

A CASE STUDY OF HIGH SCHOOL STUDENTS ASTROPHYSICAL CONCEPTION SURVEY ON THE KEPLER'S SECOND LAW OF MOTIONS AND NEWTONIAN MECHANICS IN PHAYAO

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Received: March 16, 2015; Revised date: July 03, 2015; Accepted date: July 06, 2015

Abstract

We survey the conceptual understanding in classical mechanics and applying classical mechanics principles for describing astronomical models (Kepler's second law of motion) among an experiment group of Phayao high-school students. Our results from the group reveal more than half of the students can apply the law of equal area to angular speed and describe this phenomenon by gravity force, circular motion, and distance from star/sun which is the parent star of the system. However, they cannot explain by using conservation of angular momentum which is another physical process in the Physics course content. Some students are lack of understanding about action-reaction force (Newton's third law) when they try to describe physical forces in stellar/solar system. Moreover, the mathematical concept used to represent force, i.e. vector, is another important difficulty in teaching Astronomy or Physics.

Keywords: Astrophysics Education, Physics Education, Kepler's second law of motion, Newton's law of motion

Introduction

The "Earth, Astronomy and Space" course was designed by the Institute for the Promotion of Teaching Science and Technology (IPST). The course has been lectured in science and non-science classes in Thai secondary-school level since 2008. There are many intersection of contents in Astronomy part and high-school level Physics courses e.g., Classical Mechanics, Electromagnetic Theory, Optic Physics etc. which would inspire us to do a research on how students learn concepts and apply the physical processes to explain the Astronomy phenomena? In other word, we consider the Astrophysical concept of the

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students after they studied these two courses.

The conceptual test to study the relationship between Physics Concepts and Astronomical phenomena or Astrophysics concepts began by Treagust and Smith (1989) who studied the students' understanding about Planetary Orbit around the Sun by Gravity force. There are the conceptual tests that used to survey the "Big Picture" that contain Astrophysics concepts test; e.g. Sadler (1998)'s Astronomy Concept Inventory (ACI), Zeilik (2002)'s Astronomy Diagnostic Test version 2.0 (ADT 2), Sadler *et al.* (2009)'s Astronomy and Space Science Concept Inventory (ASSCI), Balfour and Kohnle (2010)'s Astronomy Concept Survey (ACS) etc. Most of the tests mentioned above are multiple-choices that can get data in short time. In order to be suitable for Thai contexts, we create the conceptual survey test that examine students' understanding and applying between Astronomy and Physics based on Thai Curricula. At the beginning, we survey students' understanding and applying between Astronomy and Physics by using open-ended conceptual questions.

In this article, we present the preliminary results of surveying with open-ended conceptual questions to explore how the student use their understanding concepts from classical mechanics from Physics courses to explain the astronomy phenomena.

Materials and Methods

We design the open-ended questions by considering the elliptic orbit of planets, asteroids, or comets around the Sun or star which is the parent star of the solar or stellar system, as shown in Figure 1. In the figure, we try to put the Sun or star at a focus point of elliptic orbit path, the four positions of a bounded-orbit celestial body. We have two sets of questions.

A. The questions about Kepler's laws motion with angular speed and force

1. Assume that a celestial body orbits around the Sun or star, which position have the fastest angular speed? And why?

2. Assume that a celestial body orbits around the Sun or star, which position have the slowest angular speed? And why?

3. What is the physical force acting on this celestial body and affect it to obey the Kepler's law of motion?

B. The questions about the force on the celestial body to test concept of direction and amplitude.

The experiment group consists of the 30 selected students from the 60 high-school students (grade 11th) of University of Phayao Demonstration School. We choose those students because all of them study with intensive

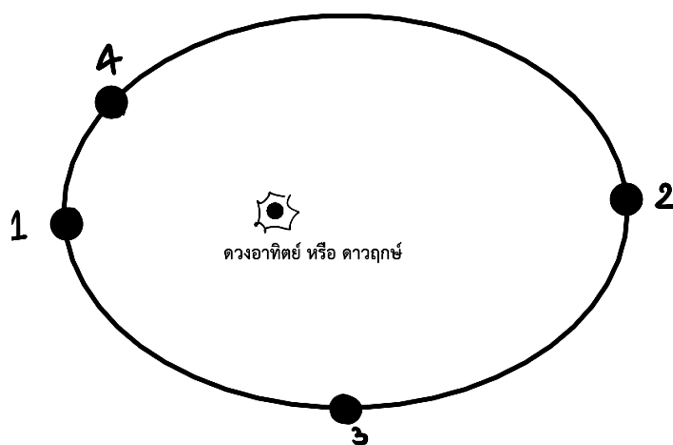


Figure 1. This picture was used for the question about Kepler's laws of motion and Newton's law of motions

astronomy and classical mechanics, extra laboratory and special lecture from experts (teachers of the school and lecturers from undergraduate curriculum). The open-ended questions are used to collect the answers from the experimental group. The answers and reasons are grouped, according to concepts they used for solving the problems.

