Science High-School Students Understanding of Velocity & Acceleration and of the Motion of Bob When Tension is Removed in a Simple Pendulum

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Abstract: The aims of this study are to investigate science high school students' understanding of velocity and acceleration of a simple pendulum bob, and to investigate their understanding of inertia and gravitational force in the motion of a pendulum bob when the tension is removed. For the study, 46 students that had already studied the physical concepts in simple pendulum were sampled from a science high school in a large city in Korea. For a comparison with general high school students' conceptions, 49 students were sampled from a general high school in the same city. The test tool for the investigation consisted of four drawing and simple-answering type questions developed by the authors. The outcomes of the study revealed that a substantial number of science high school students have misconceptions concerning acceleration in pendulum motion, and that many of them do not understand the relationship between force and acceleration. In addition, the results of the study showed that more than 30% of the students drew the path of a bob going along the tangential direction at the highest point of the motion, and approximately 20% of them drew the path of a bob falling straight down at the lowest point of the motion.

Key words: science high-school, pendulum motion, student conception, misconception, velocity, acceleration, force, inertia, gravitational force

I. Introduction

In the large number of studies concerning children's conceptions concerning natural phenomena which have been undertaken over the past two decades, the area of 'force and motion' has received the most attention. The interpretations of students from primary school to university have been explored in a variety of real world kinematics and dynamic situations.

One theme in this area has been the simple pendulum. Since Viennot (1979) first investigated students' ideas involving the simple pendulum, some researchers including Clement (1982), Gunstone and Watts (1985), Gunstone (1987), Sumida (2002) have conducted research into students' conceptions of the same situation. According to their research, many students from primary to high school realize that a force acts on the bob in the direction it moves. Research into the conceptions of the simple pendulum held by Korean students has also been undertaken. Jung (1990), Kim (1991), and Song, *et al.*, (2002) have found that many students in Korea from middle school to university think that a force acts on the bob in the direction that it moves.

Then, what is the science high school students understanding of this situation? These students are known to be well-versed in science. Song, *et al.*, (2002) also investigated Korean science high school students' understanding of force in a simple pendulum motion, and found that approximately half of the students had a scientific conception. In the preceding studies, including the research of Song, *et al.*, (2002), students' understanding of forces acting on a bob were the main focus of investigation. Although acceleration is the effect of force, we think that students lack sufficient understanding of the relation between force and acceleration; thus, we sought to investigate their understanding of velocity and

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acceleration in a simple pendulum motion, and then, to compare this conception with their understanding of force.

On the other hand, if the tension is removed, only gravitational force, ignoring the effect of air resistance, acts upon the bob of a pendulum. According to previous research into other problem situations (Clement, 1982; McDermott, 1984; Marioni; 1989; Kim, 1991; Song, *et al.*, 2002), many students do not take into account the effect of inertia in the motion of an object. In pendulum motion situation, if the students understand the concepts of inertia and gravitational force, they will be able to correctly predict the motion path of the bob after the tension is removed. We also wanted to know how science high school students understand inertia and gravity in the situation of motion of a bob after the tension is removed.

Therefore, the research problems of this study are to investigate what science high school students understand about the velocity and acceleration of a simple pendulum bob, and to investigate their understanding of inertia and gravitational force in the motion of a bob when the tension is removed.

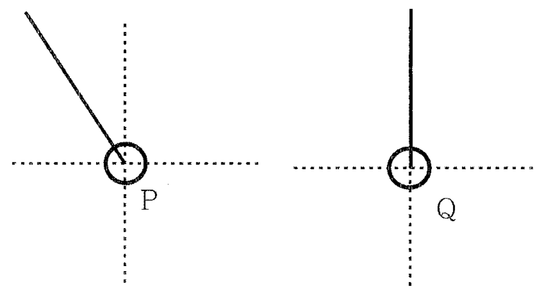
For the investigation of science high-school students' conceptions, 46 students that had already studied the physical concepts related to a simple pendulum were sampled from a science high school in a large city in Korea. Furthermore, to provide a comparison with general high school students' conceptions, 49 students were sampled from a general high school in the same city.

The test tool for the investigation consists of four drawing and simple-answering type questions developed by the authors. In this test tool, we did not ask the direction of force when asking about the direction of acceleration, because asking both questions at the same time might have provided hints to each other question's answers. Therefore, the data of Song, *et al.*,(2002) was adopted for inferring the relationships between the students' understanding of force and their understanding of acceleration.

