Promote Student Understanding on Projectile Motion Using Inquiry-Based Learning Approach: A Case Study for Cambodian 11th Graders

Piten So

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Physics

Prince of Songkla University

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This is to certify that the work here submitted is the result of the candidate's own investigations. Due acknowledgement has been made of any assistance received.

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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Author	Miss Piten So
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Abstract

This research aims to promote 11th graders' understanding of projectile motion through the Inquiry-Based Learning (IBL) approach in a Cambodian high school context. The participants involved were 204 11th graders from three high schools located in three different regions in Cambodia. The test of Conceptual Questions on Projectile Motion (CQPM) consisting of 7 open-ended questions was developed to survey and identify projectile motion misconceptions of 124 students on pre-test and 131 students on post-test at 11th grade in one high school in year 2016. The obtained preliminary results and the Cambodian curriculum served as a basis to design the IBL procedure, which addressed how to guide the students from their misconceptions to the correct scientific concept in projectile motion. The CQPM embedded with 10 related projectile motion concepts such as the direction of velocity and the direction and magnitude of acceleration of a projectile, direction and magnitude of force acting on the projectile, the time interval of the simultaneous vertical and horizontal motions, the splashdown speed and the acceleration of vertical and horizontal motion, the horizontal distance and final velocity of the projectile when the time interval changes, projectile trajectory, the acceleration of linear motion, and the acceleration of circular motion.

Our main data, the students' responses to CQPM on pre and post-tests after the IBL instruction in year 2017, were quantitatively and qualitatively analyzed by average normalized gain (<*g*>) and model analysis. It was found that <g> of all questions in CQPM was in medium gain (<<*g*>> = 0.44± 0.03), which shows that the designed IBL is an interactive-engagement teaching method, more effectively improving students' understanding of projectile motion than traditional teaching methods. IBL improved the concepts of flight time of simultaneous projectile and free-fall motion events, and the trajectories of a projectile. However, there were low gains in some concepts such as the projectile's velocity direction, magnitude and direction of a projectile's acceleration, and magnitude and direction of force on a projectile. The average gain for each concept varied owing much to the demonstration set-up in the IBL procedure. Further, we found that IBL procedure supported students to transfer their mental model from an incorrect model region to a mixed model region regarding the concept of the projectile trajectory.

It is suggested that variables in different contexts with identical concept are challenges when students had more than one popular misconception. The demonstration set-up has to be good enough to address most the students' misconceptions in each context. Our confronting difficulty in Cambodian high school context is still a lack of the facilities of teaching media such as computers and projector screen. These challenges need to be taken into consideration to achieve a satisfactory outcome in future research.

Keywords: projectile motion, IBL, interactive-engagement teaching, normalized gain, model analysis, Cambodian high school students

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List of abbreviations

ACI	Action Concept Inventory
ANOVA	Analysis of Variance
CLASS	Colorado Learning Attitudes about Science Survey
CQPM	Conceptual Questions on Projectile Motion
CSEM	Conceptual Survey in Electricity and Magnetism
FCI	Force Concept Inventory
FMCE	Force and Motion Conceptual Evaluation
IBL	Inquiry-Based Learning
IE	Interactive Engagement
ILDs	Interactive Lecture Demonstrations
IOC	Item-Objective Congruence
MoEYS	Ministry of Education, Youth and Sport
PAT	Physics and Astronomy for Teachers
PBI	Physics by Inquiry
PER	Physics Education Research
POE	Predict-Observe-Explain
SD	Standard Deviation
T	Traditional

Chapter I

Introduction

The study focuses on enhancing Cambodian high school students' understanding on projectile motion, which is one lesson in Cambodia curriculum at grade 11. Students' misconceptions on this lesson were addressed by Inquiry-Based Learning (IBL) procedure and its effectiveness evaluated by normalized gain and model analysis. The IBL procedure, mathematical assessment, and results and discussion are presented in this study.

1.1 Significance of the study

The factors of poor-quality education on high school students in Cambodia today caused by lack of qualified and quality instructors, teaching materials and school supplies, and high drop-out rate of students from schools (Dy, 2003; Rany, 2012; Chankea, 2014; CDRI, 2015). The main cause is poverty that results in twelve to fourteen-year-old children abandoning secondary schools for doing their tasks to support their family. Long way off schools from students' homes, lack of schools in rural areas are also problems (SEAL, 2016). The amount of qualified and quality instructors are limited because of barriers of pedagogies such as curriculums, contents, teaching and learning methods. Moreover, teachers' low salary does not encourage them to improve teaching methods and much take care of student performance (CDRI, 2015). Even though in the early 1990s, the Asian Development Bank (ADB) tried to consolidate instructor improvement systems and provide more schools' buildings, effective textbooks and teaching media, the progress did not obviously exist (Dy, 2003). These challenges suffered from the damage in history period in Cambodia back to forty years ago (1975-1979) in Khmer Rouge regime. The education system was destroyed systematically. A Soviet source reported that around 90% of all teachers were killed, only 50 of the 725 university instructors, 207 of the 2,300 secondary school teachers and 2,717 of the 21,311 primary school teachers survived (Ross, 1987).

To support quality of high school students in science learning as fundamental education, which is a significant way to help Cambodian students grow up with scientific ideas, this research focuses on a projectile motion topic in physics.

In Cambodian curriculum, students have studied one dimension motion in a horizontal direction in grade 8 and free fall motion in grade 10 and later in grade 11 students have to study projectile motion which is an essential basic two-dimension motion combining the horizontal direction (constant speed) and vertical direction (free fall) of motion. It is applied to explain several everyday life phenomena such as shooting the ball, jumping out of cliff, throwing an object, kicking a ball, and falling of an object. The textbook of Cambodian curriculum focuses on the equation of the projectile path, horizontal range, and its horizontal and vertical components of velocity.

However, reviewed results of previous studies showed several misconceptions in projectile motion. For example, many students believed that a moving object in projectile motion has a throwing force embedded to it (Tao 1997; Tao et al., 1998; Prescott and Mitchelmore, 2004). A fired object moves follow the imparted impetus in direction of motion, when the impetus is used up then gravity acts on an object falling straight to the ground (Halloun and Hestenes, 1985; Prescott and Mitchelmore, 2005). Many students got confusion about upward or downward direction of a projectile (Mudau, 2014). The falling stone dropped from a walking person will travel backward and land behind the point of its release (McCloskey, 1983; Prescott and Mitchelmore, 2004). At the same height, a directly dropped ball falls to the ground in a shorter time than a bullet travels with a constant initial horizontal speed (Whitaker, 1983; Prescott and Mitchelmore, 2004). Forty-five degree of projectile launching creates the maximum horizontal distance for different levels of the starting and ending points (Changjan and Mueanploy, 2008).

To directly obtain results from Cambodian students, we designed 7 open-ended questions, validated and applied to 11^{th} graders before (N=124) and after (N=131) regular classes. The results revealed some misconceptions held by the students both before and after the instructions such as most students thought that direction of velocity of a projectile lays over the trajectory with non-corresponding xy-components. The direction of acceleration follows the direction of motion. A force is in direction of motion. Two objects, which freely fall from the same height, spend different times to reach the floor because of different paths of motion (Piten et al., 2017).

Therefore, to improve Cambodian 11th graders' understanding on projectile motion, this research has applied an Inquiry-Based Learning (IBL) procedure into classes. The IBL procedure requires 6 main parts: 1) open-ended key questions to observe students' ideas, 2) hypothesis to identify evidence-based reasoning and creative problem-solving, 3) investigation to conduct an experiment to confirm with the hypothesis, 4) analyzing data from the experiment, 5) model to draw a logical conclusion based on experiment results, and 6) evaluation to match up their results with different real-world situations. In the IBL procedure, students can develop their own knowledge and skills such as collaboration and reflection which should enable them to develop and refine widely-useful cognitive and social skills. It is a significant approach to help students learn how to learn as an active learning method of the constructivism (White et al., 1998; White et al., 1999; CSMEE, 1995). In this study, the designed IBL method has been mainly based on primary resources such as preliminary results of Cambodian student misconceptions, literature review, common physics textbooks and academic websites.

To evaluate the IBL procedure designed in this study, we counted the number of students with the correct answer and incorrect answers, and compared on pre- and post-tests by using qualitative research. Moreover, we used normalized gain to compare the difference between pre-test and post-test scores to maximum possible gain, in order to display the learning gain of the students (Hake, 1998). The model analysis was employed to study students' mental model states before and after the instruction and the movement of the states. It is a quantitative evaluation of student mental models of understandings derived from a numerical analysis of students' responses to multiple-choice tests. Students' responses to a category of equivalent concept questions were used to create a class density matrix. Dominant eigenvalue and its eigenvector were computed to demonstrate a degree of agreement and class model states, respectively. Its results simplified as a model plot for representing the class model state with respect to common models (Bao and Redish, 2006).

Shortly, this research aims to enhance Cambodian 11^{th} graders' understanding on projectile motion by applying the IBL procedure. The designed instruction was evaluated by comparing the percentage of students' improvement on pre and post-tests, normalized gain, and model analysis to indicate its effectiveness. The results were analyzed quantitatively and qualitatively (grouping students' ideas). The IBL instructional method, mathematical assessment methods and misconceptions of projectile motion expressed in this study will be beneficial to physics instructors and researchers, in particular, in a Cambodian context. It is a guideline for doing research in classrooms to promote students' understanding of science concepts.

1.2 Purposes of the study

The objectives of this study are:

1) to identify Cambodian students' misconceptions on projectile motion in order to be used as a primary resource to design instructional media, and

2) to improve Cambodian students' understanding on projectile motion by applying the designed Inquiry-Based Learning (IBL) procedure.

1.3 Outputs of this research

1) Projectile conceptual questions for high school levels

2) Misconceptions of Cambodian students on projectile motion

3) Inquiry-Based Learning (IBL) module on projectile motion at high school levels (comprising lesson plans, instruments and documents)

4) Publications (proceedings or papers)

Chapter II

Literature Review

Sample sources related to our topic are provided with description, summary, and critical evaluation of each work to provide the context for our research work. Firstly, we are going to review the studies in Physics Education Research (PER) related to projectile motion, concerning students' misconceptions and teaching tools proposed by other researchers. Secondly, the assessment method is explained, including the use of normalized gain and model analysis. Inquiry-Based Learning (IBL) approach is reviewed at the end.

2.1 Students' misconceptions and related teaching tools of projectile motion

A projectile motion is a two-dimensional motion, which consists of a constant horizontal speed and a gravitational vertical acceleration. In primary levels, a projectile is given an initial velocity and then follows the path influenced by only the gravitational force. Air resistance and the variation of gravitational acceleration with height and other effects are neglected. The projectile motion is applied to explain several daily life phenomena such as kicking a ball, throwing an object, jumping off a cliff, shooting a ball, and dropping a ball as well as students' own experiences. Many researchers have found that people may interpret their experiences and observations in a similar way to the Aristotelian, often identified as an alternative conception, (Halloun and Hestenes, 1985; McCloskey, 1983; Whitaker, 1983). Moreover, several researchers have addressed the misconceptions on the projectile motion such as Bayraktar (2008), Prescott and Michaelmore (2005; 2004), Whitaker (1983), and McCloskey (1983) which is described below.

Situations of motion in daily life, in which people think of not only problem solving but also their interaction by performing a task with the real objects in the intuitive belief, was widely mentioned by philosophers in the three centuries before Newton (McCloskey, 1983). Several researchers have reviewed some issues in the history of projectile motion to describe people and students' ideas. For example, the International Handbook of Research in History, Philosophy and Science Teaching edited by Michael R. Matthews (2014) extracted the ancient philosophers' beliefs about projectile motion. For example, Aristotle believed that the medium (air) was pushed by the original force which had lost contact with the projectile. The projectile was then pushed by the air to maintain its motion. But over time, the force from the successive portions of the air gradually reduced till dissipated. The air pushed the object to maintain and also to restrain the motion. Another idea seems to be the air in the front of the projectile moving backward to fill the space behind it. The movement of the air was a force to sustain the motion till air resistance slows it and then it falls. According to these ideas, it was possible that the motion would not exist in vacuum because the air acts to maintain the motion. However, Philoponus did not agree with the statements that the projector provided the motive force to the projectile, and over time the force imparted to it gradually decreased to zero, and then it falls (Prescott and Mitchelmore, 2004; McCloskey, 1983; Whitaker, 1983). In addition, in the fourteenth century Buridan also did not agree with the role of the air and he suggested that the projector transferred a non-decay impetus to the moving body after it had lost contact. It was believed that impetus was an internal motive force, which was directly proportional to the speed.

Galileo, in his early career, also believed that projectile motion was maintained by an impressed force after it left the projector. In 1590 he explained that the projector that caused the upward motion provided the impressed force which began to decay to maintain the projectile moving at a decreasing speed until the impressed force was equal to its weight. Later its weight was greater than the impressed force which is decrease, it fell down with increasing speed. After that, the impressed force was used up the projectile moved with the natural speed to reach the destination (Matthews, 2014; Prescott and Mitchelmore, 2004; McCloskey, 1983; Whitaker, 1983). However, as described below, his later idea of projectile motion was much more similar to the idea used by physicists before Newton.

Another notion stated about the free fall is that the object is at rest falling naturally, the initial force of the rest object transferred impressed force to restrain its acceleration before reaching its natural speed. In contrast, some believed that the speed of the fallen object is proportional to the impelling force and inversely proportional to the total resistance to its motion. It seemed to be an object falling down because of the tendency which gradually increases near the center of the Earth hence its weight and its speed gradually increase when it falls. Philoponus developed Aristotle's idea by focusing on the difference of relationship between motive force and consequent speed in the vacuum. The object would move with the maximum speed in proportion to its weight through the vacuum but it would move at a slower speed proportional to the density of the air (Matthews, 2014).

In 1638, Galileo presented his last work about projectile motion, a two-dimension motion with a uniform horizontal velocity and a uniform vertical acceleration. The horizontal and vertical velocities of the projectile are independent of each other. This is the modern idea of projectile motion. Galileo explained the path of a ball, which freely falls from one end of an inclined plane, that after it escaped from the plane it moves in a parabolic curve (air resistance and the variation of gravitational acceleration with height and other effects are neglected). Impetus does not exist in the modern idea of projectile motion. The projector provides the initial force to start the motion and determines the initial velocity that leads the motion. But after the projectile has lost contact with the projector, the starting force has no effect on the projectile anymore only the initial velocity that leads the motion. The initially positive upward velocity was steadily reduced to zero, and then immediately and steadily increased downwards by the action of gravity (Matthews, 2014).

McCloskey (1983) examined 50 American high school and college students at John Hopkins University, who held misconceptions of the trajectory of projectiles in both problem solving and their interaction. From the students' interaction, some of them tried to move the object in a curve path and expected that it would continue in a curve path after it was released. By a similar token, a group of students tried to drop a golf ball in a straight line to hit the target on the floor while they were walking. Some of them tried to walk past the target and dropped the ball. They thought that the ball would move backward and hit the target. These students' ideas are similar to the question number 23 of the Force Concept Inventory. Correctly, the ball moves forward in the front of the point where it was released with the same initial speed with the carrier as the parabola path. Moreover, basketball players tried to shoot the ball too hard while they were running. The interaction shows that people misinterpret on paths of motion for lacking objects' initial motion.

