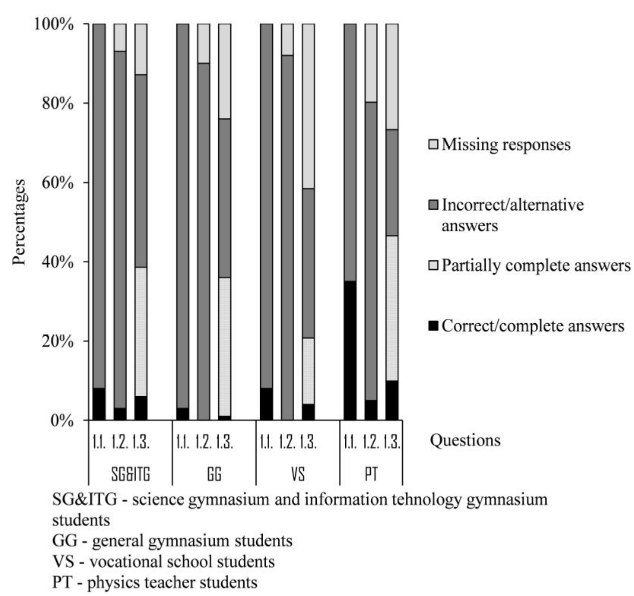

FIGURE 3. Comparison of the expected percentage of high-school students' correct/complete answers with the empirically obtained percentage of correct/complete answers.

The comparison of the teachers' expectations regarding the percentage of high-school students' correct/complete answers with the empirically obtained percentage of correct/complete answers (research question 3) is illustrated in Fig. 3.

5. Discussion

It has been shown that only 9% of high-school and university students answered correctly the question 1.1. They asserted that option C most adequately describes the orbit of the satellite which ensures TV signal coverage in Croatia. The remaining 91 % of students answered incorrectly the question 1.1. Most of them chose the option B, because that option represents the orbit which *is closer to Croatia than the other offered orbits*.

In question 1.2 students were required to explain their choice from question 1.1. The results for this question show that even a major share of students who had initially correctly chosen the option C, didn't provide a correct explanation for their choice. Thereby, the overall percentage of correct answers decreased from 9 % in question 1.1, to 1 % in question 1.2. Although we tended to direct the students' attention to most relevant parts of the diagram, by highlighting them, a large majority of the students answered the question 1.2 incorrectly (88 %) or didn't answer it (11 %), at all. As previously, emphasized they mostly chose the orbit which corresponds to the nearest distance of the satellite to the place on the Earth where the signal is to be received. Taking into account the fact that the ratio of missing responses to incorrect responses for question 1.2 is relatively small, suggests that the described (faulty) explanatory model of geostationary satellites represents a widespread misconception. Further, the fact that only 2 out of 41 physics teacher students provided a correct answer indicates that the mentioned misconception is very persistent. A closely related construct to misconceptions are the phenomenological primitives or p-prims [27]. According to Tuminaro and Redish [28], p-prims represent abstractions from everyday phenomena which are "irreducible and undetectable" to the student. They introduce the "closer is stronger" primitive as a typical example of p-prims, which could be, inter alia, abstracted from the phenomena that "the closer one is to fire, the warmer it feels" [28]. It is interesting to recall that the majority of the students who participated in our study, asserted that "the closer the satellite is to Croatia, the better (stronger) the signal". Thus, we can say that their thinking approach seems to mostly resemble the p-prim "closer is stronger" which is described by Tuminaro and Redish [28].

When it comes to question 1.3, it should be noted that only 4 % of students provided complete answers regarding the factors which affect the illustrated motion of the satellite. Those students who provided partially complete answers, mainly considered the gravitational force (32 %) to be the only factor which contributes to the nature of satellite's motion. The share of the students who had asserted that the velocity of the satellite is the only factor which affects satellite's motion was rather low (2 %). Within the pool of alternative answers, other forces, characteristics of the Earth and the satellites' have been considered as causes of the chosen satellite's motion (Table III).

Despite the extremely low percentage of correct answers, from Fig. 2 and from calculations of the Fisher's test, we can conclude that there are certain differences between the given groups of students. When it comes to the question 1.1, physics teacher students (PT) achieved a statistically significant higher rate of correct answers with respect to high-school students, whereby the obtained effect size has been large. However, the results for the question 1.2 show that 12 out of 14 PT students who initially had chosen the correct orbit, were not able to correctly explain their choice. It follows that many PT students correctly answered question 1.1 without having a complete understanding of the corresponding physical situation. Generally, the between-group differences related to the percentage of correct answers were rather small (up to 5 %) for question 1.2.

A relatively small number of respondents (4 %) provided a complete answer to the question 1.3, by pointing out that the gravitational force, as well as the velocity of the satellite determines the satellite's motion around the Earth. On the other side, a much higher percentage of students (32 %) provided partially complete answers by asserting that the gravitational force alone is sufficient to cause the given satellite's motion. The PT group stands out again, by having the highest percentage of fully/partially complete answers, as well as by having the lowest rate of alternative answers. Thereby, the differences between PT students and high-school students are relatively small (7 %), but statistically significant. The lowest rate of complete answers has been observed in the general gymnasium (GG) and vocational school (VS) groups of students, whereby the students from science/informational technology gymnasiums (SG/ITG) provide the highest percentage of alternative responses. These results suggest that the conceptual understanding of the satellite motion (as represented by the diagram) is stronger associated with students' educational level than with the curriculum to which the students had been exposed. The largest number of VS students didn't provide an answer to question 1.3, at all. A possible reason why students often failed to recognize the gravitational force as the cause of satellite's motion in question 1.3, can be found in the fact that students have serious difficulties regarding the perception of such physical interactions. In this respect, Gönen [16] asserts that perceptual difficulties related to certain interactions (gravitational force, frictional force, inertial force) may induce students to assign to these interactions an inferior status, or to simply discard them as possible causes of natural phenomena.