1. Students Understanding of Velocity and Acceleration in a Simple Pendulum

The tools, presented in Fig. 2, were used to investigate students' understanding of velocity and acceleration in a simple pendulum. The primary tasks required the students to draw velocity and acceleration using vectors(arrows) and to simply write the names or meanings of the vectors on the bobs arriving at the highest point and the lowest point during the pendulum motion.

A pendulum bob is swinging from right to left. In the figure, 'P' is the highest point and 'Q' is the lowest point of pendulum motion. Air resistance is ignored. Represent velocity and acceleration of the pendulum bob at the points 'P' and 'Q' with vectors (arrows). If it is zero, write a zero in the picture instead of an arrow. In the picture, the bold line represents a string of a pendulum, and the intersection of the dotted lines represents the position of a bob during motion.



(a) The bob is at the highest point 'P' (b) The bob is at the lowest point 'Q'

Fig. 1 *Tools for investigating students understanding about velocity and acceleration in simple pendulum*

This test tool was used by Gunstone (1987) and Song *et al.*, (2002) to investigate students understanding of forces in a pendulum.

The patterns which the students drew in Fig. 1(a) are shown in Fig. 2, and the frequency ratios of the patterns are shown in Table 1.

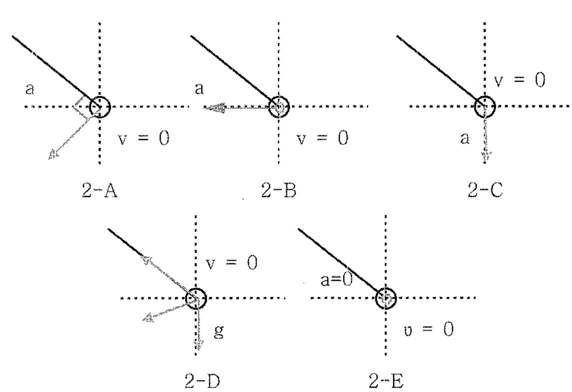


Fig. 2 *Students' drawing patterns of velocity and acceleration at the highest point of the pendulum motion*

Table 1

Frequency ratio of each pattern of Fig. 2.

Pattern		2-A*	2-B	2-C	2-D	2-E	others	no answer
Frequency Ratio (%)	Science High School (N=46)	76.1	6.5	2.2	6.5	0	8.7	0
	General High School (N=49)	51.0	6.1	4.1	4.1	6.1	22.5	6.1

*Scientifically correct

As can be seen, the Pattern 2-A students think that there is no velocity in any direction and that there is acceleration in a tangential direction at that point. This understanding is scientifically correct. The Pattern 2-B students think that there is no velocity, but that there is acceleration to the left horizontal direction at that point. The Pattern 2-C students think that there is no velocity in any direction and that there is acceleration in the same direction as gravity. These students seem to consider gravitational force, but do not seem to consider the tension of the string. The Pattern 2-D students think that there is no velocity in any direction and that there are accelerations in three directions such as the tensional, gravitational, and tangential directions at that point. The Pattern 2-E students think that there is no velocity in any direction and that there is no acceleration in any direction.

As shown in Table 1, 76 % of the science high school students have a scientific conception (Pattern 2-A), while 51% of the general high school students have a scientific conception. Also, 7% of the science high school students and 6% of the general high school students think that there is acceleration in a horizontal direction (2-B pattern). In addition, 9% of the science high school students think that there were accelerations in three directions such as the gravity, tension, and tangential direction, or acceleration in gravity only, although no students think that there was no acceleration at the highest point. For the general high school students, 8% think that there is acceleration in three directions such as the gravitational, tensional, and tangential directions, or acceleration in the gravitational direction only, and 6% think there is no acceleration at the highest point.

Before being taken, this question was expected to be correctly answered by almost all the science high school students; however, more than 20% of them were found to have alternative conceptions, although to a much lesser degree than the alternate conceptions among the general high school students(more than 50%.

The patterns which the students drew in Fig. 1(b) are shown in Fig. 3, and the frequency ratios of the patterns are shown in Table 2.