Furthermore, McCloskey (1983) asked students to solve the problem test by drawing a path of a ball, when a tethered ball was swung overhead in a horizontal circle, if the string was cut suddenly. Students thought that the curvilinear motion of the ball was sustainable even though it was cut off from the string. In fact, the path of the ball is in a straight line with a constant horizontal speed after the string was cut. There is no tension from the string imparted to the ball. Moreover, students described the vertical motion of a coin tossed upward using a similar idea with the medieval theory proposed by Hipparchus that the upward force, imparted to the object, would be greater than its weight to maintain the motion upward, later the imparted force gradually decreased to zero by the action of its weight, then it falls down with increasing speed. However, in the modern idea of projectile motion, there is no imparted upward force acting on the object after it loses contact. The vertical velocity of the object is steadily reduced by the action of the gravity till it reaches zero at the highest point, then it is steadily increased when falling straight down. This is similar to a situation of pushing a ball located on the top of a cliff horizontally so it falls off the cliff. Students' answers to the path of the ball agreed with Albert of Saxony's theory, which drew a reverse L to present the path of the ball after it left the edge of the cliff. In a reverse L path, there is a horizontal force greater than its weight preserved in the straight line, then it falls straight down when the horizontal force was gone. In fact, the ball moves approximately in a half-parabola path at the horizontally constant speed and steadily increasing vertical downward speed. Moreover, in a situation in which a ball, which was dropped from a plane moving with a horizontal constant speed, many students believed that an observer on a ground would see the ball path as a straight line because there is no force pushing it forward (ignore air resistance). Some students misinterpreted that the ball would land backward to the point where it is released. In fact, an observer on the plane will see the ball move straight down, and an observer on the ground will see the ball move forward in the direction of the plane in a half-parabola path. McCloskey also found that many high school students still held misconceptions both before and after receiving instruction in a physics course.

Moreover, Whitaker (1983) reported students' "common sense" of motion as determined from six questions of trajectory motion in two sections of calculus-based and two sections of algebra-based introductory physics courses. The common sense of students were discussed for each question. For example, a greater mass moves faster in a vertical motion. In the vertical motion, there is a force to maintain the object's movement and that force disappears quickly soon after the object falls straight down. For a ball directly dropped, and another one launched in the horizontal direction, both would spend different durations of time flying to hit the ground because of different paths and different initial speeds (true or just an idea?). The students also had the confusion between position and acceleration, and between velocity and acceleration, which is similar to that of Trowbridge and McDermott (1980). In addition, the difficulty of two-dimensional motion was mentioned by Whitaker (1983) that students have to understand clearly the differences between position, velocity, acceleration, and time of the object and the independent vertical and horizontal velocity components before starting projectile motion.

Tao and Gunstone (1997) invented a computer simulation program named Force and Motion Microworld (FMM). It was used to investigate 27 students' alternative concepts of force and motion in a grade ten-science class for 10 weeks. The FMM showed alternative concepts such as force imparts to the object making it slow down or stop when force is exhausted. Motion implies force: there is no force acting on it if an object is at rest, there is a force acting on the object during its movement. Effect of force refers to a constant speed that needs a constant force imparting to the object, an increasing force applied to the object to makes acceleration.Some students believe that an object with constant speed has a constant force acting on, and for acceleration to occur there must be an increasing force. To confront these issues, three contexts were considered in the FMM. *Context 1* involves a model car moving on a flat route, without engine or brakes. The invention refers to the question "Is there a net force acting on the car when it rests, it moves with a constant speed, and it moves at a gradually increasing speed?" Theoretically, if a friction force is equal to a net force, the car is at rest or at a constant speed when it moves. Acceleration occurs when the friction force is smaller than a net force. Deceleration happens when there is an opposite net force acting on the car opposite with its motion. *Context 2* involves a spaceship designed to answer these questions: 1) is there a net force acting on the spaceship while it is in a uniform motion? And 2) what are the effects on the spaceship when the stern rocket is fired (push forward)? Suddenly shut down (no pushing)? Then it restrains the retro-rocket (push backward)? The correct responses to these questions are as follows: 1) the spaceship moves at a constant speed when there is no force acting on it. 2) There is forward force acting on the spaceship to produce the acceleration. Force off produces a constant speed. The backward force produces deceleration. *Context 3* involves a skydiver, which relates to the questions: is there net force acting on a skydiver, which initially increases speed, and later it falls at a constant speed? In this case, when the air resistance is smaller than his weight it will produce acceleration. On the other hand, a constant speed appears when his weight is equal to air resistance. These three contexts refer to the generalization of the Newton's first law mechanics, i.e. when it is at rest or at a constant speed there is a zero-net force, a positive net force produces acceleration, and a negative net force produces deceleration. Tao and Gunstone (1997) also reported that many students held the alternative conceptions in the three contexts.

Students from several countries held misconceptions about projectile motion. For example, in Australia, in 2004-2005 Prescott and Mitchelmore conducted research about students' understanding of projectile motion, which was taught in grade 11 and grade 12 extension 1 mathematics. Two schools located in Sydney participated in this research. Forty-seven students from grade 12, and seventeen students from grade 11 were asked to answer 21 questions, and were also interviewed for 15-20 minutes. The 21 questions included 8 questions asked about launched objects and an object rolling off a cliff, 3 questions needed students to compare dropped and launched objects simultaneously, 5 questions asked about the time of flight of the objects, 3 questions asking about initially confined to a horizontal constant speed and suddenly dropped object, one question asked about a flare gun shooting vertically from a moving snowmobile, and the last question asked about the force acting on a throwing stone in a vertical direction. Prescott and Mitchelmore reported that not only students but also teachers with ten to twenty years of teaching experiences held misconceptions about the path of an object dropped from a moving carrier. Moreover, they had confusion about the time of the dropped object and the launched object with a constant horizontal speed at the same height. In addition, traditional mathematics teaching seems to have little or no effect on students' misconceptions. Prescott and Mitchelmore (2004) suggested that it would be better to continue teaching projectile motion in grade 12 to reduce students 'misconceptions disclosed in grade 11.

Bayraktar (2008) have conducted a study with 79 pre-service teachers at the faculty of education in Turkey using FCI to investigate whether misconceptions vary depending on gender and educational levels. To compare the differences of FCI score between gender and the years of education, the data was analyzed by using frequencies, t-test and ANOVA. The results showed that pre-service physics teachers carried strong misunderstanding on impetus and active forces. There was no significant difference between FCI scores of male and female samples. Furthermore, the misunderstanding of force and motion decreased when educational levels increased.

Jimoyiannis and Komis (2001) investigated the effectiveness of interactive physics including the computer simulation related to velocity and acceleration of a free fall object in three different contexts. Students were divided into two groups: control group (N=30), and experimental group (N=60). Those students came from a variety of social-economic backgrounds located in three different high schools in the city of Ioannina, Greece. The computer simulation program was used to address students' misconceptions in three tasks. In Task 1, a greater mass of the ball has a larger velocity in free fall, and it also has a larger acceleration. In Task 2, at the different height, a higher ball has greater velocity when it falls freely to hit the ground because it has greater acceleration. The higher ball has a greater acceleration because it falls with a longer distance. In Task 3, a freely falling ball has a greater acceleration than that released at a constant horizontal speed because the falling ball falls vertically. A ball released at a horizontal and constant speed has greater acceleration than the falling ball because it falls horizontally. The results from task 3 were similar to the studies of Dilber (2009), Prescott and Mitchelmore (2004), and Whitaker (1983). The results showed an outperformance of using the computer simulation with the experimental group.

Dilber (2009) used conceptual change-based instruction and computer simulation to address Turkish high school students in the experimental group (N=43). They found the significant effect of the experimental group of students much better than the control group (N=32) taught via traditional teaching method. The conceptual change-based instruction proposed by Roth (1985) consists of 4 steps: classify students' misconceptions, elicit the prior knowledge, address and compare evidence, and discuss the scientific concept. The students' misconceptions reported in Dilber (2009) were 1) the final speed of the falling object would depend only on the gravitational force. In fact, its final speed depends on both the height and the gravitational acceleration for the same initial speed. 2) For two objects fired with a different initial horizontal speed at the same height, the slower object would reach the ground first. Correctly, both objects reach the ground at the same time. 3) In a vacuum tube, the metal ball would hit the bottom before a piece of paper when both were simultaneously dropped. Indeed, both hit the bottom at the same time because of only gravitational force acting on them, and independent of mass. 4) The weight of an object depends only on its mass. Actually, the weight of one object depends on both its mass and the gravitational field of the planet. Dilber (2009) reported that the computer simulation together with the conceptual change-based instruction supported the students' learning, which immediately showed the output when the students changed a variable. The students also visualized the consequences of their manipulations by looking for the difference between their beliefs and the scientific ideas.

Klein and colleagues (2014) introduced the video analysis of the projectile motion. They proposed that it would be better if students themselves recorded the videos and used the program to analyze. For example, there is a situation in which one skater moved with a constant horizontal speed and directly tossed a ball up. Students can simply record this situation by a mobile phone. Moreover, the students could observe that the skater could catch the ball again sometime after it was launched, and the ball moves in the parabolic path. The skater saw the ball move straight. The video analysis supported students to observe the projectile trajectory and to calculate the displacement, speed, and acceleration of the ball. Moreover, it confirmed that the skater and the ball had the same initial horizontal velocity.

Ukwumonu and colleagues (2015) designed the spreadsheet simulation on Excel program, in which initial velocity, angle, and mass of projectile in the vacuum and in the air, can be varied to see the path. Theoretically, without a drag force, the 45° launch angle of the projectile displays the maximum horizontal range. This program shows that if we consider the drag force of the air resistance acting on the projectile, its maximum horizontal range will occur at the launched angle smaller than 45°. Moreover, many parameters such as the projectile's size and density, initial speed, and launched angle can be adjusted to observe the different paths both in the vacuum and in the air.

Misconceptions about the projectile motion presented above are summarized with relative references in **Table 2.1.**

Table 2.1: summary of misconceptions on projectile motion and its references

Misconceptions	Scientific ideas	References
1) A projectile is maintained by an impressed force after it left from the projector.	There is no impressed force acting on the projectile after it lost contact from the projector.	(Bayraktar, 2008; Tao and Gunstone, 1999; Tao, 1997; Hestenes et al., 1992; Hallon and Hestenes, 1985; McCloskey, 1983; Whitaker, 1983; Clement,1982)
2) The object moves in the direction of a greater imparted force than its weight which is the downward impetus. At the highest point in the path of the projectile the original force is	The projectile moves under the gravitational force in a parabolic trajectory. Its horizontal speed is constant, but vertical speed changes over time.	(Hallon and Hestenes, 1985; McCloskey, 1983; Whitaker, 1983; Clement, 1982)

used up then it falls down because of its weight.		
3) A vertical projectile is driven by a greater upward force than its weight along the path.		(Hallon and Hestenes, 1985; McCloskey, 1983; Whitaker, 1983; Clement, 1982)
4) A launched or rolling-out object on the cliff in the horizontal direction follows a reversed L path.	A launched object out of the cliff moves in a half-parabolic path at a constant horizontal speed and steadily increasing downward speed.	(McCloskey, 1983; Hallon and Hestenes, 1985;
5) An object falls straight down from where it is dropped by a body moving with constant horizontal speed.	An observer on a ground will see the projectile trajectory in a parabolic path.	(McCloskey, 1983; Hallon and Hestenes, 1985;
6) An object falls backward from where it is dropped when it is confined to the initial horizontal constant speed.		
7) Force is not imparted to the object dropped from a moving carrier.	An object is dropped forward in a parabolic path because its initial velocity is the same with that of the carrier.	
8) Air resistance is imparted to the dropped object from a moving carrier creating a backward path.		

9) At the same height, a falling object hits the ground first because it flies in a shorter path than the fired object. Or fired object will hit the ground first because it has a greater speed than the falling object.	Two objects in free-fall and projectile motion simultaneously released from the same height hit the ground at the same time.	(Jimoyiannis and Komis, 2001; Dilber, 2009; Prescott and Mitchelmore, 2004; Whitaker, 1983;)
10) At the same height, dropped and fired objects hit the ground at different time because the fired object has horizontal velocity or acceleration or force.		(Whitaker, 1983; Dilber, 2009)
11) Students have confusion between position and velocity, and between velocity and acceleration.	Velocity is the rate of change of displacement with time. The acceleration is the rate of change of velocity with time.	(Bayraktar, 2008; Jimoyiannis and Komis, 2001; Hestenes et al., 1992; Rosenquist and McDermott,1987; Hallon and Hestenes, 1985; Whitaker, 1983;)
12) A greater mass of the object falls freely and hits the ground at different time from a smaller object (neglect air resistance).	All free falling objects hit the ground at the same time because they are acted only by the gravitation force (neglect air resistance).	(Dilber, 2009)
13) The final speed of the falling object depends on the gravitational force.	The speed of the falling object depends on its	(Dilber, 2009)

14) A greater mass of the ball has a larger velocity in free fall.	height and the gravitational acceleration.	(Jimoyiannis and Komis, 2001)
15) A greater mass of the ball has a larger acceleration in free fall.		(Jimoyiannis and Komis, 2001)
16) At a different height, a higher ball has a greater velocity when it falls freely to hit the ground because it has greater acceleration.		(Jimoyiannis and Komis, 2001)
17) A higher ball has a greater acceleration because it falls within a longer distance		(Jimoyiannis and Komis, 2001)
18) The students confound the sign for an upward and downward of projectile motion.		(Mudau, 2014)

2.2 Normalized gain

To evaluate the effectiveness of a teaching tool or method in promoting student understanding, Hake (1998) presented an average normalized gain ($< g >$) defining the ratio of the actual average gain ($\% < G >$) to the maximum possible average gain ($\% < G >_{\max}$). $\% < G >$ is the difference between average post-test score ($\% < S_f >$) and average pre-test score ($\% < S_i >$). $\% < G >_{\max}$ is the difference between maximum score (100) and average pre-test score $\% < S_i >$. It can be shown as:

$$< g > \equiv \% < G > / \% < G >_{max} \quad \text{or}$$

$$< g > = (\% < S_f > - \% < S_i >)/(100 - \% < S_i >)\,.$$

Hake used the normalized gain to analyze two teaching approaches evaluated by the Halloun-Hestenes Mechanics Diagnostic test (later called Force Concept Inventory (FCI)). Participants were made of 6,542 students from 62 introductory physics courses in high schools (HS), colleges (COLL), and universities (UNIV). Those courses consisted of 14 traditional (T) courses (N= 2,084) and 48 interactive engagement (IE) courses (N=4,458). Interactive engagement (IE) methods are methods designed at least in part to promote conceptual understanding via interactive engagement of students in heads-on (always) and hands-on (usually) activities. These methods support students to get immediate feedback from peers and/or instructors. Traditional (T) methods are methods designed by little or no use of IE methods, focusing on passive-student lectures, recipe laboratories, algorithmic-problem exams (Hake, 1998).

Hake's results revealed that all points of the average normalized gain (<g>) for 14T courses were lower than 0.3. The average of averages; $\ll g \gg_{14T} = 0.23 \pm 0.04$sd (sd ≡ standard deviation). For the 48 IE courses, he found that 85% (41IE, N=3,741) of them obtained <g> greater than 0.3, but 15% (7IE, N=717) obtained <g> lower than 0.3. Overall, the average of averages; $\ll g \gg_{48IE} = 0.48 \pm 0.14$sd. There was no course of which <g> appeared greater than 0.7. The absolute of slope line represented <<g>> is shown in Figure 2.1.

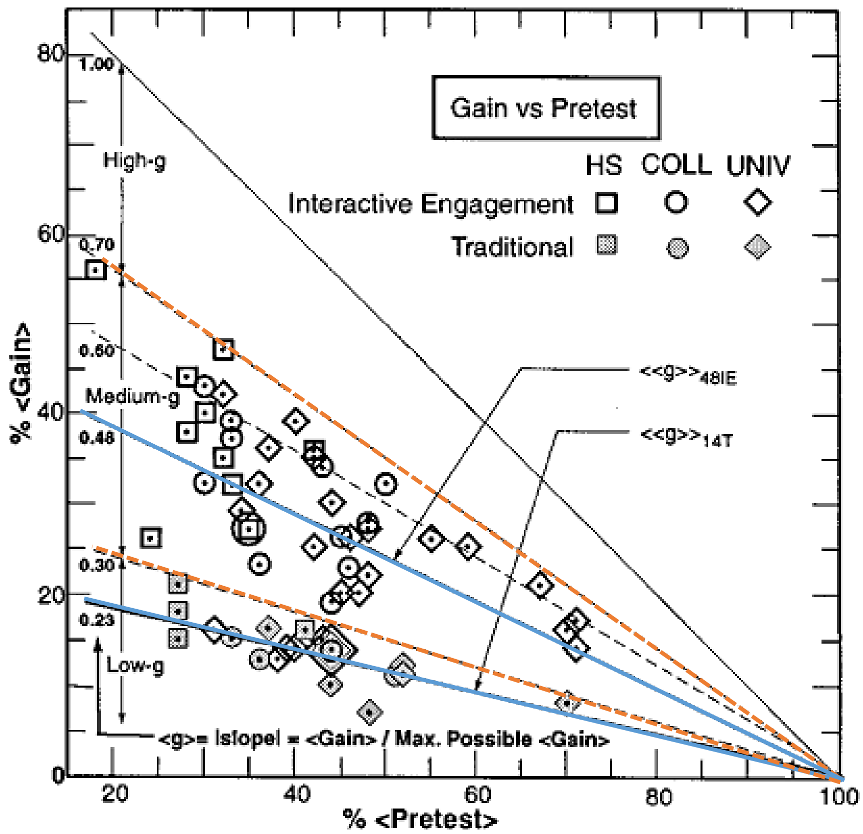


Figure 2.1: y-axis is %<Gain>, x-axis is %<Pre-test> scores on the FCI test for 62 courses enrolling a total N=6,542 students:
14T courses (N=2,084) ; $\ll g \gg_{14T} = 0.23 \pm 0.04$sd,
48IE courses (N=4,458); $\ll g \gg_{48IE} = 0.48 \pm 0.14sd$.