Results and Discussion

The answers from questions about Kepler's laws of motion (group A) with angular speed and force are shown in Tables 1, 2 and 3.

A1: Due to Kepler's law of equal area "an imaginary line drawn from the center of the Sun to the center of the planet will sweep out equal areas in equal intervals of time". This law can

be interpreted to angular speed by considering the radial distance between star/sun's centers, angular distance and time interval. Thus the nearest position to the star/Sun (position 1 or P1), the planet/comet will orbit with the fastest angular speed.

Three of 30 students do not answer this question. However we will investigate the 27 students' answer and their explanations.

Eleven of 30 students answer the position 1 (P1).

- Five of them describe only because it is the nearest position to their parent stars. This is not a clear reasons and cannot tell which skill that the students used to answer, remembering or understanding skills?

- There are two students who give their reasons by mention about the shortest distance from the star and strongest gravity from it will

Table 1. Group of the answers from the A1 question: "Assume that a celestial body orbits around the Sun or star, which position have the fastest angular speed? And why?"

Grouped reasons	Number of answered position (P)					
	P1	P2	P3	P4	P1 & P4	None
The nearest position to star/sun	5	-	-	2	1	-
The nearest position to star/sun & strongest gravity in their orbits cause the celestial body move faster	1	-	-	-	-	-
The nearest position to star/sun & weakest gravity in their orbits cause the celestial body move faster	-	1	-	-	-	-
The nearest position to star/sun & gain maximum heat from star/sun	1	-	-	-	-	-
The farthest position from the star/sun & the weakest gravity in their orbits cause the planet/comet move faster	-	3	-	-	-	-
Need high velocity to escape from sun/star attractive force	1	-	-	-	-	-
At curve of the orbital path there is the stronger force acts on the planet/comet	1	-	-	-	-	-
Due to gravity of star/sun acts on planet/comet	-	1	-	-	-	-
Due to smallest angular distance	-	-	-	2	-	-
No Reason	2	4	-	-	1	3

Table 2. Group of the answers from the A2 question: “Assume that a celestial body orbits around the Sun or star, which position have the slowest angular speed? And why?”

Grouped reasons	Number of answered position (P)					
	P1	P2	P3	P4	P1 & P4	None
The nearest position to star/sun & strongest gravity in their orbits is the cause of faster speed of planet/comet	3	-	-	-	-	-
The selected position has the strongest gravity in the orbit	-	2	-	-	-	-
The selected position has the weakest gravity in the orbit	-	1	-	-	-	-
The farthest position from the star/sun	-	10	-	-	-	-
The farthest position from the star/sun & the weakest gravity in their orbits cause the celestial body move faster	-	1	-	-	-	-
Due to gravity of star/sun act on planet	-	-	1	-	-	-
Due to largest angular distance	-	1	-	-	-	-
Due to smallest angular distance	-	-	-	1	-	-
No Reason	3	2	1	1	-	3

Table 3. Group of the answers from the A3 question: “What is the physical force acting on this celestial body and force it to obey the Kepler’s law of motion?”

Answers	Number of students
Clear and correct answers	
• The attractive force between masses	3 (10.00%)
• Gravity	5 (16.67%)
• Gravity & Centripetal force	1 (3.33%)
Unclear answers	
• Centripetal force to center of mass	1 (3.33%)
• Centripetal force	1 (3.33%)
• The attraction force or inductive force to center of masses	1 (3.33%)
• Attraction force	4 (13.33%)
• Energy conservative force	1 (3.33%)
Wrong answers	
• Attractive force, Gravity, Magnetic Field	1 (3.33%)
• $\Sigma F = ma$ (Newton’s second law)	2 (6.67%)
• Curvilinear motion	1 (3.33%)
• Rotation motion	1 (3.33%)
• Momentum	1 (3.33%)
Not answer	7 (23.33%)

be the factor. We explore the Earth Astronomy and Space of IPST's textbook and think that this reason might come from the planet's circular motion with gravity or attractive force by masses as shown in equation (1)

$$m\omega^2 r = \frac{GMm}{r^2}. \quad (1)$$

- One student explains that the planet/comet needs high speed to escape from strongest attractive force by masses. However, the student did not explain clearly which factor accelerates the celestial body.