As shown in the figure, the Pattern 3-A students think that velocity is tangential and acceleration is zero at the illustrated point. This idea is almost correct, if this point represents the resultant pattern when it approximates a very small angle linear oscillation; however, this idea is not exactly correct. The Pattern 3-B students think that velocity is tangential and acceleration is in an outward radial direction at the illustrated point. These students seem to consider gravitational force or centrifugal force, but not to consider the tension of the string. The

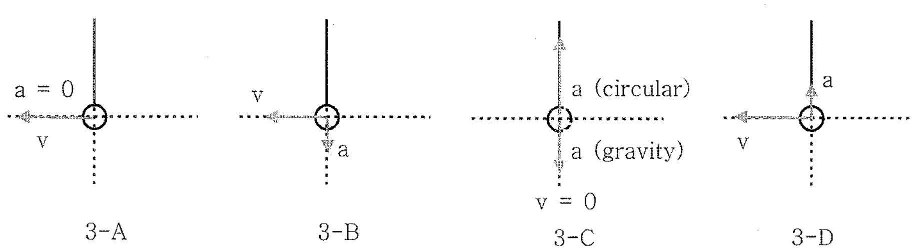


Fig. 3 *Students' drawing patterns of velocity and acceleration at the lowest point of the pendulum motion*

Table 2
Frequency ratio of each pattern of Fig. 3.

	Pattern	3-A	3-B	3-C	3-D*	others	no answer
Ratio (%)	Science High School (N=46)	80.4	8.7	8.7	0.0	2.2	0.0
	General High School (N=49)	40.8	8.2	4.1	6.1	30.6	10.2

*Scientifically correct

Pattern 3-C students think that there is no velocity in any direction, and that there are accelerations in inward and outward radial directions at the illustrated point. These students also seem to consider gravitational and centripetal force; however, we wondered why they think that there is no velocity at that point during motion. The Pattern 3-D students think that velocity is in a tangential direction and acceleration is in an inward radial direction at the illustrated point, which is scientifically correct.

For the question shown in Table 2, no science high school student have a scientific conception (Pattern 3-D), although 9% of the students have a correct conception of acceleration only, while 6% of the general high school students have a scientific conception velocity and acceleration. Furthermore, most of the science high school students (80%) think that there is no acceleration of the bob at the lowest point, while 40% of the general high school students think there is no acceleration of the bob at that point.

This question also, before being taken, was expected to be correctly answered by almost all of the science high school students; however, no student gave the exact correct answer: 80% of them were found to have the acceleration conception without considering centripetal force, while 6% of the general high school students gave the exact correct answer, and 40% had the acceleration conception without considering centripetal force.

2. Relationship between Students Understanding of Force and Understanding of Acceleration in Simple Pendulum

We have cited the recent data of Song, *et al.*, (2002) involving science high school students understanding of force in a simple pendulum motion for inferring the relationship between students' understanding of force and understanding of acceleration. Song, *et al.*, (2002) used the tools presented in Fig. 1 to investigate science high school students' understanding of force in the simple pendulum motion.

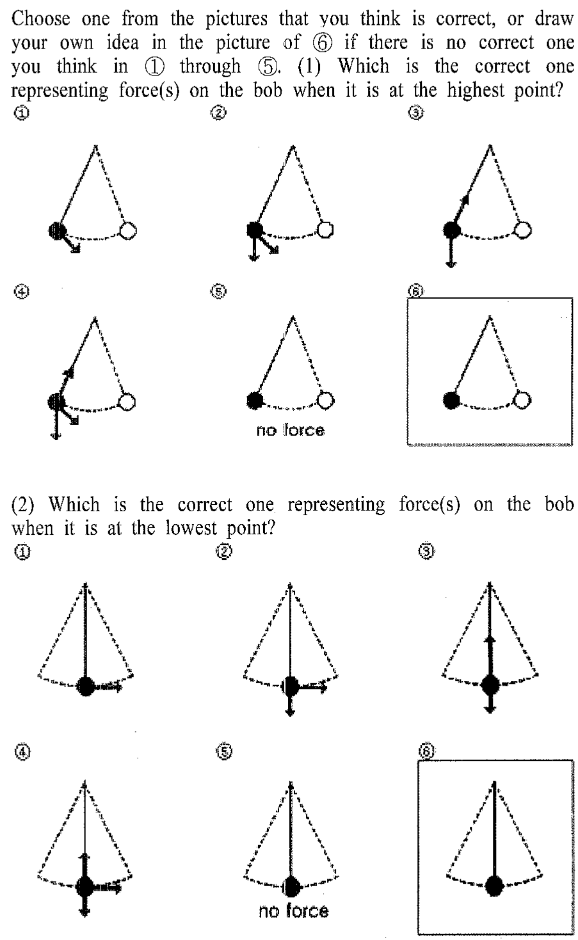


Fig. 4 *Test tools used by Song, et al., (2002) for investigation of students understanding about force in simple pendulum motion.*