Based on the experimental results, Hake suggested the standard criteria as follows:

High-gain courses as those with <g> ≥ 0.7,

Medium-gain courses as those with 0.7 > <g> ≥ 0.3 and,

Low-gain courses as those with <g> < 0.3.

Moreover, a standard error of <g>, denoted by Δ<g>, can be calculated based on the error propagation using a partial differential equation. More conveniently, it can define average post-test score $< S_f > \equiv x$, average pre-test score $< S_i > \equiv y$, C ≡ the total number of questions on the exam. Since the random error Δx (or Δy) is the standard error of the mean, $\Delta x = \frac{sd_x}{\sqrt{N}}$ and $\Delta y = \frac{sd_y}{\sqrt{N}}$. sd_x (sd_y) is standard deviation of average of post-test scores (pre-test scores). N is number of students. From the equation $< g >= \frac{(x-y)}{(C-y)}$, therefore, $\Delta < g >= \sqrt{\left[\left(\frac{\partial <g>}{\partial x}\right)\Delta x\right]^2 + \left[\left(\frac{\partial <g>}{\partial y}\right)\Delta y\right]^2}$.

Here, $\left(\frac{\partial <g>}{\partial x}\right) = \frac{1}{(C-y)}$ and $\left(\frac{\partial <g>}{\partial y}\right) = \frac{(x-C)}{(C-y)^2}$.

Finally, it achieves $\Delta < g >= \sqrt{\left[\left(\frac{1}{(C-y)}\right)\Delta x\right]^2 + \left[\left(\frac{(x-C)}{(C-y)^2}\right)\Delta y\right]^2}$.

Furthermore, Hake's results displayed that the Pearson correlation coefficient between normalized gain values and pre-test scores for individual students was very low +0.02. The coefficient is calculated to demonstrate strength and direction of a linear relationship between two variables, such as normalized gain and pre-test score. The value of correlation coefficient can vary between +1 and -1. If the value lies around ± 1, it indicates a strong degree of association between the two variables including positive sign for positive association (negative sign for negative association). If the correlation coefficient value goes towards 0, the relationship between the two variables will be weak. Here, the correlation coefficient = +0.02, it indicates that students with high pre-test scores are not necessary to get high normalized gain (weak correlation). In contrast, he found the correlation coefficient = +0.55 for post-test and pre-test scores, and the correlation coefficient = -0.49 for <Gain> and pre-test scores.

Normalized gain is widely used in Physics Education Research (PER) because it is easy to calculate and shares standard criteria of 3 gain levels (high-gain, medium-gain, low-gain) introduced by Hake. For example, in 1999, Cumming and others applied normalized gain to study the *standard* Studio Physics courses and the Studio Physics courses integrated with Interactive Lecture Demonstrations (ILDs) and Cooperative Group Problem Solving (CGPS) by using the Force Concept Inventory (FCI) and the Force and Motion Conceptual Evaluation (FMCE) as assessment tools. They found the low-gain level for the *standard* Studio Physics courses (similar to traditional courses), the medium-gain level for the Studio Physics + ILDs + CGPS. This study suggested that *standard* Studio Physics, which much focused on practicing problem-solving, but not on research-based activities, was difficult to lead students to improve conceptual understanding. In 2005, Coletta and Phillips examined the correlation between normalized gains and pre-FCI scores from low-ability and high-ability groups of students taught through interactive engagement methods from 4 universities (N=2,948). Students' abilities were measured by Lawson's Test of Scientific Reasoning ability. They found a significant positive correlation between normalized gain and pre-FCI scores. They suggested that high school students, who were limited in scientific reasoning ability, were likely to rarely get success in their university level, which resulted in low pre-FCI scores and low normalized gain. Moreover, Bao (2006), presented the mathematic difference of calculating normalized gain in a class by using average pre-and post-test scores (<g>), and using the average of individual student gains ($\bar{g}$). He assumed that all students had greater post-test scores than pre-test scores. If $\bar{g}$ is greater than $< g >$, it indicates that low pre-test score students display to similar or smaller score improvement than high pre-test score students. But if $\bar{g}$ is smaller than $< g >$, it indicates that low pre-test score students display to larger score improvement than high pre-test score students. In 2010, John and Gay asked students to answer FCI and Conceptual Survey in Electricity and Magnetism (CSEM) with 3 more options (I am sure, I am not sure, and I guess), to examine the effects of guessing on normalized gain calculation. They found that the normalized gain was insensitive to the effects of guessing. However, to confirm that, they introduced correction equations of pre-and post-test scores to discourage guessing effects before calculating normalized gain.

2.3 Model analysis

Several studies indicated that students always bring prior knowledge into classes. The prior knowledge encourages misconception which is hard to change. To help students improve understanding on physics concepts, instructors should develop teaching media according to the difficulty of students (Posner et al., 1982; McCloskey, 1983; Whitaker, 1983; Hestenes et al, 1992; Redish et al., 1998; Tao & Gunstone, 1999; Bao et al., 2002; Bao & Redish, 2006). In order to display whether or not a teaching tool is well designed, an evaluation method is necessary. However, previous evaluation methods used in Physics Education Research (PER), such as t-test, and normalized gain, took only data from a correct choice. Benefits of incorrect choices (distractors) of a research-based multiple-choice test were ignored. The distractors contain important clues to identify student misunderstanding, which is a significant resource for designing a teaching process.

In 1999, Lei Bao has developed an evaluation method named "*model analysis*" based on data analysis of both correct and incorrect choices of a test. Model analysis contains 2 algorithms: 1) concentration factor and 2) model estimation. *Concentration factor* displays the distribution of students' responses on a test, such as the responses are concentrated on one choice or widely scattered among different choices indicating random guessing. It is helpful to design a test and evaluate the quality of the test questions (Bao, 1999; Bao and Redish, 2001). *Model estimation* analyzes the relationship of student responses and extracts the detailed structural information of student models states to identify student knowledge (Bao, 1999; Bao et al., 2002; Bao and Redish, 2006). This research focuses only on the part of model estimation of the model analysis, which is used to investigate student misconceptions and students' model state of knowledge before and after classes.

The theoretical framework of the model estimation is based on scientific research of neuroscience, cognitive science and education (Bao, 1999). It takes advantage of qualitative research to design quantitative parameters. Since students' responses depend on a context of a question, we can use a set of equivalent conceptual questions in different physical contexts to activate student in choosing a mental model to respond. The probability for a student to apply different mental models in solving these questions can be measured by using model estimation, as shown in Figure 2.2.

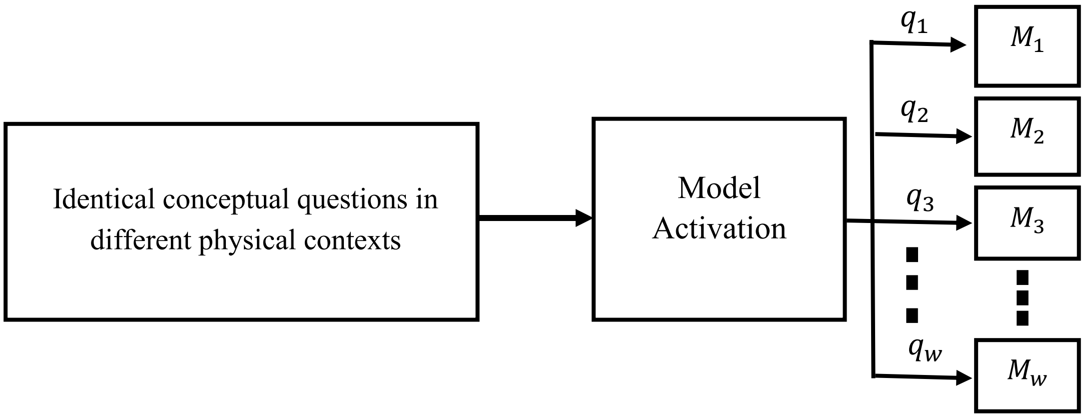


Figure 2.2: Applying a set of questions designed for a particular physics concept, the probability for a single student to use different models in solving the questions can be measured. In the figure, $M_1, \cdots, M_w$ represent the different mental models. There is a total of w models including a null model. The $q_1, \cdots, q_w$ represent the probabilities for a student being triggered into activating the corresponding models. (Bao, 1999)

This process is analogous to that of a quantum measurement. The different mental models with context dependence are defined as mental model states. Each mental model is represented by an element of an orthonormal basis $(\widehat{e_\eta})$in a linear vector space. Its mathematical representation is shown in equation (1):

$$\widehat{e_1} = \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \end{pmatrix}, \qquad \widehat{e_2} = \begin{pmatrix} 0 \\ 1 \\ \vdots \\ 0 \end{pmatrix}, \cdots, \widehat{e_w} = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{pmatrix} \qquad (1).$$

Responses from a single student (the k^{th}student) to a test of m questions with w mental models are used to construct the k^{th} student's probability distribution vector $\overrightarrow{Q_k}$, as shown in equation (2):

$$\overrightarrow{Q_k} = \begin{pmatrix} q_1^k \\ q_2^k \\ \vdots \\ q_w^k \end{pmatrix} = \frac{1}{m} \begin{pmatrix} n_1^k \\ n_2^k \\ \vdots \\ n_w^k \end{pmatrix} \qquad (2),$$

where q_η^k represents the probability for the k^{th} student to use the η^{th} model in solving these questions and n_η^k represents the number of questions in which the k^{th} student applied the η^{th} common model, and

$$\sum_{\eta-1}^{w} n_\eta^k = m\,.$$

Then the model state for the k^{th} student in a class is represented with a vector of unit length in the model space ($|u_k\rangle$). The elements of the vector represent the *probability amplitude*. This gives the normalization condition that the mental models form a complete set and the probability for a student to be activated into one of the mental models is 1. Therefore, $|u_k\rangle$ is the *square root* of the probability vector $\overrightarrow{Q_k}$ shown in equation (3):

$$|u_k\rangle = \begin{pmatrix} \sqrt{q_1^k} \\ \sqrt{q_2^k} \\ \vdots \\ \sqrt{q_w^k} \end{pmatrix} = \frac{1}{\sqrt{m}} \begin{pmatrix} \sqrt{n_1^k} \\ \sqrt{n_2^k} \\ \vdots \\ \sqrt{n_w^k} \end{pmatrix} \qquad (3),$$

where

$$\langle u_k | u_k \rangle = \sum_{\eta - 1}^{w} q_\eta^k = 1 \, .$$

The k^{th}student model state is used to construct the *single student density matrix* (D_k), where $D_k = |u_k\rangle\langle u_k|$. The D_k for $w = 3$ is shown in equation (4):

$$D_k = |u_k\rangle\langle u_k| = \frac{1}{m} \begin{bmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_2^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{bmatrix} \qquad (4).$$

For the entire class, individual student density matrices are combined to create the *class density matrix* (D), as shown in equation (5):

$$D = \frac{1}{N} \sum_{k-1}^{N} D_k = \frac{1}{N.m} \begin{bmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_2^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{bmatrix} = \begin{bmatrix} \rho_{11} & \rho_{12} & \rho_{13} \\ \rho_{21} & \rho_{22} & \rho_{23} \\ \rho_{31} & \rho_{32} & \rho_{33} \end{bmatrix} \qquad (5).$$

The diagonal elements of the class density matrix reflect the percentage of the responses generated with the corresponding models used by the class. The off-diagonal elements reflect the consistency of the individual students' use of their models. Large off-diagonal elements signify low consistency (large mixing) for individual students in their model use. An off-diagonal element is significant if its value > 50% of its components.

In general, a class density matrix can display one of three types.

(a) When entire students in the class have the same physical model, the class matrix consists of one element and others are zero, called *consistent one-model*, as the following.

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

(b) Students have 3 different groups with a consistency physical model, so the class matrix shows 3 different diagonal elements and off-diagonal elements are zero, called *consistent three-model*, as the following.

$$\begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 0.3 & 0 \\ 0 & 0 & 0.2 \end{bmatrix}$$

(c) Students have multiple physical models and inconsistency in using these models, so the class matrix shows non-zero value of diagonal and off-diagonal elements, called *inconsistent three-model* or *mixed model states*. This is the most frequent density matrix of general classes. An example is shown in the following.

$$\begin{bmatrix} 0.5 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.1 \\ 0.1 & 0.1 & 0.2 \end{bmatrix}$$

Then the class density matrix is computed to find out the eigenvalues and eigenvectors for showing the students' distribution in each mental model. For total $w = 3$ mental models, its class matrix is 3×3 and we will obtain three eigenvalues (σ_μ^2; $\mu = 1, 2, 3$) and three corresponding eigenvectors ($v_\mu = (v_{1\mu} \;\; v_{2\mu} \;\; v_{3\mu})^T$). These can be simply presented by three class model vectors as shown in Figure 2.3.

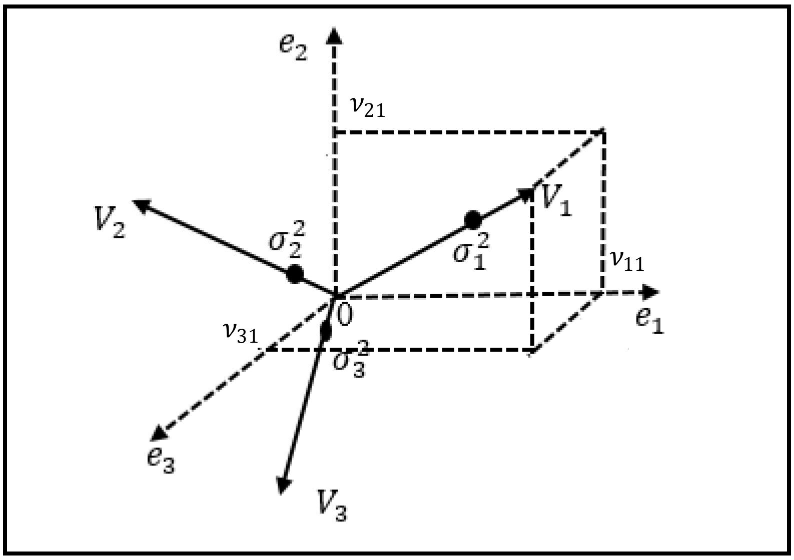


Figure 2.3: Student class model state vectors (Bao, 2006)

The class model vectors are the weighted average of all the individual student model vectors. In order to choose one class model vector as a representative of the class model state, we focus on the largest dominant eigenvalue. A large eigenvalue indicates that many students are similar to each other and the single student model vectors for different students are similar. In contrast, if students are all different from one another, the single student model vectors have different structures, so it is difficult to find a vector that agrees well with others. This is defined by a small eigenvalue. Therefore, the eigenvalues can be used as a measure to tell if the students' vectors are similar with or different from one another. Ultimately, the largest eigenvalue and its eigenvector are selected to describe the class model state. Based on experimental results, Bao (2006) suggests that a large eigenvalue requires > 0.65 for proper demonstration of the agreement of a single student model vector with the favorable physical models.