- The other one explain by maximum heat which the planet/comet gains from the nearest position to its parent star. This reason is wrong.

- Two of eleven students did not give any reasons.

Seven of sample group answer the position 4 (P4) or P1

- Two of them explain only P4 is the nearest position to the star/sun as same as 5 of 11 who answer P1.

- One of them give their explanation about strongest gravity force at the perihelion (nearest point to the parent star)

- The other two select P4 because P4 has the smallest angular distance. This is not a clear answer because they need to mention about the other position beyond P4 to describe the angular distance such as P1 or P2.

- Two of them answer both P1 & P4. One gives reason only position and the other gives no reason.

We need to discuss about why seven of the sample group select P4 is nearest position to star/sun. This may be the result from question's figure (Figure 1) that star/comet is not in a focal point of elliptical orbit. The realistic figure causes the confusion about the position to the students. This issue should be consider for correcting the figure in the developing conceptual survey test as we mention in the introduction section.

Nine of sample group select the aphelion position (farthest position from the parent star) or position 2 (P2).

- Four of nine explain that the weakest gravity force at P2 allows the celestial body move faster. This is the remarkable issue to investigate as the misconception about radial force and curvilinear path motion. The students might be confused with the direction of force effect on linear path motion which pulls the object back (deceleration).

- One of nine gives the reason about gravity but does not explain that the gravity is weakest or strongest at P2.

- The other four students do not given any reasons.

A2: At position 2 (P2), the planet/comet will have the slowest angular speed in astronomical explanation (Kepler's law of equal area). Three of 30 also given no answers and reasons the same as P1.

Seventeen of 30 students answer at P2, the celestial body has the slowest angular speed.

- Ten of 17 students give the reason only the farthest position. This is not a clear explanation and cannot determine that students can remember or understand concept?

- Two of 17 students give their explanations that there is the weakest gravity at P2 which allows the comet or planet to move in the angular slowest speed, as shown in equation (1).

- However, two students still have some misunderstanding that the gravity from parent star is strongest at position P2.

- The other two students have given no reasons.

Six of 30 students answer P1. Three of six students give no reasons. However, we consider the other three of them. They give the reasons that due to the strongest gravity at P1 the planet or comet's angular speed is decelerated. This issue resembles to the case of A1 question that some students have misconceptions about fastest angular speed at P2.

Two of 30 students answer P3. One has no reason. The other explanations are about a gravity but are still unclear.

The other two students who answer P4, one student has no reasons. The others try to

explain with the smallest angular distance or the smallest angle in their orbits. This reason is not clear because P4 is only a position.

From the question A1 and A2, some students understand that the gravity and distance from the Sun are essential factors of how fast of angular speed of celestial body in the orbit. However, beside of force and circular motion, this phenomenon can be described by using physical reason of the angular momentum conservations of radial force to describe.

By approximation, more than half numbers of students from the sample group understand and link the second law of Kepler (Law of equal area) with the angular speed of the planet/comet in their orbit. However, no one uses the law of angular momentum conservation for radial force to describe why the angular speed is faster or slower in a celestial body's orbit. They only use the gravity or distance in their explanations.

A3: The answers from question "What is the physical force acting on this celestial body and affect it to obey the Kepler's law of motion?" The results are shown in Table 3.

Nine of 30 students give a clear and correct answer which is the gravity or attractive force due to masses. However, eight of them give various unclear or not specific answers enough; e.g. centrifugal force, centrifugal force to center of mass, attractive force, inductive force to center of mass, which may be the electric force by electric charge or another radial force type that can pull the object to the center of mass of another object. In addition, six students give the wrong answers, such as magnetic field, momentum etc., and the 7 of them did not tell anything.

The unclear answer might come from the students who cannot remember the correct technical terms. While the wrong answer comes from the student who did not know the physical mechanics that work behind the orbit of planet /comet around the parent star.

B: Questions about the force direction on celestial bodies to test concept of direction and amplitude.

Only 3 of 30 students draw the vector correctly. They draw the vector of gravity force of the Sun acts on planet and the planet acts on the Sun. However, thirteen of 30 students draw incomplete answers, as shown in Table 4 and Figure 2(a-e). This implies that by approximation half of the students have concept have concepts of attraction force. However, 13 of them did not remember reaction force from the Newton's third law of motions or lack of drawing skill to explain what they remember or understand.