The first question was designed to investigate students' conceptions of force when the bob was at the highest point of its motion. Table 3 shows the research results of Song, *et al.*, (2002) concerning students' force conceptions, as compared with our investigation results involving students' acceleration conceptions.

According to the results of Song, *et al.*, (2002), 80% of the science high school students in their study had scientific conceptions of force(s) on a bob, and 15% of them revealed misconceptions in which force acts on the bob in the direction of its motion, and 2% thought that there is no force. In comparison, according to our results, 76% of the science high school students had an accurate acceleration conception, 16% of them had alternative ideas such as accelerations in horizontal direction only, in the gravitational force direction only, and in three directions including the tangential direction. These results show that a significant number of students seem to possess an accurate conception of the relationship between force and acceleration.

On the other hand, according to Song, *et al.*, (2002), 40% of general high school students in their study had a scientific conception, 43% had a misconception in which a force acts on the bob in the direction of its motion, and 11% of them thought that there is no force, while, according to our investigation, 51% of the general high school students had a scientific conception, 6% thought that there is acceleration in a horizontal direction, 8% thought acceleration in three directions such as gravitational, tensional, and tangential directions, or acceleration only in a gravitational direction, and 6% thought there is no acceleration at the highest point.

The second question of the tool used by Song, *et al.*, (2002) was to investigate students' conceptions of force when the bob is at the lowest point of its motion. Table 4 shows the research results of Song, *et al.*, (2002) regarding students' force conceptions, compared with our investigation results regarding students' acceleration conceptions.

According to the results of Song, *et al.*, (2002), 47% of the science high school students in their study had a scientific conception of force(s) on a bob, and 42% had misconceptions in which a force acts on the bob in the direction of its motion, and 7% thought that there is no force; in comparison, according to our results, only 9% of the science high school students have an accurate acceleration conception, 80% think there is no acceleration at the lowest point of the pendulum motion, and 9% think the acceleration is only in a gravitational direction.

Greatly differing from the results of the first question, the results of the second question never show an accurate conception of the relationship between force and acceleration, as is evident from the finding that 80% of the students think that there was no acceleration of the bob at the lowest point in our test, while only 7% thought that there is no force on the bob at the same point in Song, *et al.*, 's test. Furthermore, according to the research results of Song, *et al.*,(2002), a significant number of students (47%) in their study had an accurate understanding of force conception; however, in our research, only a few students possess an accurate conception of acceleration. This result indicates that many science high school students, even those whom are high -achievers in school science, do not understand that acceleration is proportional to, and has same direction with, the force acting on a bob.

Table 3

Science high school students conceptions of force and acceleration in a simple pendulum (When the bob is at the highest point)

Force Conceptions (Result of Song, *et al.*,)	Frequency Ratio(%)	Acceleration Conceptions (Our research result)	Frequency Ratio(%)
① force in tangential direction(total force)*	3	2-A. acceleration in tangential direction*	76
② force in moving direction and gravity	1	2-B. acceleration in horizonal direction	7
③ gravity and tension*	77	2-C. acceleration in gravity direction	2
④ force in tangential direction, gravity, and tension	14	2-D. accelerations in directions of tangent, gravity, and tension	7
⑤ no force	2	2-E. no acceleration	0
⑥ others	2	others	9

Table 4

Science high school students conceptions of force and acceleration in a simple pendulum (When the bob is at the lowest point)

Force Conceptions (Result of Song, *et al.*,)	Frequency Ratio(%)	Acceleration Conceptions (Our research results)	Frequency Ratio(%)
① force in moving direction	4	acceleration in moving direction	0
② force in moving direction and gravity	26	acceleration in direction of movement and gravity	0
③ gravity and tension*	47	3-C. accelerations in directions of gravity and tension 3-D. acceleration in direction of tension	9 0
④ force in moving direction, gravity, and tension	12		
⑤ no force	7	3-A. no acceleration	80
		3-B. acceleration in gravity direction	9
⑥ others	4	others	2

On the other hand, Song, *et al.*, (2002) reported that 15% of general high school students in their study had a scientific conception, 70% had a misconception in which a force acts on the bob in the direction of its motion, and 7% thought that there is no force, while, according to our investigation, 6% of the general high school students have a scientific conception of velocity and acceleration, and 40% think that there is no acceleration of the bob at that point.