Moreover, the class model state can be simply shown in a two-dimensional model plane by using the two mental (correct and incorrect) models as axes called *model plot*. This is more helpful if the null model has small element (around 5%) indicated by Bao's results. To comfortably display and study the states and the movement of student models in a given situation, the probability of using correct model (model 1) is represented in y-axis, and the probability of using incorrect model (model 2) is represented in x-axis of the model plot, as shown in Figure 2.4.

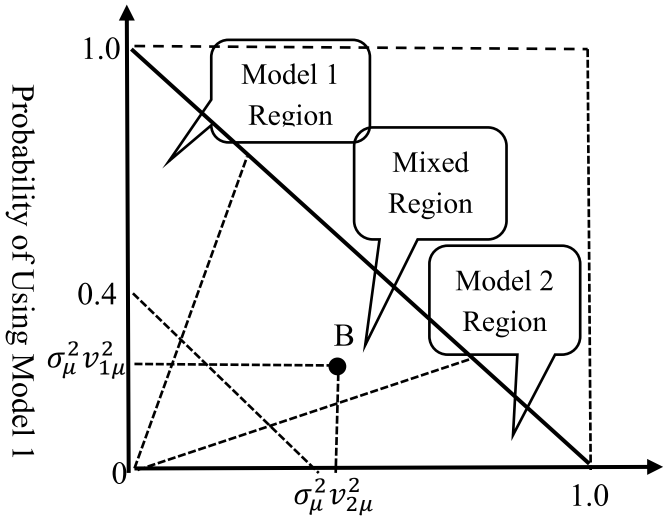


Figure 2.4: Model regions on model plot
(Bao, 2006)

The model 1 (model 2) region represents corresponding model states with dominant model 1 (model 2) components. The mixed model region represents mixed model states. Then the largest eigenvalue (σ_μ^2) and its primary eigenvector, denoted by

$v_\mu = (v_{1\mu}\ v_{2\mu}\ v_{3\mu})^T$, are pointed on the model plot with a coordinate (P_2, P_1) or point **B** for example, where $P_1 = \sigma_\mu^2 v_{1\mu}^2$ and $P_2 = \sigma_\mu^2 v_{2\mu}^2$.

In order to describe the different regions of the plot, Bao (1999) separated the plot by drawing two straight lines from the original with slopes equal to 1/3 and 3, respectively. Both slopes are translated from model state angular distribution, as shown in Figure 2.5(b). For analyzing student model structures, it can project the student model states on the plane spanned by the two dominant physical models. The angle between the physical models and its projections can be used to explain the mixing characteristics of a model state. As shown in Figure 2.5(a), $\emptyset_{\eta\mu}$is the angle of the state vector on the plane spanned by the $\eta^{th}$and the μ^{th}physical models. As aforementioned, the state vector is the square root of the probability vector, then

$$\phi_{\eta\mu} = \tan^{-1}\left(\frac{\sqrt{q_\mu}}{\sqrt{q_\eta}}\right).$$

Therefore, the probability of using model μ (q_μ) and the probability of using model $\eta(q_\eta)$ can be defined as:

$$\frac{q_\mu}{q_\eta} = tan^2(\phi_{\eta\mu}).$$

Two lines in the equal separation of $\pi/2$ are $tan^2(\pi/6) = 1/3$ and $tan^2(\pi/3) = 3$.

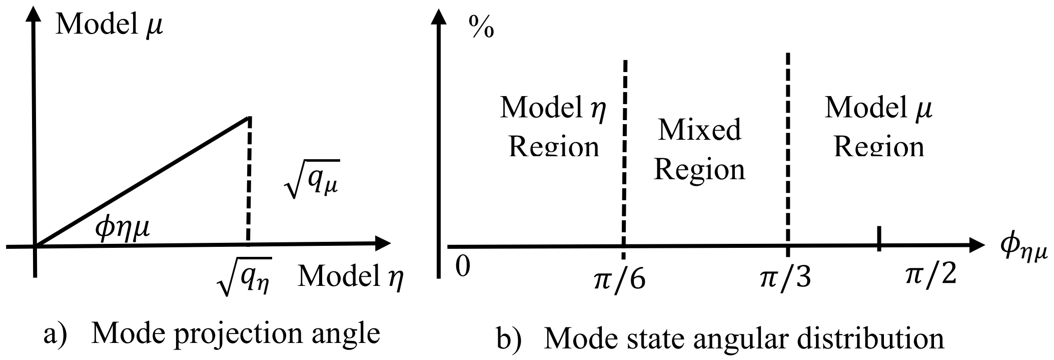


Figure 2.5: Schematics of model projection angle and model states angular distribution.

Moreover, in Figure 2.4, Bao (1999) also drew the line corresponding to the condition P_1+P_2 = 0.4 to separate primary and secondary regions. In his experimental results, most cases the primary model state has an eigenvalue 3-4 times larger than the second largest eigenvalue. If a model point of small eigenvalues is plotted, it is below the boundary of 0.4 indicating secondary region. The secondary region is not considered in the model analysis.

Overall, model estimation is a tool to evaluate the student model states in a class. It describes a student's responses with a vector in a linear model space representing student probabilities of using different common models. The largest eigenvalue and its eigenvector of a class density matrix are selected to describe the student model structures. Moreover, the change of the student model states can be simply presented via the model plot.

Many researchers applied model estimation to evaluate and study the movement of student model states before and after classes. For instance, in 2014 Rakkapao and colleagues used model estimation to compare two instructional methods named predict-observe-explain (POE) and instructor-led problem-solving approaches integrated into force and motion lecture classes of freshmen university students in Thailand. Their model plot indicated that the POE method promotes students' learning better than problem-solving method for the velocity and acceleration concepts, but both still occur a small shift of students' model states. In 2016, McGinness and Savage performed a model analysis to analyze data collected by Action Concept Inventory (ACI) at Australian National University and found that their class was ineffective in moving students towards the correct model. In the same year, Smith presented uncertainty on model analysis plots to refine error bars on model points and provide additional details about the methods and assumptions. Smith firstly mentioned about error bars on model points when he and his colleagues compared FMCE data obtained from model analysis and normalized gain, and found that model plots provided more information than normalized gain graph (Smith et al., 2014).

2.4 Inquiry-Based Learning (IBL) Approach

In 1969, the learning pyramid was reproduced by the National Training Laboratories (Bethel Maine) (modified from the Dale' cone in 1954), as shown in Figure 2.6. It is used to illustrate that the more active instructions are, the more memory retention for such subject matters learners have, as strongly indicated in education research (Lalley and Miller, 2007). The learning pyramid provides the average retention rates for different instructional methods (or experiences). Only reading (listening), people tend to remember 10%(20%) of what they read (listen). They are just able to explain what they read. This is often called *passive learning methods*. In contrast, the *active leaning methods*, such as participating in hands-on workshop, design collaborative lessons, perform experiments, practice by doing and teaching each other, were found to provide the most retention (70-90%). Hence, learners have ability to analyze, create and evaluate things.

The Learning Pyramid

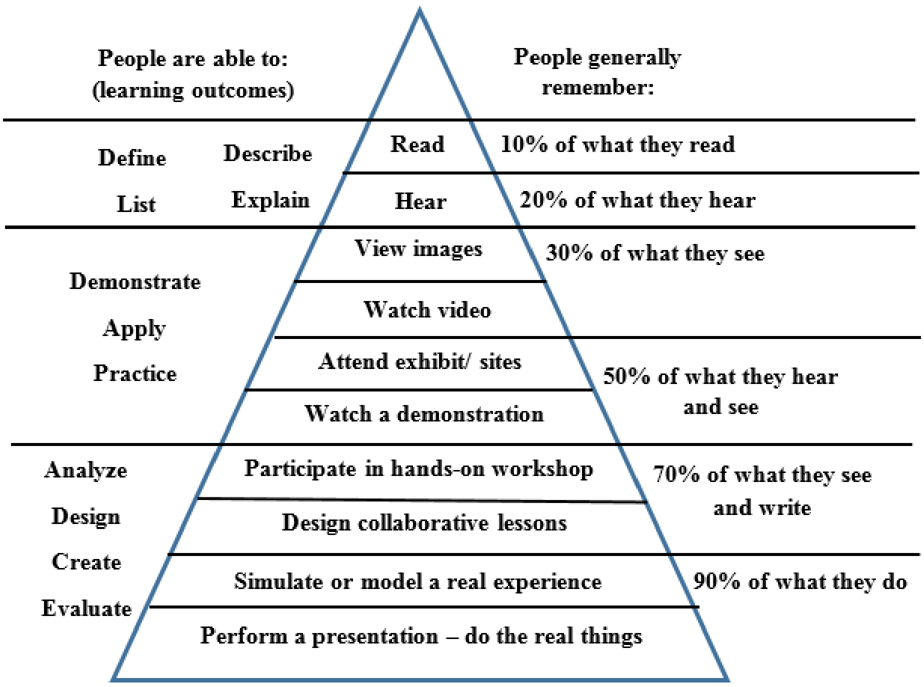


Figure 2.6: Modification of Dale's Cone of Experience

In order to support students to have high ability in learning, this research aims to integrate the Inquiry-Based Learning (IBL) method into classrooms. Inquiry means "hunting knowledge by questioning". IBL is defined as the lesson in which students are encouraged to work together to get answer of their question rather than receiving direct answer from the teacher. It obviously enhances students' critical thinking. IBL requires students to observe and think of scientific phenomena to identify a question, to conduct experiments to answer their question, and to draw the conclusion from the result of experiment, and compare it with the law. In this process, they will understand scientific concepts more deeply and acquire scientific knowledge and skills more effectively. When students study science in an approach of inquiry-based learning, they become "mini-scientist" because they go through the same process as scientists do. Moreover, to get success in the procedures, teachers themselves require more solid scientific knowledge and teaching skills rather than a general conventional approach does (CSMEE, 1995). To follow the IBL approach, in a class we applied the inquiry cycle as shown in Figure 2.7.

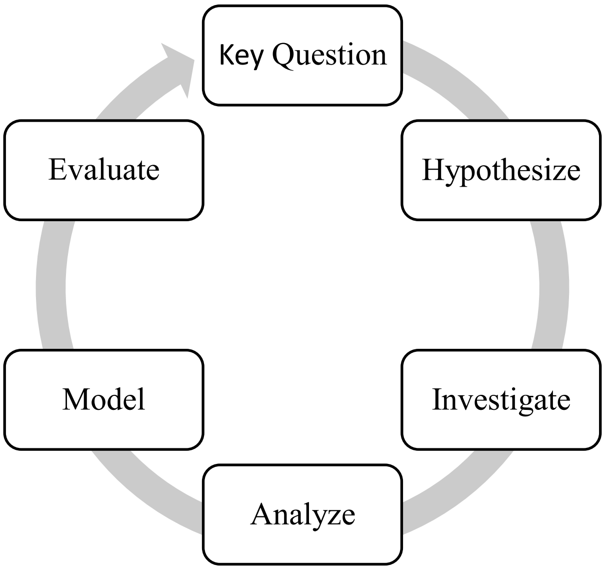


Figure 2.7: The inquiry cycle provides students with a goal structure for guiding their inquiry (White et al., 1999)

The classroom procedures starts from

1) Key Question: question is derived from lesson objective,

2) Hypothesize: perform the prediction of the question,

3) Investigate: conduct the experiment or investigate demonstration setup,

4) Analyze: analyze the result from the experiment or investigation,

5) Model: draw the conclusion from the experiment results by formulating a law and compare to the answer key of the question, and

6) Evaluate: try to apply the law from result of experiment to the real world situations.

Then a new key question comes up for further topics. Several researchers have reported the achievement of using IBL approach. For example, in 2011, Loverude and colleagues applied inquiry-based course in physics and chemistry for pre-service K-8 teachers and found that the course activities had a great impact on learning concepts. Moreover, they suggested that before the starting of a class instructors have to well prepare many things more than context knowledge. Moreover, in 2012, Lindsey and others reported that the class of Physics by Inquiry (PbI) obtained the significant positive attitudinal shifts evaluated by the Colorado Learning Attitudes about Science

Survey (CLASS). However, in 2013, Gaffney addressed the issue of some students reported that they were unsatisfied with the Physics and Astronomy for Teachers (PAT) courses of the inquiry method. Gaffney did the investigation and found that these students expected to learn different things instead of the inquiry lesson objectives. In this case, the students had prior knowledge of the course before encountering active-learning classes. Therefore, instructors should be aware of reasons behind their pedagogy.

Chapter III

Research Methodology

In order to promote Cambodian high school 11th graders' understanding on projectile motion, we invented some tools applied into the inquiry-based learning (IBL) procedure. The research methodology consists of three phases as shown in the following.

Phase I: survey misconceptions

Phase II: design and apply IBL procedure

Phase III: evaluation

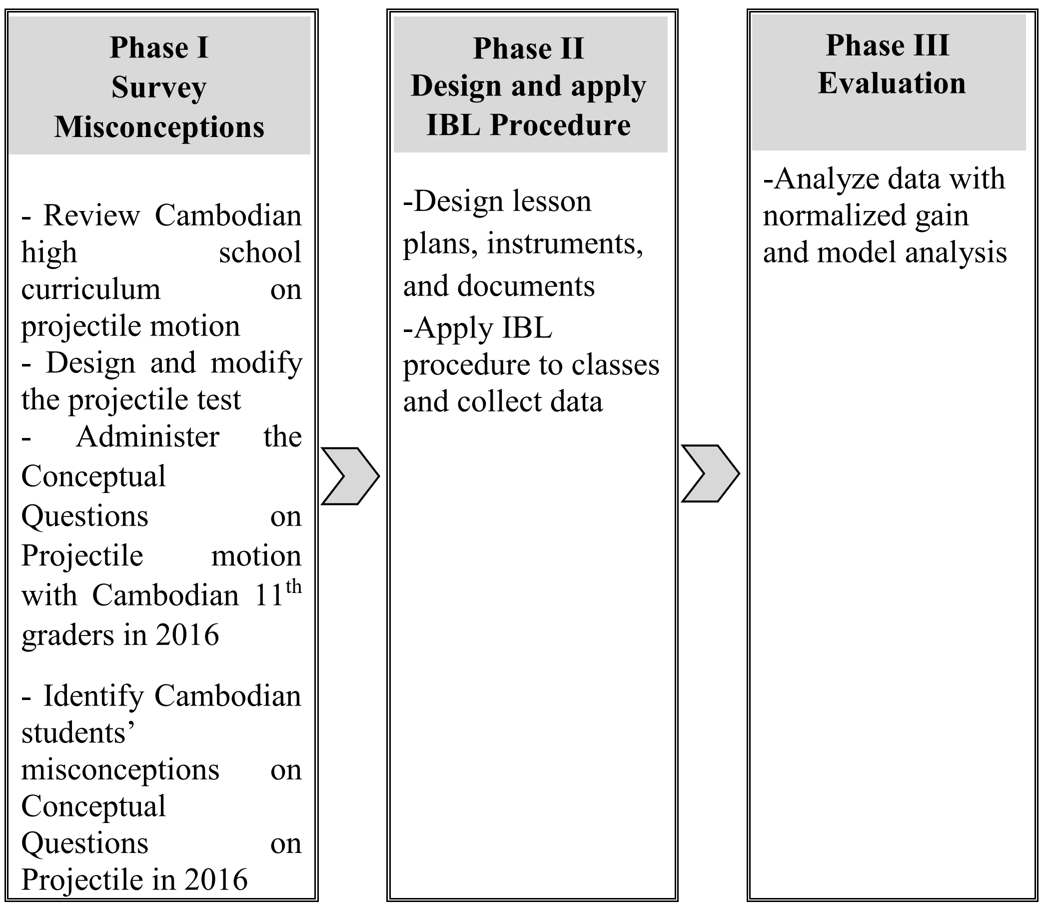


Figure 3.1: Three main phases in the research methodology

Details for each phase are explained in the following.

3.1 Phase I: Survey Misconceptions

3.1.1 Review Cambodian high school curriculum on projectile motion

Based on Cambodian national physics textbook in 2009 for grade 11th students, they were taught with 4 chapters and 14 lessons in the whole year. The outline is as below.