The other 5 students draw the wrong or unclear picture; i.e. the vectors but do not mention type or name of vectors, the comet's tail, and the line from the sun/star light Archimedean spiral line (This would be student's confusion between the Archimedean spiral magnetic field line from the Sun). Nine of 30 students did not answer this question.

Conclusions

More than half of the tested students has knowledge, understanding of the Kepler's second law of motion. They can remember, understand, and apply the law of equal area to angular speed and describe this phenomenon by gravity force, circular motion, and distance from star/sun which is the parent star of the system. However, they did not answer the question by using conservation of angular momentum, which is another approach in context of Physics courses. Some students are still lack of understanding about action-reaction force (Newton's third law) to describe force in stellar/solar system. Moreover, the mathematics concept of force; i.e. vector, is the major problem for students to apply in physics context.

This preliminary result is only the first step to survey the problem of Physics and Astronomy teaching in Thai School. Nonetheless, due to a still incomplete question(s) and a small number of tested subjects, we need to develop further the survey test and increase the number of tested students or teachers in the next phase of the project.

Table 4. Group of the answers from question B

Answers	Number of Student
Draw both star/sun's attractive force vectors effect on a planet/comet's and planet/comet's attractive force effect on a star/sun.	3 (10.00%)
Draw both star/sun's attractive force vectors effect on a planet/comet's and planet/comet's attractive force effect on a star/sun. But the vector size is not equal.	3 (10.00%)
Draw only star/sun's attractive force vectors effect on a planet/comet	7 (23.33%)
Draw only star/sun's attractive force effect on a planet/comet and include planet/comet's velocity	1 (3.33%)
Draw only star/sun's attractive force effect on a planet/comet but not draw the vector direction	2 (6.67%)
Draw the vectors but not mention type or name of vectors	3 (10.00%)
Draw the comet's tail	1 (3.33%)
Draw the line from the sun/star light Archimedean spiral line	1 (3.33%)
No answer	9 (30.00%)

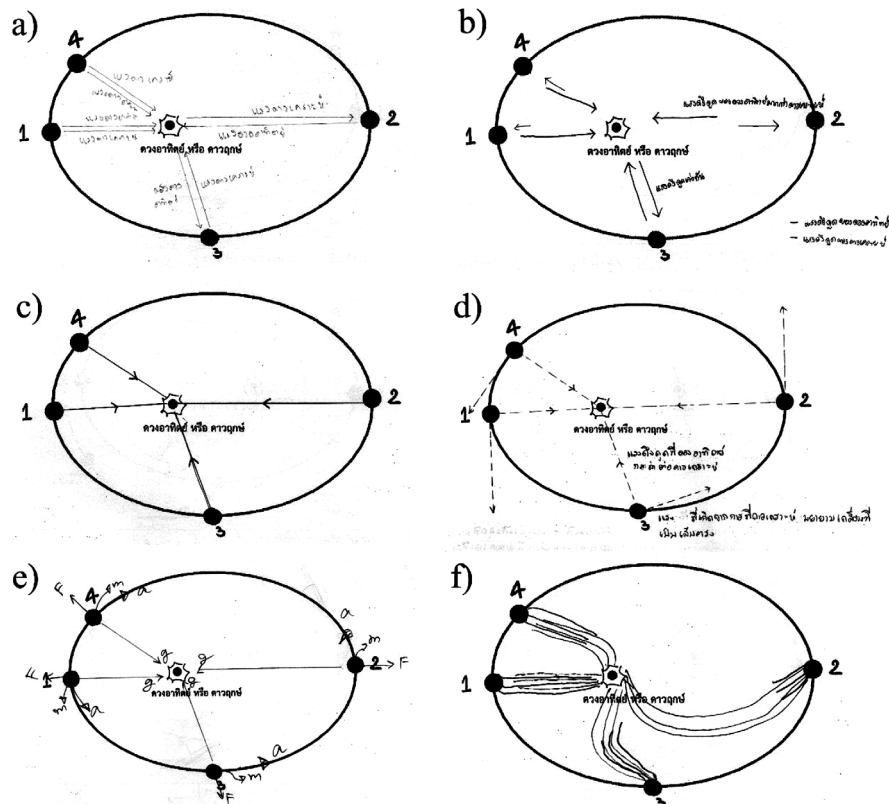


Figure 2. Examples of students' answers from question B

Acknowledgements

This work is financially supported by School of Science, University of Phayao from Research Project number SC05/2557. The authors would like to thank Acting Sub Lt. Manus Phuthawee, lecturer of University of Phayao Demonstration School for helping with data survey.

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