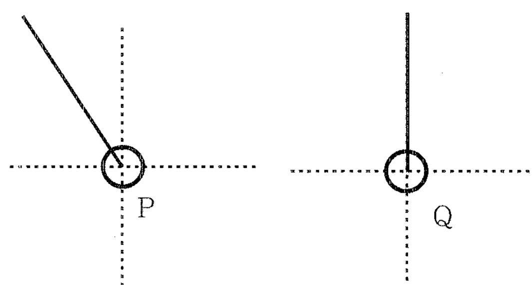
3. Students understanding of the moving path of a bob when tension is removed

In this study, the tools presented in Fig. 5 were used to investigate students understanding of the effect of inertia and gravitational force when the tension of a simple pendulum was removed. The primary task the students were required to perform in this task was to draw the moving path of the bob using lines and arrows after tension is removed from the bob at the highest and lowest points, respectively.

The test tool was developed by the authors to investigate students' understanding of motion of the bob after the tension is removed, which was not used by Gunstone (1987) and Song *et al.*, (2002) in their research.

The patterns which the students drew and the frequency ratios of the patterns are shown in Fig. 6 and Table 5, respectively.

What is the moving path of a bob if the string of a pendulum is broken during oscillation? Draw the moving path of a bob when the string is broken at the highest point 'P' and at the lowest point 'Q', respectively.



(a) If the string is broken at the highest point 'P　　(b) If the string is broken at the lowest point 'Q'

Fig. 5 *Tools for investigating students' understanding of the motion of a bob when tension is moved from a simple pendulum*

Table 5

Frequency ratio of each pattern of Fig. 6.

Pattern		6-A*	6-B	6-C	6-D	etc
Ratio(%)	Science High School (N=46)	60.9	23.9	8.7	0	6.5
	General High School (N=49)	51.0	20.4	4.1	10.2	14.3

*Scientifically correct

The Pattern 6-A students think that the bob falls straight down from the breaking point, which is scientifically correct. The Pattern 6-B students think that the bob takes a projectile motion from the

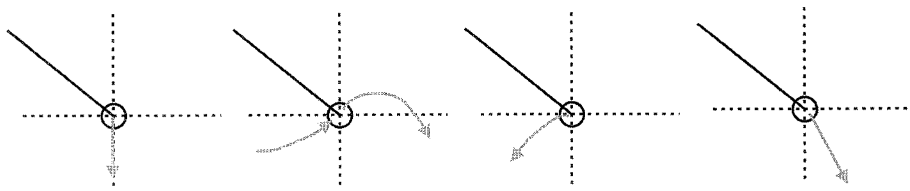


Fig. 6 *Path patterns of a bob after the string is broken (at the highest point)*

breaking point; that is, they think the bob initially goes slightly up, and then takes a descending trajectory, which is not scientifically correct; the Pattern 6-C students think that the bob falls backward from the breaking point, which is also not scientifically correct.

Sixty-one percent of the science high school students displayed Pattern 6-A, 24% displayed Pattern 6-B, and 9% displayed Pattern 6-C. These results show that about one third of the science high school students did not apply the law of inertia to the bob motion after losing tension, implying that they do not thoroughly understand the law of inertia. On the other hand, 51% of the general high school students displayed Pattern 6-A, 20% displayed Pattern 6-B, and 4% displayed Pattern 6-C. These results show that about half of the general high school students did not apply the law of inertia to the bob motion, implying that they also do not thoroughly understand the law of inertia.

The second task was to simply draw the path, using arrows, where the bob would take when the string is broken as it arrives at the lowest point. The patterns which the students drew are shown in Fig. 7, and the frequency ratio of each pattern is shown in Table 6.