Chapter I: Mechanics

Lesson 1: Motion in Space	6 hours
Lesson 2: Applications of Newton's Laws	6 hours
Lesson 3: Gravitational Force	6 hours
Lesson 4: Linear Momentum and Impulse	6 hours
Lesson 5: Conservation of Energy	6 hours

Chapter II: Thermodynamics

Lesson 1: Temperature and Heat	9 hours
Lesson 2: The Kinetic Theory of Gases	6 hours

Chapter III: Wave

Lesson 1: Oscillations	3 hours
Lesson 2: Waves	6 hours
Lesson 3: Sound Wave	12 hours

Chapter IV: Electricity

Lesson 1: Electric Charge and Electric Field	12 hours
Lesson 2: Electric Potential and Electric Energy	12 hours
Lesson 3: Capacitor	6 hours
Lesson 4: Current, Resistance, and Electromotive Force	6 hours

In chapter 1 of Mechanics, 6 periods were designed for lesson 1 on motion in space and each period lasted 45 minutes including projectile motion. Lesson 1 contains:

1. Displacement and velocity
2. Acceleration
3. Projectile motion
4. Curve motion

Projectile motion was taught for 4 periods including 1) the equation of the path, 2) the horizontal range, and 3) the horizontal and the vertical motions.

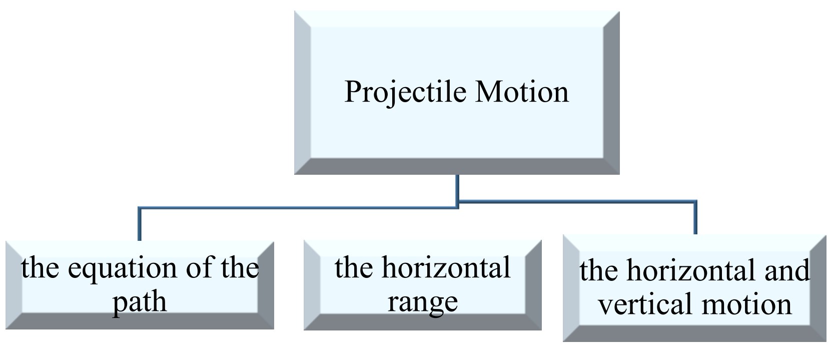


Figure 3.2: Subtopics of the projectile motion

Since 1996, with the purpose of enhancing education quality, the Ministry of Education and Sport (MoEYS) carried out the educational reforms by launching curriculum and textbook development in the general education system as 6 years for the primary school level, 3 years for the lower secondary school level, and 3 years for the upper secondary school level. In 2009, MoEYS again launched a new curriculum and adopted new textbooks; the 11^{th} grade students in the upper secondary school have to study projectile motion, which is in the lesson one, chapter one in the physics textbook. Despite nine years of the education reform, projectile motion was taught by conventional methods because teachers still lacked understanding of interactive teaching methods, as well as instructional instruments. Therefore, aiming at strengthening students' understanding on projectile motion at the high school level, we designed 7 open-ended conceptual questions to investigate students' conceptual understanding.

3.1.2 Design and modify the projectile test

Seven open-ended questions were designed based on previous research, textbooks, and the researchers' experiences. We used Index of the Item-Objective Congruence (IOC) to evaluate the agreement between items and their behavioral objectives. As examples, two items (Q2 and Q6) are shown in the IOC evaluation forms in Tables 3.1 and 3.2

Table 3.1: A form for evaluating the Item-Objective Congruence (IOC) for item 2

Item 2	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
Two identical divers plan to dive off a cliff into the water. Diver A drops straight down. Diver B runs off the cliff with an initial horizontal speed v_0 , as shown in the figure below. (Simultaneous events) 2.1) Which diver will reach the water first? Give your reasons.	Students are able to compare the time interval between the projectile motion and the free fall.			
2.2) Which diver has the greater splash down speed? Give your reasons.	Students are able to compare the final velocity between the projectile motion and the free fall.			
2.3) Are the accelerations of the two divers equal? Give your reasons.	Students are able to compare the acceleration in the projectile motion and the free fall.			
2.4) For diver B, if the height H of the cliff increases, when the diver runs off with the same initial horizontal speed v_0, the distance W' and the splashdown velocity v' will be <u>greater than</u>, <u>less than</u>, or <u>equal</u> to the former? Give your reasons.	Students are able to identify the horizontal distance and final velocity of the projectile when the time interval changes.			

Table 3.2: A form for evaluating the Item-Objective Congruence (IOC) for item 6

<table>
<tr><td rowspan="2">6. Draw the parabolic trajectory of the projectile launched with the same initial velocity but at different angles, 30°, 45° and 60° to the horizontal plane.</td><td rowspan="2">Behavioral Objectives</td><td colspan="3">Levels of Consistency</td></tr>
<tr><td>+1</td><td>0</td><td>-1</td></tr>
<tr><td></td><td>1) Students are able to identify the maximum horizontal distance of the projectile at the angle of 45°.
2) Students are able to identify the same horizontal distance of the projectiles at the two complementary angles.</td><td></td><td></td><td></td></tr>
</table>

Index of the Item-Objective Congruence (IOC) was used to validate our conceptual questions, which is the formula of the Rovinelli and Hambleton (1977) as below:

$$\mathrm{IOC}_k = \frac{\sum R}{N}$$

where IOC_k is the Index of Item-Objective Congruence of the k item

$\sum R$ is the total score of item k from the experts, and

N is the number of the experts.

The IOC evaluation forms (see appendix A) were provided to 8 experts, who have taught physics in projectile motion, to verify the agreement between items and the behavioral objectives. When the expert is confident that the item agrees with its objective, (+1) is given. When the expert is not sure, (0) is marked. However, when the expert is confident that the item disagrees with its objective, (-1) is labeled. When the value of IOC is (+1), it is interpreted that the questions are in perfect agreement with the objectives (Rovinelli and Hambleton, 1977). The IOC value of each item in the conceptual questions on projectile motion is greater than 0.75. The average IOC value for the seven questions is 0.95, which is acceptable (a required IOC value > 0.75 (Turner and Carlson, 2003)). According to the suggestions from our content experts, the items were modified to create a new version of the completed questions.

3.1.3 Administer the Conceptual Questions on Projectile Motion (CQPM) with Cambodian 11th graders in 2016

In order to identify students' misconceptions as our preliminary resources, we applied CQPM into six regular classes at high school located in a small town (Tbong Khmum province) in Cambodia in 2016. The results revealed several consistent misconceptions held by the students both before (N=124) and after (N=131) classes. In common classes in Cambodian high school, a teacher often asks a student to read textbooks out loud and the others to listen to him/her. Later the teacher asks questions and students answer. Then the teacher corrects students' answers, gives lecture, and does the passive-problem solving then students take notes. In the Cambodian curriculum, teachers spend approximately 6 periods on lesson 1 on motion in space, and 45 minutes for each period. Particularly, teachers spend 4 periods on projectile motion. Three weeks after completing projectile lessons, the same seven open-ended questions as tested on the pre-test were administered with the students again.

3.1.4 Identify Cambodian students' misconceptions on Conceptual Questions on Projectile Motion in 2016

In order to identify students' misconceptions, we grouped their answers based on their overlap ideas before and after common classes. Here we presented students' answer patterns of item 2 and item 6 as the example and the others are presented in the Table 3.6 as summary.

Question 2: Two identical divers plan to dive off a cliff into the water. Diver A drops straight down. Diver B runs off the cliff with an initial horizontal speed v_0, as shown in the figure below (simultaneous events).

2.1) Which diver will reach the water first? Give your reasons.
2.2) Which diver has the greater splashdown speed? Give your reasons.
2.3) Are the accelerations of the two divers equal? Give your reasons.

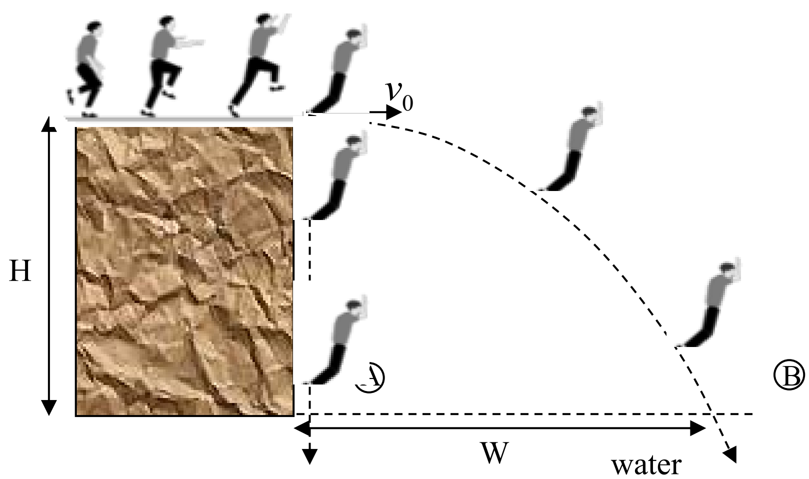


Figure 3.3: Question 2 on two divers' simultaneous motion

a) Results for item 2.1

The answer for item 2.1 is that both divers will reach the water at the same time; $t_A = t_B = \sqrt{\frac{2H}{g}}$.

Our results in item 2.1 showed that around 73% and 74% of the students on pre- and post-tests believed that diver A will reach the water first and expressed some equations such as $y = (-)\frac{1}{2}g\frac{x^2}{v_0^2\cos\theta^2} + \tan\theta$; $x(y, \text{or } H) = \frac{v_0^2 \sin 2\theta}{g}$; $y = \frac{1}{2}gt^2$ as shown in Table 3.3. Some explained that $y = \frac{1}{2}gt^2$ is an equation of free fall motion, and $y = -\frac{1}{2}g\frac{x^2}{v_0^2\cos\theta^2} + \tan\theta$ *or* $y = \frac{1}{2}g\frac{x^2}{v_0^2}$ is an equation of projectile motion. They thought that diver A follows the free fall motion, but diver B follows the projectile motion. Therefore, diver A will reach the water first. In this case, it indicates the misconception that flight time depends on the type of motions. With similar equations above, some students on pre and post-tests thought diver A will reach the water first. However, when we focus on variables, affecting students' ideas, it is possible that they think about the distance (or path of motion). They may think that diver A moving straight down (named as free fall motion), takes a shorter path than B, moving in a curve path (name as projectile motion), thus, diver A will reach the water first. This result agrees with the misconception found in Prescott (2004) that the dropped ball travels in a shorter path than the horizontally launched ball and it will reach the ground first.

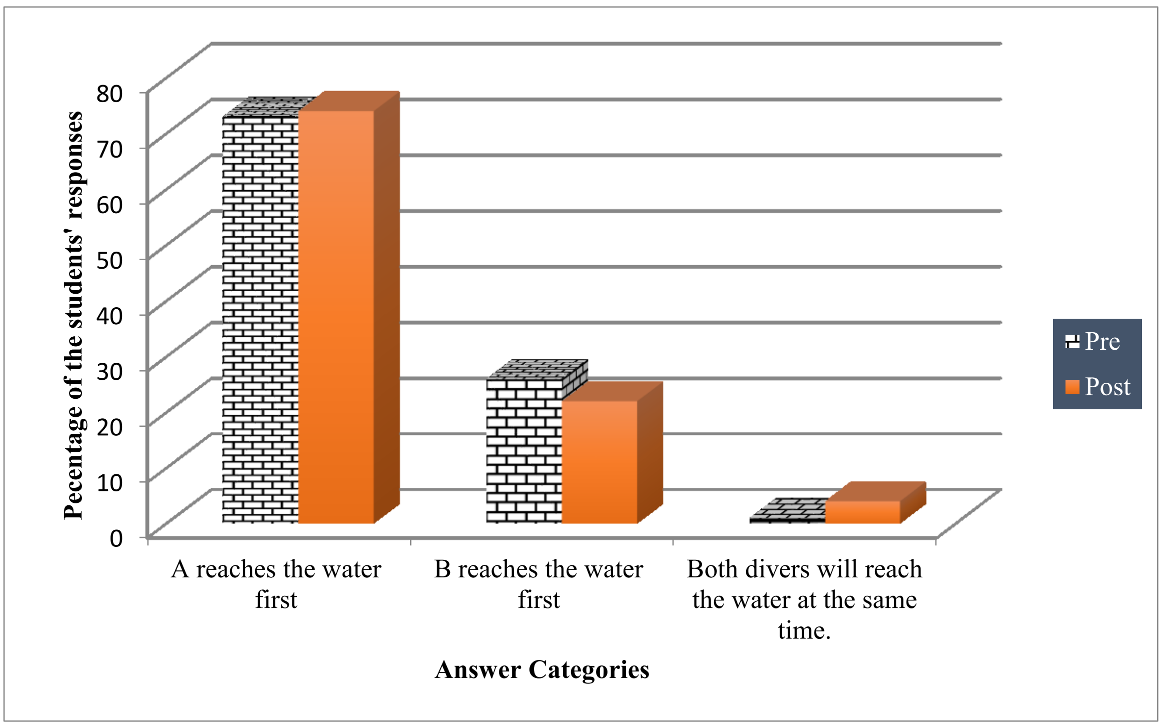


Figure 3.4 Students' responses to item 2.1 before (N=124) and after (N=131) traditional instructions

Velocity (II#) is also a variable which affects students' thinking (see Table 3.3). Some believed that diver A has no initial velocity so it will reach the water first according to some equations $v = \sqrt{2gh + v_0^2}$; $v_A = \sqrt{2gh}$; $v = at$. In contrast, on pre and post-tests around 26% and 22% of the students believed that diver B has initial velocity faster than A, so it will reach the water first. In fact, B is faster than A, but it takes longer path than A. These parameters make A and B reach the water at the same time with identically initial conditions. After the conventional instruction, we found that only one student correctly explained this item as shown in the Figure 3.4.

Table 3.3: Students' responses to item 2.1 on pre and post-tests

Students' Answers	Reasons	Percentage in the Pre-Test (N=91)	Percentage in the Post-Test (N=106)
Diver A will reach the water first. (73% on pre-test, 74% on post-test)	No reason.	31%	44%
	I(A)# Express x or y using equations such as $x(y, \text{or } H) = \frac{v_0^2 \sin 2\theta}{g}$; $y = (-)\frac{1}{2} g \frac{x^2}{v_0^2 \cos\theta^2} + \tan\theta$; , $x = v_{0x}t$; $x = at$; or $x = \frac{1}{2}at^2$	19%	9%
	I(B)# Express y using equations such as $y = \frac{1}{2}gt^2$ and named "free-fall motion" or $y = \frac{1}{2} g \frac{x^2}{v_0^2}$ and named " projectile motion".	2%	14%
	II# Express v using equations such as $v = \sqrt{2gh + v_0^2}$; $v_A = \sqrt{2gh}$; $v = at$ or write that driver A has no initial velocity	11%	4%
	Express t using equations such as $t = \frac{x}{a}$; $t = \sqrt{\frac{2y}{g}}$; $t = \sqrt{\frac{y}{2g}}$; $t = \frac{v_0}{x}$	10%	3%

Diver B will reach the water first. (26% on pre-test 22% on post-test)	I# Express x or y using equations such as $x=\frac{v_0^2\sin 2\theta}{g}$; $y=(-)\frac{1}{2}g\frac{x^2}{v_0^2\cos\theta^2}+\tan\theta$; $x=v_{0x}t$; $y=(-)\frac{1}{2}gt^2; y=\frac{1}{2}g\frac{x^2}{v_0^2}$	13%	8%
	II# Express v using equations such as $v_B=\sqrt{2gh+v_0^2}$; $v_M=\sqrt{v_0^2+(gt)^2}$ or $v_B^2=2ad$	3%	2%
	Express t using equations such as $t=\sqrt{\frac{2y}{g}}$ or $t=\frac{x}{v_0}$	7%	0
	No reason.	3%	12%
Both divers will reach the water at the same time. (1% on pre-test 4% on post-test)	*Show a correct idea	0	1%
	Show incorrect equation or no reason	1%	3%

b) Results for item 2.2

The correct answer for item 2.2 is that diver B has the greater splashdown speed because $v_{\text{at }B}=\sqrt{v_x^2+v_y^2}=\sqrt{v_0^2+\left(2gH\right)}$ but $v_{\text{at A}}=v_y=\sqrt{2gH}$.