From Fig. 3, it follows that teachers overestimate students' understanding of the concepts which are relevant for the satellite's rotation around the Earth, *i.e.* the concepts of circular motion, gravitational force and first cosmic velocity. When it comes to question 1.1.2 which required the choice of the correct orbit and an adequate explanation, teachers expected that 10 % of high-school students would answer correctly, but the empirically obtained data showed that only 0.85 % high-school students had answered correctly. Large disagreements between teachers' expectations and student achievement have been also identified for the question which required the students to explain the causes of motion of geostationary satellites. For this question, the percentage of complete answers for the group of high-school students amounted to 2.55 %, which is approximately 12.5 times lower rate in comparison to the expected 35 %.

The described results provide further evidence that there is a mismatch between methods of instruction and methods of learning within the traditional approach to teaching physics [29]. Thereby, the traditional approach is characterized by product oriented instruction, whereby the teacher serves primarily as a transmitter of information and students are passive recipients. On the other side, research has shown that students frequently enter the introductory physics courses with erroneous preconceptions [16]. If the physics teacher fails to uncover and explicitly treat these misconceptions, they probably won't be changed as a result of traditional, formal instruction [30]. Consequently, the misconceptions can negatively interfere with learning, as it is the case with erroneous perceiving of classroom experiments [31-32]

We believe that non-traditional problems [33-38] can be used as a helpful tool for purposes of promoting classroom discussion, probing students' mental models, and confronting them with their misconceptions. The problem which was used for purposes of this study, proved to be useful for revealing students misconceptions regarding some fundamental physics concepts, like the concept of gravitational force. By identifying the students' misconceptions related to the gravitational force, we can more effectively plan the process of corresponding conceptual change which is a necessary prerequisite for the acquisition and understanding of more complex physics concepts. One additional question which could be asked within the discussion about satellite's motion is as follows: *Does the satellite need fuel for getting in order to start its motion and which orbit is associated with least fuel consumption?* Students can also be asked if they notice direction of satellite antennas. Some of them surely notice that they are not directed vertically, but somewhere on south. Finally, one could ask them to calculate orbit, launching speed and velocity in orbit. In this way it could be clear that it is hard to calculate orbit different of one of the great circle. Also, they could notice that wrong orbit requires additional force. Calculation of orbit can also suggest that gravity does not need conducting medium, because it is far from Earth surface, *i.e.* there is no atmosphere.

6. Conclusion

In this study, we used a diagram for purposes of assessing students' conceptual knowledge related to physical phenomena embedded in a real-life context. Concretely, we were interested in students' conceptions regarding the rotation of geostationary satellites around the Earth. Furthermore, we aimed to investigate the teachers' ability to estimate their students' answers to the given problem. In this way, we indirectly explored whether the teachers are aware of their students' needs and abilities, which is an important pre-requisite for effective planning of instruction.

The results of our study show that students' thinking about the geostationary (communication) satellites is characterized by the existence of certain phenomenological primitives [27]. In other words, the corresponding explanatory models of most students obviously lack necessary physics schemata, so that most of students offered explanations of the type: "the closer the satellite... the better/stronger the TV signal", which is very similar to the "*closer is stronger*" phenomenological primitive which can be found in the relevant literature [28]. As earlier emphasized, most students didn't even try to provide an explanation in terms of physical concepts. This is a further evidence that students in the end rely on their intuitive knowledge and p-prims when faced with problems which are embedded in real-life contexts. In these cases, they often don't even attempt to think about the problem in terms of formal physical concepts. Specifically, the results of our study show that students across all educational levels in Croatia lack deep understanding and functional knowledge related to basic physics concepts, like the concepts of circular motion, gravitational force and first cosmic velocity. This conclusion is supported by the fact that only 4 % of students provided complete answers regarding the causes of satellite's motion. Further, it has been shown that there is no statistically significant association between students' educational level and their ability to provide a physically based explanation for the characteristics of the orbit of geostationary satellites. These results are in line with the findings of Libarkin *et al* [6], Abell *et al* [7] and Trumper [8]. Furthermore, the curriculum to which students had been exposed does not seem to have an important impact on the development of corresponding conceptual knowledge, either. In other words, the results suggest that none of the curricula across different educational levels in Croatia, provides a sufficiently effective basis for development of the concepts of circular motion, gravitational force and first cosmic velocity. Finally, the results of our study indicate that teachers tend to overestimate their students' abilities, which can have negative influences on the quality of their instructional planning.

Additionally, it has been shown that diagram-based problems can be an efficient tool for uncovering misconceptions. Generally, we believe that the use of diagrams could facilitate designing an interactive classroom environment, especially when it comes to promoting creative classroom discussion. However, further experimental studies are necessary in order to additionally reinforce the effectiveness of the proposed approach.

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