The Pattern 7-A students think that the bob will take a descending projectile path from the breaking point, which is scientifically correct. The Pattern 7-B

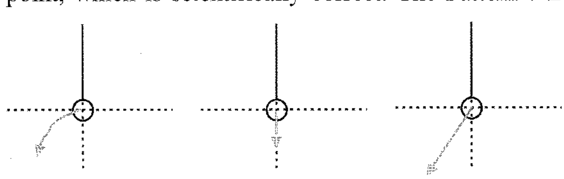


Fig. 7 *Path patterns of a bob after the string is broken (At the lowest point)*

Table 6

Frequency ratio of each pattern of Fig. 7.

Pattern		7-A*	7-B	7-C	others
Ratio(%)	Science High School (N=46)	80.4	17.4	0	2.2
	General High School (N=49)	40.8	34.7	8.2	16.5

*Scientifically correct

students think that the bob will fall in a straight direction from the breaking point, which is not scientifically correct. The 7-C pattern students think that the bob will take straight askew path from the breaking point, which is also not correct.

Approximately 80% of the science high school students displayed Pattern 7-A, and approximately 17% of the students displayed Pattern 7-B, while 41% of the general high school students displayed Pattern 7-A; 35% displayed Pattern 7-B, and 8% displayed Pattern 7-C.

The above results show that some of the science high school students and more than half of the general high school students do not apply the law of inertia to the motion of a bob without tension, implying that they do not thoroughly understand the law of inertia.

Ⅱ. Conclusions and Discussion

The outcomes of the study revealed that a substantial number of science high school students have misconceptions of acceleration in pendulum motion, and that many of them do not understand the relationship between force and acceleration. In particular, at the lowest point of a pendulum motion, only about 10% of the science high school students in the study had a scientific conception of acceleration, although approximately 50% of the students had a scientific conception of force. In addition, these study results show that many science high school students do not understand inertia. It is evident from that more than 30% of the students in the study drew the path going on along the tangential direction even at the highest point of the motion, and from that about 20% of them drew the path falling down directly even at the lowest point of the motion.

In addition, some science high school students may not consider acceleration due to centripetal force at the lowest point of the pendulum motion. It is evident from the results that some students think that there is no acceleration at the lowest point of pendulum motion. In the oscillation of pendulum, the centripetal force acting on the bob at the lowest of its motion is dependent on the oscillation amplitude. The ratio of centripetal force to gravitational force at that point is shown in Fig. 8.

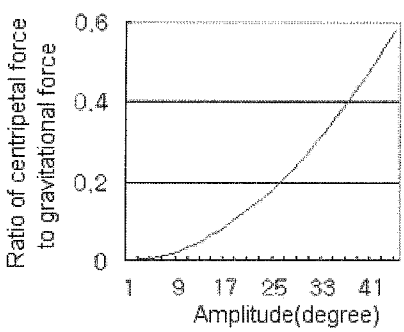


Fig. 8 *Graph of the ratio of centripetal force to gravitational force by the amplitude of pendulum*

Fig. 8 shows that if the amplitude of pendulum (oscillation angle of pendulum) is less than 10°, the magnitude of centripetal force at the lowest point of the pendulum is so small compared to the gravitational force (below 5%) that it can be ignored. However, if the amplitude of pendulum (oscillation angle of pendulum) is greater than 15°, it cannot be ignored. Therefore, the motion of a simple pendulum would be best explained using a small oscillation angle. In most physics textbooks, the oscillation angle of a pendulum is more than 30°. In this case, the ratio of centripetal force to gravitational force at the lowest point of oscillation is approximately 27%; therefore, it would be advisable to avoid represent total force acting on the bob of the pendulum at that point as zero, and the direction of the total force would be best represented as upward.

Nevertheless, some current high school physics textbooks do not describe this aspect of small oscillation angles. Furthermore, a specific diagram like Fig. 9 in a physics textbook represents acceleration vectors only horizontally and becoming zero at the center of the oscillation. Some students' conception of acceleration of a bob at the highest point (2-B in Fig. 2) and at the lowest point (3-C in Fig. 3) of pendulum motion were very similar to the accelerations of this diagram.