According to our table, 79% (91%) of the students on pre-and post-tests asserted that diver B has the greater splashdown speed than diver A but most showed incorrect ideas. Many students thought about the path of motion by expressing equations involving x or y variable (I#). Another group of students thought about initial velocity of B, but some still showed incorrect equations. Moreover, we found that 6 students (8%) correctly expressed equations for this item on pre-test, but all cannot do it again on post-test after 3 weeks passed. The students did not have difficulties in using physics formulas and mathematics but experienced difficulty in understanding physics concept. If the students clearly understand the physics concepts, they will be able to solve the problem correctly on post-test. This is the most difficult challenge of instructors to help students figure out about problem solving.

Table 3.4: Students' responses to item 2.2 on pre-post tests

Students' Answers	Reasons	Percentage on Pre-Test (N=76)	Percentage on Post-Test (N=92)
Diver B has the greater splashdown speed than A. (87% on pre-test 91% on post-test)	No reason.	42%	72%
	I# Express x or y using equations such $y = \frac{1}{2}gt^2$; $x = \frac{v_0^2 \sin 2\theta}{g}$; $y = \frac{1}{2}g\frac{x^2}{v_0^2}$; $y = \frac{1}{2}g\frac{x^2}{v_0^2 \cos\theta^2} + \tan\theta$; $x = \frac{1}{2}gt^2 + v_0t$; or $x = at + v_0$	16%	7%
	II# Write " B has initial velocity" but show incorrect equations, or write incorrect/ non-relate equations to find a velocity variable $v_B = \sqrt{v_0^2 - 2gh}$; $v_A = \sqrt{v_0^2 - 2gh}$; $v_B = gt_B$; $v = v_0t$; $v_0 = \frac{x}{t}$; $v = \sqrt{\frac{g}{l\cos\theta}}$; or $v_B = \sqrt{v_0^2 - 2gh}$	16%	9%
	*Explain a correct idea.	8%	4%
	Other	6%	0
Diver A has the greater splashdown speed than B. (13% on pre-test 9% on post-test)	No reason.	8%	8%
	Write about diver A having no initial velocity, or find v or x with non-relate/ incorrect equations such as $v_A = \sqrt{v_0^2 - 2gh}$ or $x = \frac{v_0^2 \sin 2\theta}{g}$	5%	1%

a) Results for item 2.3

The correct answer for question 2.3 is that accelerations of both divers are equal and its magnitude is $g = 9.8\ m/s^2$.

Our results showed that 87% of the students gave an opinion that the accelerations of the two divers are not equal with four different incorrect reasons, shown in the Table 3.5.

Table 3.5: Students' responses to item 2.3 on pre-post tests

Students' Answers	Reasons	Percentage on Pre-Test (N=76)	Percentage on Post-Test (N=90)
Both divers have different accelerations $a_A \neq a_B$ (87% on pre-test) (87% on post-test)	No reason.	13%	11%
	Diver A has no initial velocity but B has initial velocity or splashdown speed of diver B is greater than A.	37%	33%
	Diver A spends shorter time than B or both divers reach the water at different time.	16%	11%
	Both divers have different distances of motion.	11%	11%
	Diver A has initial force and initial velocity or force of diver B is greater than A.	11%	3%
	Other (N=13 repeated question)	0%	16%
Both diver are equal accelerations $a_A = a_B$ (13% on pre-test) (13% on post-test)	No reason.	0	4%
	Only gravitational force acts on it.	1%	9%
	Both events occur at the same time.	4%	1%
	Both divers go down together.	3%	0%
	Others	5%	0%

Most believed that the acceleration in this event depends on the initial horizontal velocity. The initial horizontal velocity will make the diver move faster, so it would have the greater acceleration. It means that they directly linked the acceleration with the instantaneous velocity. The confusion between the concept of velocity and acceleration has been addressed by Rosenquist and McDermott (1987). In order, 16%

(13%) of students on pre and post-test might believe on question 2.1 that both divers will reach the water at different time, which the idea led students to misinterpret again in question 2.3 by claiming that both divers will reach the water at different time and they are going to have different accelerations, or if both divers will reach the water at the same time so they are going to have the same accelerations. Besides that 13% of students on post-test still lacked initial concept by stating that the force of diver B is greater than A so they are going to have different accelerations when they reach the water, the students have the same Aristolian idea about impetus which embeded with the object after it lost contact. Our result is quite similar with that found in other studies (Prescott and Michaelmore, 2004; Tao and Gunstone, 1999; Halloun and Hestenes, 1985; Hestenes et al., 1985; McCloskey, 1983; Whitaker, 1983). In the last part, less than 10% of students could correct the answer. In reality, both divers have the same magnitude and direction of accelerations because acceleration is the ratio of change of velocity with respect to time, especially both divers freely fall down and they have only gravitational force acting on them (ignoring air resistance).

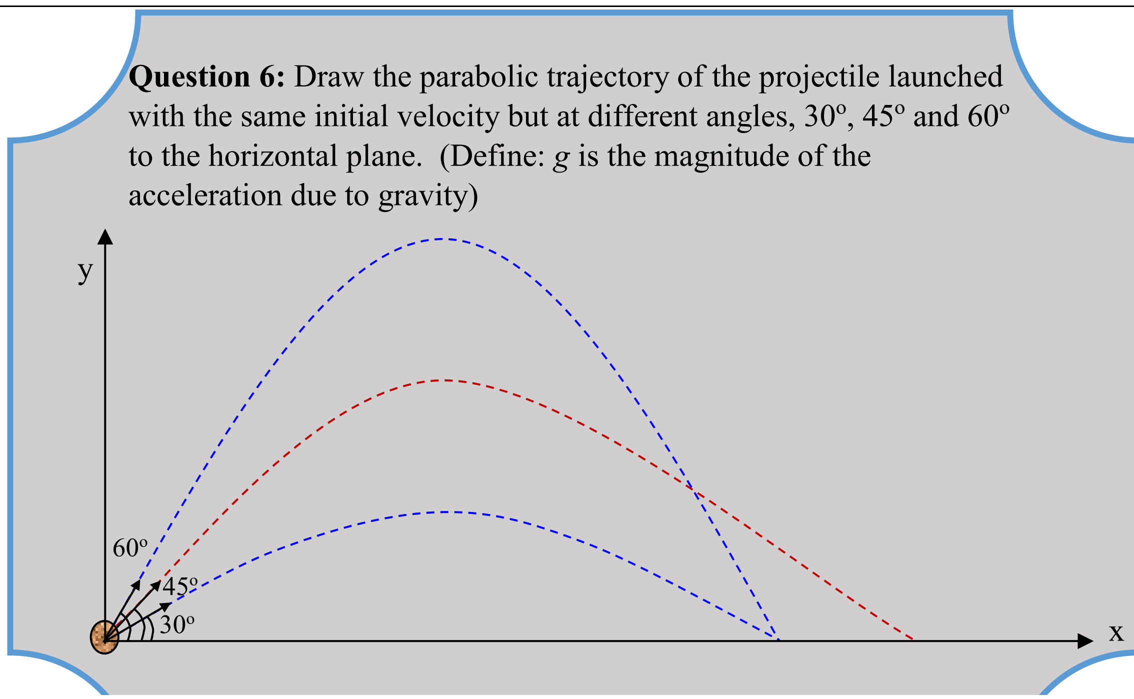
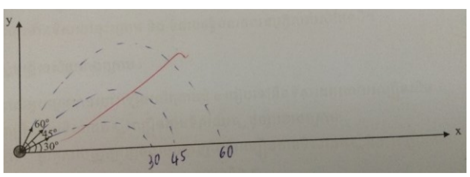
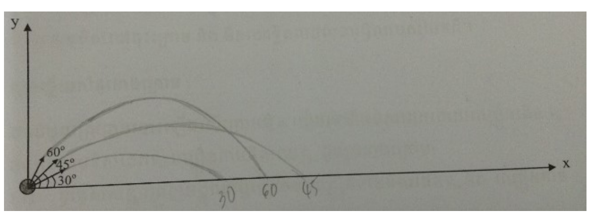
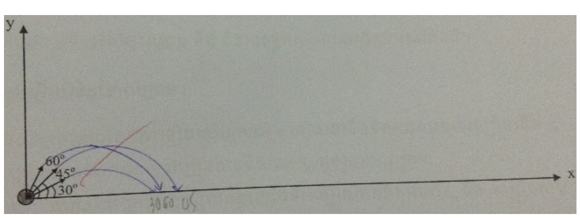


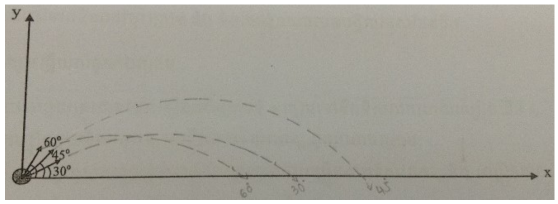
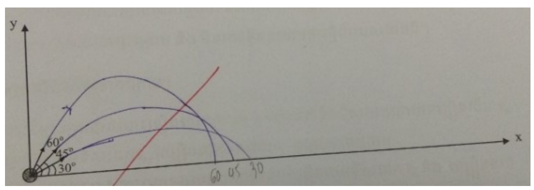
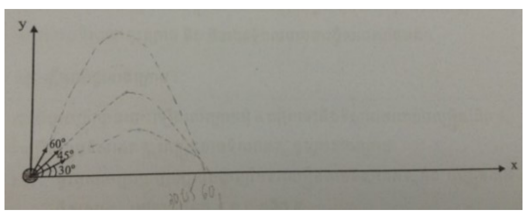
Figure 3.5: Question 6 on drawing the parabolic paths of the projectile

Results for question 6

In question 6, we aim to evaluate whether students understand that 1) projectile launched at 45° to the horizontal plane has the theoretically maximum range, 2) the projectile launched at 60° to the horizontal plane has higher altitude than 30° and 45°. And 3) the identical projectiles are launched at complementary angles (i.e., 30° and 60°) reaching the same range. The responses of the students before and after common classes are presented in Table 3.6.

Table 3.6: Students' drawing patterns of the parabolic trajectory for item 6

Group	Pattern	Interpretation	Percentage
1	Draw the parabolic paths with $x_{60} > x_{45} > x_{30}$ and $y_{60} > y_{45} > y_{30}$. 	The greater angle launched the greater horizontal range of the projectile flies.	62% (pre) 57% (post)
2	Draw the parabolic paths with $x_{45} > x_{60} > x_{30}$ and $y_{60} > y_{45} > y_{30}$ 	The confusion between the angle launched, and the horizontal range, and the altitude	13% (pre) 11% (post)
	Draw the parabolic paths with $x_{45} > x_{60} > x_{30}$ and $y_{60} = y_{45} > y_{30}$ 		3% (pre) 4% (post)

	Draw the parabolic paths with $x_{45} > x_{60} > x_{30}$ and $y_{60} = y_{30} > y_{45}$  		6% (pre) 5% (post)
3	Draw the parabolic paths with $x_{30} > x_{45} > x_{60}$ and $y_{60} > y_{45} > y_{30}$  		7% (pre) 16% (post)
4	Draw the parabolic paths with $x_{30} = x_{45} = x_{60}$ and $y_{60} > y_{45} > y_{30}$  		4% (pre) 3% (post)

Around 85 % of students on pre and post-tests drew the greater angle of the projectile launched, at the higher altitude of the projectile flew ($y_{60} > y_{45} > y_{30}$) and among that in the Group 1 around 60% of the students drew the greater angle of projectile launched at, the greater horizontal range flew ($x_{60} > x_{45} > x_{30}$). The students had the correct idea only on projectile altitude but they still misunderstood the projectile horizontal range. The students were not aware that the projectile launched at 45° to the horizontal plane has the theoretically maximum range. Moreover, 30° and 60° are complementary angles, the objects launched at complementary angles fly at the same horizontal range ($x_{60} = x_{30}$). It implies that students had the misconception that the greater angle the projectile is launched at, the greater horizontal range the projectile reaches.

In Group 2 around 20 % of the students on pre and post-tests realized that the projectile launched at $45°$ to the horizontal plane has the theoretically maximum range but they still misjudged that the horizontal range launched at $60°$ is greater than that at $30°$ and some of them drew $60°$ launched and $45°$ launched flying to the same altitude. In Group 3, 7% and 16% of the students on pre and post-tests drew the horizontal range $x_{30} > x_{45} > x_{60}$ and $y_{60} > y_{45} > y_{30}$. Furthermore, student Group 4 scratched the horizontal range $x_{30} = x_{45} = x_{60}$ and $y_{60} > y_{45} > y_{30}$. The hint revealed that students in Group 2, 3, and 4 (33% and 39% on pre and post-tests) had the confusion between the angles launched to the horizontal range and the altitude of the projectile.

In summary, students had misinterpretation that at the greater angle of the projectile is launched at, the greater horizontal range of the projectile flies. Moreover, students have the confusion between the angle launched to the horizontal range and the altitude.

Table 3.7: Summary of students' misconceptions revealed in this study

Item	Misconceptions	Scientific ideas	Other references
1.1	A vector to represent instantaneous velocity lays over trajectory and consists of non vectorial components.	A vector to present instantaneous velocity of a projectile is a contact line with the parabolic path at a given point. It consists of two vectorial components $\vec{v}_x$ and $\vec{v}_y$.	-
	At higher position, an object has greater velocity (velocity-position confusion)	Instantaneous velocity is the rate of change in	Hestenes et al., 1992

		position with respect to time.	
	Components of instantaneous velocity of a projectile $\vec{v}_x$ and $\vec{v}_y$ are identical at every point.	$\vec{v}_x$ of a projectile is constant. $\vec{v}_y$ is the rate of change in position with respect to time.	-
2.1	The direction of acceleration follows the direction of motion	The direction of acceleration follows direction of velocity with time.	Tao, 1997, Tao and Gunstone, 1999
	Magnitudes of acceleration and instantaneous velocity are always the same parameter.	Magnitude of acceleration is the change in velocity with respect to time.	Rosequist and McDermott, 1987
	The direction of velocity follows level of y-axis (negative velocity if y <0).	The direction of velocity follows the direction of motion.	-
1.3	Direction of a vector presenting force lays on the projectile trajectory.	Directions of force and acceleration are the same	McCloskey, 1983; Toa, 1997; Toa and Gunstone, 1999; Prescott and Michaelmore, 2004
	A hand force (or thrown force) and reaction force are embedded on a projectile after it lost contact.	There is only gravitational force acting on the projectile.	-
2.1	At the same height, the object falling straight (shorter path) spends shorter time reaching the ground than the object moving in a curve.	At the same height, free fall objects spend the same time to reach the ground.	Prescott and Michaelmore, 2004
	At the same height, an object with initial horizontal velocity (faster) spend shorter time reaching the ground than the object moving without initial velocity.		Prescott and Michaelmore, 2004

2.2	Splashdown speed of two freely falling objects depends on the type of motion (straight or curve).	Splashdown speed of an object depends on the magnitude of its horizontal and vertical components.	-
2.3	Two projectiles with different initial horizontal speed have different vertical accelerations.	Acceleration is the ratio of change of velocity with respect to time.	
3	Impetus acting on the fired ball greater than its weight causes the ball moving in a straight line, then the initial impetus slowly reduces and the downward gravitational force gradually acts on the ball so the net force makes the ball moving in a curve path.	The fired ball moves in a curve path and there is only gravitational force acting on it.	Whitaker, 1983; McCloskey, 1983; Halloun and Hestenes, 1985; Hestenes et al., 1992; Prescott and Michaelmore, 2004
4.1	Observed by a person on the ground, the falling object drops from a plane moving with a constant speed will travel backward and land behind the point of its release.	Observed by a person on the ground, the falling object drops from a plane moving with a constant speed will travel forward in a curve projectile path	McCloskey, 1983; Whitaker, 1983
4.2	Observed by a person on the plane, the falling object drops from a plane moving with a constant speed will travel backward and land behind the point of its release.	Observed by a person on the plane, the falling object drops from a plane moving with a constant speed will travel directly.	-
5	The direction of acceleration points from the higher position to lower position.	The direction of acceleration follows the change of velocity.	Whitaker, 1983; Hestenes et al., 1992;

6	The projectile launched at greater angles will give longer horizontal distance.	At the same level of the starting point, the projectile launched at 45° will give maximum horizontal distance.	-
	The projectile launched at complementary angles will give different horizontal distance.	At the same level of the starting point, the projectile launched at complementary angles will give the same horizontal distance.	-
7	The hand force embedded in the ball leads the ball going straight to hit the target.	There is no hand force embedded with the ball after it lost contact.	Whitaker, 1983; McCloskey, 1983; Hestenes et al., 1992; Halloun and Hestenes, 1985; Hestenes et al., 1992; Prescott and Michaelmore, 2004

3.2 Phase II: design and apply IBL procedure

3.2.1 Design lesson plans, instruments, and documents

We designed the Inquiry-Based Learning (IBL) procedure on projectile motion. The procedure consists of 1) 4 lesson plans including 6 steps of IBL approach (one lesson plan for one period, 45 minutes), 2) teaching instruments (quiz, worksheet and demonstration set-up) for each period. The lesson plans were designed based on Cambodian students' misconceptions found in our preliminary works, and some parts were reported (Piten et al., 2017) in publication part of the book.