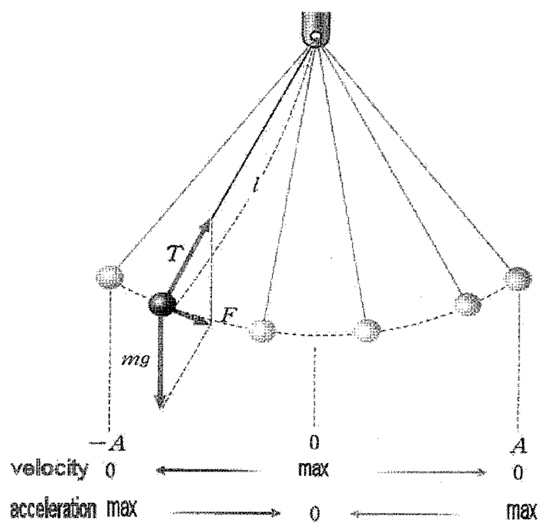


Fig. 9 *A diagram of pendulum motion in a high school physics textbook*

The pendulum motion, which is treated as an approximate linear motion so that there is no force on the bob at the lowest point, is first taught in middle school. In high school physics, if centripetal force caused by tension on the string during the pendulum motion is not emphasized, the students will still possess the conceptions learned in middle school. Therefore, we suggest that high school physics teachers would benefit by stressing the net force (total force) at a few points in the pendulum motion. In addition, in physics textbooks for high school students, net force or total force on the bob at a few points in the pendulum motion would best be represented in and explained through a diagram, as is shown in Fig. 10.

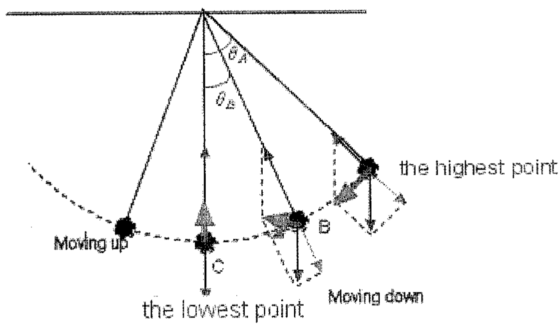


Fig. 10 *Forces on a pendulum bob during oscillation (A diagram captured from an Interactive Physics program)*

Almost every high school physics textbooks explains the physical concepts behind a simple pendulum motion (Galili & Sela, 2002; Santos-Benito & Gras-Marti, 2004), and recently, many internet programs have been explaining about it; however, some materials contain drawing errors of the simple pendulum (Santos-Benito & Gras-Marti, 2004): these inaccurate sources may lead students to carry misconceptions of the physics underlying a pendulum motion. Therefore, we need to give attention to the point that Alexander (1994) argued after analyzing recent research into learning through physics textbooks, that certain content actually prohibits students' learning.

References

Alexander, P. (1994). Learning from physics text: A synthesis of recent research. Journal of Research in Science Teaching, 31, 895-911.

Vinnot, L. (1979). Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1(2), 205-222.

Clement, J. (1982). Student preconceptions in introductory mechanics. American. J. of Physics. 50, 66-71.

Galili, I. & Sela, D. (2002). Pendulum activities in the physics curriculum: Used and missed opportunities. Sydney Conference at UNSW (16-19 Oct. 2002).

Gunstone, R. F. and Watts, D. M. (1985). Force and motion. In: R. River, E. Guesne, and A. Tiberghien (eds), Children's ideas in science, Open University.

Gunstone, R. F. (1987). Student understanding in mechanics: A large population survey. American. J. of Physics. 55, 691-696 .

Jung, D. Y.(1990). Change of high school students' concepts about force and motion through science instruction, Theses, Seoul National University.

Kim, I.(1991). College students' conceptual change about force and acceleration through critical discussion of the rival concepts based on evidence and reflective thinking, doctoral dissertation, Seoul National University.

Marioni, C. (1989). Aspect of students' understanding in classroom settings (age 10-17): Case study on motion and inertia. Physics Education 24, 273-277.

McDermott, L. C. (1984). Research on conceptual understanding in mechanics. Physics Today, July, 24-32.

Santos-Benito, J. V. and Gras-Marti, A. (2004). Ubiquitous drawing errors in the simple pendulum. http://www.saum.uvigo.es/reec/volumenes.

Song, J., *et al.*, (2002). Map of misconception in physics. Seoul: Books Hill.

Sumida, M. (2002). The public understanding of pendulum motion: From 5 to 8 years old. Proceedings of the International Pendulum Project, Sydney Conference at UNSW (16-19 Oct. 2002).