Here, we present 2 lesson plans, which address the students' misconceptions, on flight time, splash down speeds, and accelerations of two freely falling objects fly at the same height with different initial velocity to reach the ground. Another lesson plan we designed to enhance student learning on projectile altitude and horizontal range. The other two are in appendix D, in which we addressed students' misconception on drawing direction and magnitude of instantaneous velocity as well as projectile trajectory.

The demonstrative devices and teaching tools to address students' misconceptions on flight time, splashdown speed, and acceleration of two freely falling objects flying at the same high with different initial horizontal velocities

Designed IBL procedure was applied to enhance student learning on flight time, splashdown speeds, and accelerations of two freely falling objects flying at the same high with different initial horizontal velocities. Aforementioned, our preliminary works found that students misinterpreted that time flight of the vertical motion and the projectile motion depends on motion type. They define that the vertical motion is free fall, but the projectile is not the free fall motion. Theoretically, both motions are free fall acted by only gravitational force and ignoring air resistance. Moreover, some students misunderstood that the vertical motion flies shorter path than projectile motion so they spend different flight time reaching the ground. In scientific idea both motions take the same time to reach the ground because the projectile motion flies longer path and in a greater splashdown velocity than the vertical motion. Some students declared that both motions spend different flight time because of the difference in the initial horizontal velocity (Piten et al., 2017). Moreover, students misinterpreted that the splashdown velocity and acceleration of two freely falling objects depend on it path and initial horizontal velocity. Relevant instruments designed to improve students learning the concepts are described in the following.

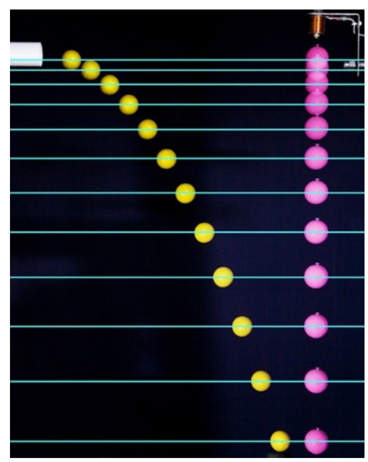
(a) Key question (2)

Quiz 2: The independent of vertical and horizontal components

Quiz 2 (5 min.)

ការណុងបាញ់កូនបាល់B តាមទិសដេកដោយល្បឿន$v_0 = 20m/s$ បាញ់ព្រមគ្នាជាមួយនឹងកូនបាល់ A ទម្លាក់ដោយសេរី ក្រោមកម្ពស់ $H = 80m$ ។

ក) តើបាល់មួយណាធ្លាក់ដល់ដីមុន? ហេតុអ្វី?
ខ) តើបាល់មួយណាល្បឿនធ្លាក់ដល់ដីធំជាង? ហេតុអ្វី?
គ) តើសំទុះរបស់វាស្មើគ្នាឬទេ? ហេតុអ្វី?



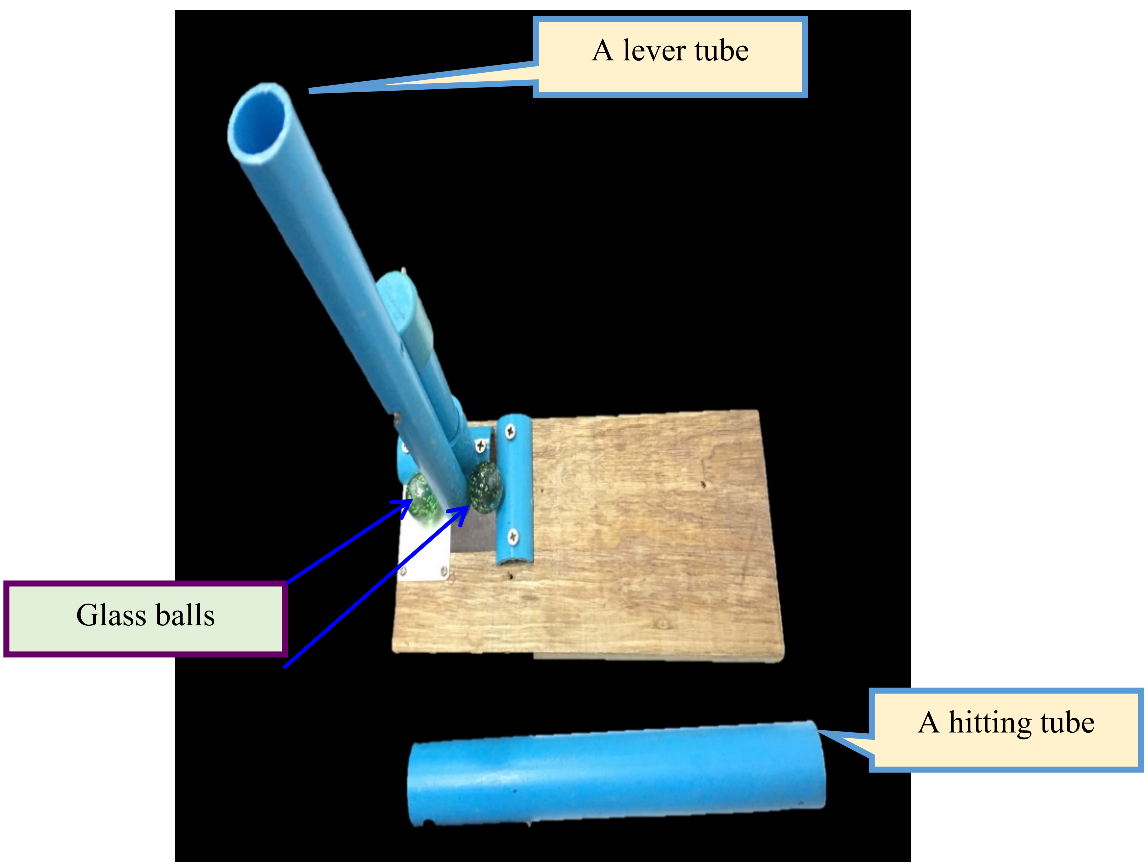
A canon shoots the ball with the horizontal speed 20m/s at the same time with a ball dropping at the same height (H=80m).

a) Which ball will reach the ground first (shooting ball or dropping ball)? Give your reasons?
b) Which ball has the greater splash-down velocity? Give your reasons?
c) Are their accelerations equal? Give your reasons?

b) Demonstration set-up of independent horizontal and vertical components

The demonstration set-up of the horizontal and vertical components of the projectile was integrated in IBL procedure. It was seen as independent variables components and students compared the flight time, splashdown velocities and accelerations of two freely falling objects flying at the same height with different initial velocity to reach the ground by their eyes, ears, and slow-motion.

At the edge of the board there is a hole, when the top of the tube is hit; the marble balls, one is dropped from the hole and another is launched in the horizontal direction. A big piece of white paper is placed to get the both marbles ball moving to the ground. A slow-motion camera records the demonstration to allow students to see the marble~~s~~ balls moving at the same time to reach the ground.



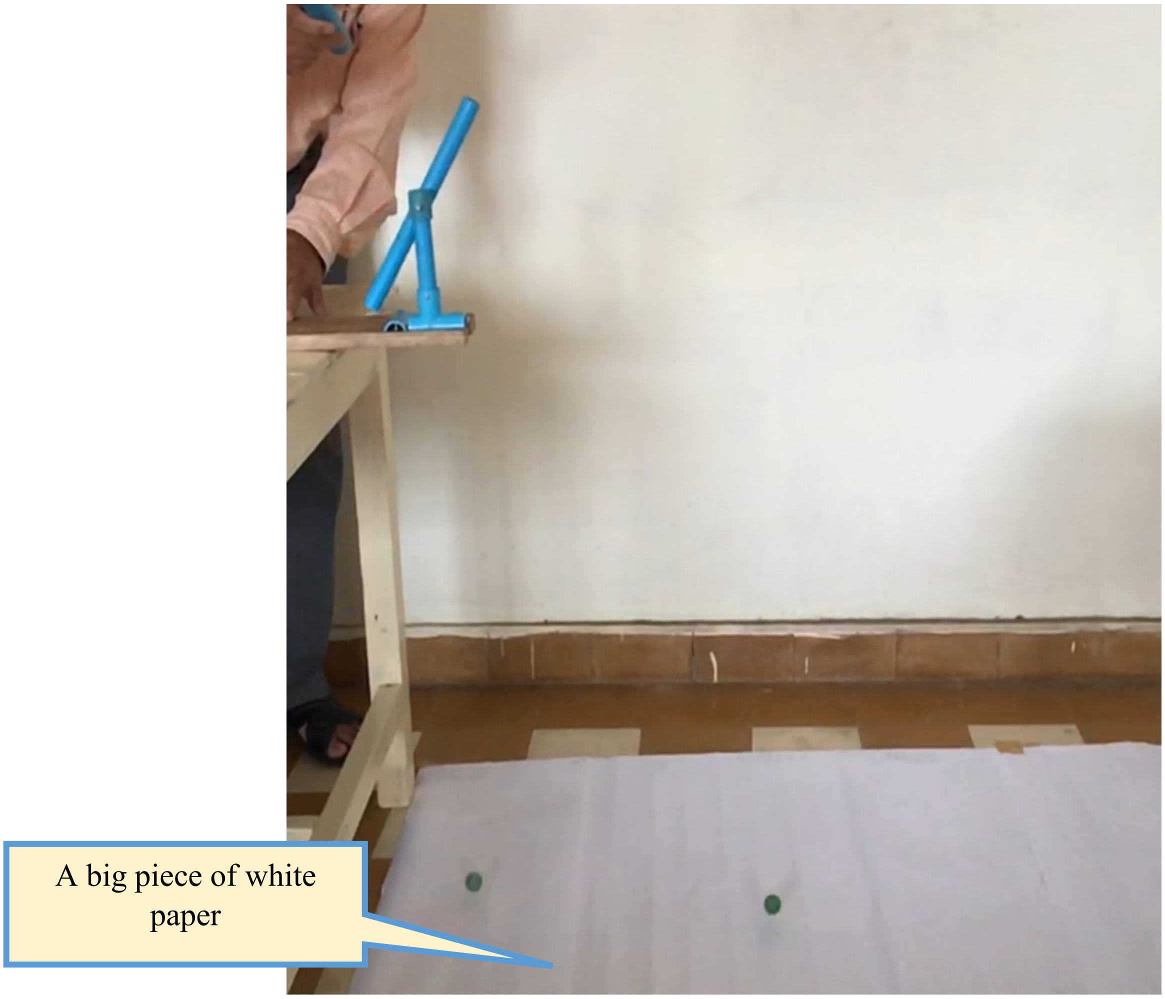


Figure 3.6: A demonstration set-up (1) for the independent of vertical and horizontal components

(c) Worksheet for the independent of vertical and horizontal components

Worksheet 1: for demonstration of the independent of the vertical and the horizontal components

Worksheet 1

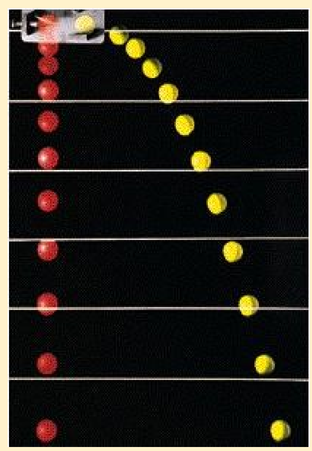
I. Objective: វត្ថុបំនង

- សិស្សប្រៀបធៀបរយៈពេលធ្លាក់រវាងអង្គធាតុធ្លាក់ដោយគន្លងត្រង់ នឹងធ្លាក់ដោយគន្លងកោងបាន យ៉ាងត្រឹមត្រូវ តាមរយៈលទ្ធផលពិសោធន៍។ (Students compare the flight time of a dropped object and a launched object with initial horizontal velocity moving at the same level and at the same time)
- សិស្សប្រៀបធៀបល្បឿនធ្លាក់ដល់ដី របស់អង្គធាតុធ្លាក់ទាំងពីរ និង សន្និដ្ឋានអំពីសំទុះ របស់វា បានច្បាស់លាស់។ (Students compare correctly the splashdown speeds between the object moving in a straight path and a curve path)
- សិស្សស្រាយបញ្ជាក់ចម្ងាយធ្លាក់ និង ល្បឿនចុងក្រោយធ្លាក់ជិតដល់ដីបានត្រឹមត្រូវកាលណាកម្ពស់ធ្លាក់ខ្ពស់ ជាងមុន។ (Students identify the horizontal range of an object moving in a curve path and compare between the splashdown speed of the object moving in a straight path and a curve path when we increase the height of flying)

តំណើរការពិសោធន៍ (the demonstration)

សំនួរគន្លឹះ (Key questions)

ការណុងបាញ់កូនបាល់ A តាមទិសដេកដោយល្បឿន v_0 បាញ់ព្រមគ្នាជាមួយនឹងកូនបាល់ B ទម្លាក់ដោយសេរី ក្រោមកំពស់ H ដូចគ្នា។ ក) តើបាល់មួយណាធ្លាក់ដល់ដីមុន? ហេតុអ្វី?



ខ) តើបាល់មួយណាមានល្បឿនធ្លាក់ដល់ដីធំជាង?

ហេតុអ្វី?

គ) តើសំទុះរបស់វាស្មើគ្នាឬទេ? ហេតុអ្វី?

ឃ) ប្រសិនបើគេបាញ់កូនបាល់A តាមទិសដេក ដោយល្បឿនv_0 នៅកម្ពស់H' ខ្ពស់ជាងមុន។ តើចម្ងាយធ្លាក់ និង ល្បឿនធ្លាក់ដល់ដី របស់វាប្រែប្រួលឬទេ? ព្រោះអ្វី? ចូរស្រាយបញ្ជាក់រូបមន្ត?

A cannon launches a ball (A) with the initail horizontal velocity at the same time and at the same height with the one which is dropped (B). 1) Which ball will reach the ground first? Give your reasons? 2) Which ball have the greater splashdown speed? Give your reasons.

3) Are their accelerations equal? Give your reasons?

4) At the same initial horizontal speed and if the height of the launched ball is increased, does its splashdown speed increase? How ?

a) <u>សម្មតិកម្ម (Hypothesis)</u>

ចំពោះចលនាទន្លាក់សេរី (the vertical motion) $\boldsymbol{H = \frac{1}{2}gt^2 + v_{0y}t}$ (កម្ពស់ធ្លាក់)

$\boldsymbol{x = v_{0x}t}$ (ចម្ងាយធ្លាក់)

b) <u>ឧបករណ៍ពិសោធន៍ (tool)</u>

…………………………………………………….

c) <u>តំណើរការពិសោធន៍ (demonstration of the independent vertical and horizontal components)</u>

....

....

d) <u>លទ្ធផល និង គំរូ (results and models)</u>

<u>លទ្ធផល (results)</u>

យើងប្រៀបធៀបរយៈពេលរវាង កូនបាល់ធ្លាក់ជាកន្លងត្រង់ និង ធ្លាក់ជាកន្លងកោង (we compare the flight time of independent of the vertical and the horizontal components moving at the same level and at the same time)

t_1 ………….t_2 (equal, greater, smaller). Why? ....

យើងប្រៀបធៀបល្បឿនធ្លាក់ជិតបុកដី រវាង កូនបាល់ធ្លាក់ជាកន្លងត្រង់ និង ធ្លាក់ជាកន្លងកោង (we compare the splashdown speed of two freely falling objects one drops and another flies with initial horizontal speed.)

v_1 ……………v_2 (equal, greater, smaller). Why?..

តើសំទុះរបស់វាស្មើគ្នាឬទេ? Are their accelerations equal? ហេតុអ្វី? why?.......................................

ប្រសិន គេបាញ់កូនឃ្លី A នៅរយៈកម្ពស់ខ្ពស់ជាងមុន។ តើល្បឿនធ្លាក់ជិតបុកដីប្រែប្រួលឬទេ? ហេតុអ្វី? ចូរស្រាយបញ្ជាក់រូបមន្ត? (At the same initial horizontal speed and if the height of the launched ball is increased, does its splashdown speed increase? How ?

<u>**Model (equations)**</u>

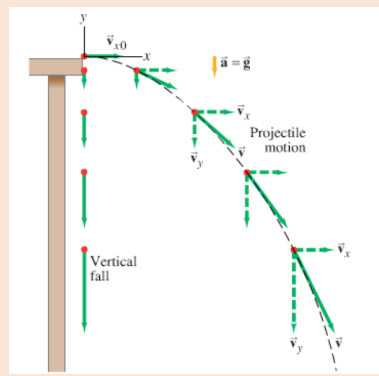
$$\boldsymbol{H = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2H}{g}}}\ , \quad \boldsymbol{x = v_{0x}t \Rightarrow v_{0x} = \frac{x}{t}}\ , \ \boldsymbol{v_y = \sqrt{2gH}}$$

$$\boldsymbol{v_{total} = \sqrt{(v_x)^2 + (v_y)^2}}$$

(d) Homework for the independent of vertical and horizontal components (2)

Homework 2: The independent of the vertical and the horizontal components

ច្រាំងចោទមួយកម្ពស់H ពីផ្ទៃទឹក កីឡាករហែលទឹក A និង B ដែលមានម៉ាស និង
រៀងរៅដូច គ្នា។ កីឡាករ A ទម្លាក់ខ្លួនដោយគ្មានល្បឿនដើម v_0 ចូលក្នុងទឹក។ កីឡាករ
B រត់ពីចម្ងាយដោយល្បឿនដើម v_0 ដើម្បីលោតចូលក្នុងទឹក ក្នុងពេលតែមួយជាមួយ
កីឡាករ A ដូចបង្ហាញក្នុងរូប



1) តើកីឡាករណាធ្លាក់ដល់ផ្ទៃទឹកមុន? ហេតុអ្វី?
ចូរស្រាយបញ្ជាក់ពីរូបមន្ត?
2) តើកីឡាករមួយណាដែលមានល្បឿន
ធ្លាក់ដល់ផ្ទៃទឹកធំជាង? ហេតុអ្វី?
ចូរស្រាយបញ្ជាក់ពីរូបមន្ត
3) តើសំទុះធ្លាក់ដល់ផ្ទៃទឹករបស់កីឡាករ
ទាំងពីរស្មើគ្នារឺទេ? ព្រោះអ្វី?

At the top of the cliff athlete A drops straight down and athlete B runs off the cliff with an initail horizontal speed as shown in the figure. (Simultaneous event)

1) Which athlete will reach the water first? Give your reasons.
2) Which athlete has the greater splashdown speed? Give your reasons.
3) Are the acelerations of the two athletes equal? Give your reasons.

3.2.2 Apply IBL procedure

Our first lesson plan, we designed to help students' learning on flight time, splashdown speed, and acceleration of two freely falling objects at the same height with different initial horizontal velocities. Two freely falling objects spend the same duration of time to reach the ground. The object flies with initial horizontal velocity has greater splashdown speed than the object without initial velocity. Both objects fly with the same acceleration to the ground. Moreover, another the lesson plan we designed to help students to learn on the horizontal distant and the altitude of a projectile. Stating at the same level, the projectile lunched at 45° to the horizontal plane has the theoretically maximum range; the identical projectile lunched at 60° to the horizontal plane has higher altitude than 30° and 45°; and the identical projectiles launched at complementary angles (i.e., 30° and 60°) reach the same range.

Apply IBL procedure to help students learning on independent of vertical and horizontal components

I. The objectives

Knowledge: Students compare correctly flight time, splashdown speeds, and accelerations of the two freely falling objects at the same height with different initial horizontal velocities following the IBL procedure and the textbook.

Skill: Students apply correctly flight time, splashdown speeds, and accelerations of the two freely falling objects at the same height with different initial horizontal velocities following the demonstration.

Attitude: Students interested with the demonstration of the independent of vertical and horizontal components, which matches to the situation in daily life.

II Content

Chapter 1: Mechanics, Lesson 1: Motion in space

1.1 Projectile motion

a) The comparison of fly time, splashdown velocities, and accelerations between two freely falling objects at the same height with different initial horizontal velocities.

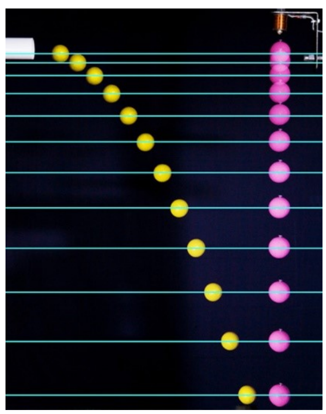
III. Instruments

-Student textbook at page 5-6 published in 2009

- Teacher book and quiz

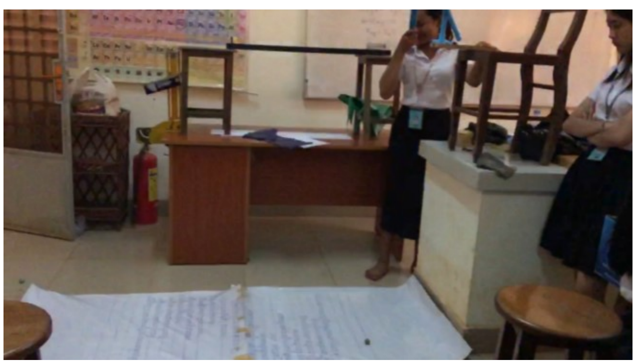
- A set-up for demonstration of the independent the vertical and the horizontal components

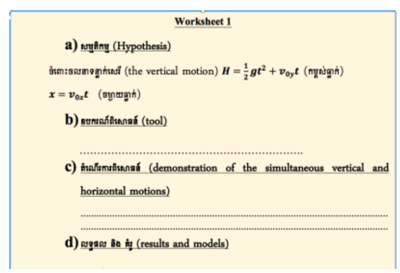
IV The instruction process (45 min.)

IBL procedure	<u>Teacher and students activities</u>
(1) <u>Key questions 1</u> **<u>Quiz (5 min.)</u>** A canon shoots the ball with horizontal speed 20m/s at the same time with a ball dropping at the same height H=80m (simultaneous event). a) Which ball will reach the ground first (shooting ball or dropping ball)? Give your reasons. b) Which ball has the greater splash down velocity? Give your reasons. c) Are their accelerations equal? Give your reasons. 	Students do the quiz. 
<u>(2) Hypothesis (5min.)</u> a) Some students believe that ball A will reach the water first because ball A moves straight, which is shorter path then B. And some thought that ball A will reach the water first because of different types of motion. Ball A moves as a free fall and B moves as a projectile motion. Some think that ball A has no initial velocity so it will reach the water first. b) Few students give the correct answer that both balls reach the water at the same time. Some give incorrect reasons that B has greater velocity than A because B has an initial force. Some state that because ball B is shooting has a greater acceleration. c) Some students believe that both accelerations are not equal because of the both balls move in the different	Students' responses are our hypothesis.

<table>
<tr><td>paths.</td><td></td></tr>
<tr><td>(3) <u>Investigation (15 min.)</u>
A few students do the demonstration

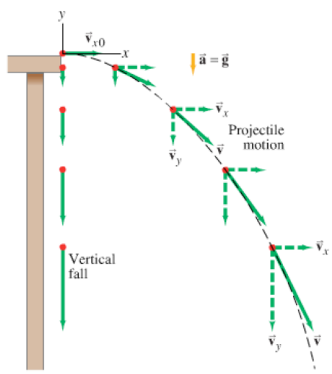
</td><td>- A few students do the demonstration and the others do the investigation.
- Students have to observe by their eyes and their ears to record two freely falling balls fly at the same height to the ground with different initial horizontal velocities. The sound of two balls crust with the ground at the same time.
- Students use a small camera to record the slow-motion.</td></tr>
<tr><td><u>(4) Analysis (10 min.)</u>
The results are analyzed based on the demonstration set-up and the video recoding.

</td><td>Students analyze the results from the demonstration and slow-motion recording and then students take notes on the worksheet.


Worksheet 1
a) (Hypothesis)
(the vertical motion) $H = \frac{1}{2}gt^2 + v_{0y}t$
$x = v_{0x}t$
b) (tool)
....
c) (demonstration of the simultaneous vertical and horizontal motions)
....
....
d) (results and models)</td></tr>
<tr><td><u>(5) Modeling (5min.)</u>
Teacher asks students to draw the conclusion on the white-board for the modeling.

Teacher elicits the equations of both balls flight time.
Ball A drops at height (H)
$$H_A = \frac{1}{2}gt_A^2$$
Ball B is shot out of the cannon at hight (H)
$H_B = \frac{1}{2}gt_B^2 + v_{0y}$, but $v_{0y} = 0$, $H_A = H_B$
So $t_A = t_B$</td><td>Students draw the conclusion on the white-board for the modeling.

</td></tr>
</table>

<u>(6) Evaluation (5min.)</u> -Teacher looks roughly at students' answer sheets and does the evaluation. -Teacher gives students feedback	Students correct their answer and take a note.
<u>Homework</u> At the top of the cliff athlete A drops straight down and athlete B runs off the cliff with an initail horizontal speed as shown in the figure. (Simultaneous event) 1)Which athlete will reach the water first? Give your reasons. 2)Which athlete has the greater splashdown speed? Give your reasons. 3) Are the acelerations of the two athletes equal? Give your reasons. 	Students do homework at home.

The demonstrative devices and teaching tools addressing students' misconceptions for horizontal range and altitude of a projectile

Based on the misconception present in Table 3.3, we designed a quiz, the shooting-gun for the demonstration, and a worksheet. Shortly, many student believed that the object is launched at the greater angle, the greater range the object flies. Theoretically, 1) projectile lunched at 45° to the horizontal plan has the maximum range, 2) the projectile lunched at 60° to the horizontal plan has higher altitude than 30° and 45°, and 3) two identical projectile launched at complementary angle (i.e., 30° and 60°) have the same range.

a) Key question (4)

In the quiz, we ask students to identify the angle launched to the maximum horizontal range and the complementary angles of the projectile. The last question we ask students to draw the parabolic path of 45 degree, 30 degree and 60 degree to recognize the projectile altitude and the horizontal range.

Quiz 4 (5 min.)

1) តើគេត្រូវបាញ់ក្រោមមុំប៉ុន្មានទើបបានចម្ងាយធ្លាក់អតិបរិមាក្នុងចលនាគ្រាប់បាញ់?

1)Which angle is the ball launched to reach the maximum horizontal range in projectile motion?

2) តើគេត្រូវបាញ់ក្រោមមុំប៉ុន្មានខ្លះ ដែលអាចទទួលបានចម្ងាយធ្លាក់ស្មើគ្នា?

2) What angles are complementary in projectile motion?

3) ចូរគូសបង្ហាញ សំនួរពីរ ខាងលើ កាលណាល្បឿនបាញ់$v_0 = 25m/s$

3) Draw 2 questions above with speed $v_0 = 25m/s$

(b) Demonstration set up addressing students' misconceptions for horizontal range and altitude of a projectile

A ball was shot from spring gun, which varies 3 different speeds but in our demonstration, the ball was shot at the same speed and at the different angles, which are 30°, 45° and 60°. A protractor was provided to measure the angle launch. Three pages of papers and the carbon papers were placed to mark the ball dropped. The dots on the white paper was marked by the ball launched. A ruler was measured the horizontal range of the ball flew from the spring gun to the dot. So the students compared the horizontal range from each angle.

Figure 3.7: Spring gun shooting of the projectile with the same initial velocity (2)

<u>(c) Worksheet addressing students' misconceptions for horizontal range and altitude of a projectile</u>

Worksheet 1: Spring gun shooting of the projectile with identical velocity

Worksheet 3

I. វត្ថុបំនង (objective)

- សិស្សកំនត់មុំបាញ់ដែលធ្លាក់បានចម្ងាយអតិបរមារបស់ចលនាគ្រាប់បាញ់បានយ៉ាងត្រឹមត្រូវតាមរយៈ លទ្ធផលពិសោធន៍ (Students identify the angle launched to the maximum horizontal range of the projectile)
- សិស្សកំណត់សំគាល់ពីចម្ងាយធ្លាក់ របស់មុំបំពេញមានតម្លៃស្មើគ្នា និង កម្ពស់ឡើងរបស់មុំបំពេញរបស់ ចលនាគ្រាប់បាញ់បានយ៉ាងត្រឹមត្រូវតាមរយៈលទ្ធផលពិសោធន៍។ (Students recognize correctly the horizontal range and altitude of the complementary angles of the projectile by following the demonstration)

II. តំណើរការពិសោធន៍ (Demonstration)

a) សំនួរគន្លឹះ (Key questions)

តើតម្លៃមុំប៉ុន្មានបាញ់បានចម្ងាយអតិបរមា(ល្បឿនបាញ់មានតម្លៃស្មើរគ្នាៗ)

…………………………………………

What is the angle of the projectile launched to the maximum horizontal range?

ចូរវាស់តម្លៃចម្ងាយធ្លាក់របស់មុំបំពេញ ដែលបានមកពីកាពិសោធន៍ហើយប្រៀបធៀប

What are the angles of the projectile launched to the same horizontal range?

$\theta = 30°$ and $\theta =$………………… …,

$\theta = 35°$ and $\theta =$………………,

$\theta = 40°$ and $\theta =$……………… ,

$\theta = 45°$ and $\theta =$ ………………,

b) សម្មតិកម្ម (Hypothesis)

ចម្ងាយធ្លាក់ (Horizontal range);

$$x = \frac{2v_0^2\ sin\theta cos\theta}{g} = \frac{v_0^2\ sin2\theta}{g}$$

$$sin30 = cos\ \dots\dots\dots.?$$

Figure 3.5b: Spring gun shooting of the projectile with the same initial velocity

c) ឧបករណ៍ពិសោធន៍(tools)

....

d) ដំណើរការពិសោធន៍ (Describe the demonstration set up)

....

....

e) លទ្ធផល និង គម្រូ (Results and models)

លទ្ធផល (Results)

....

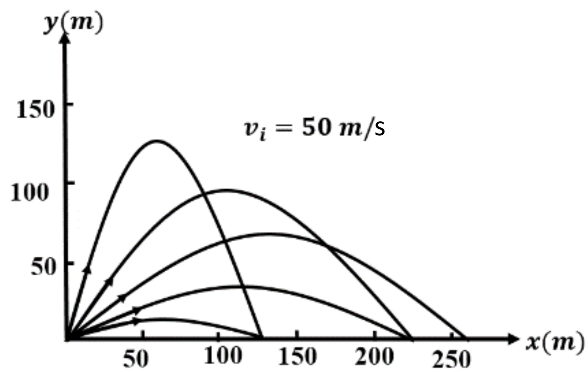
……………….......

R_{30} =…………………………….

R_{60} =…………………………….

R_{45} =..

គម្រូ (models)



ចូរបកស្រាយ មុំបំពេញ ដែល ចលនាគ្រាប់បាញ់ បាញ់ បានចម្ងាយស្មើគ្នា

How can you define the horizontal range of the complementary angles?

តាមរូបមន្ត $x = \frac{2v_0^2 \cos\theta \sin\theta}{g}$

$\cos 15° = \sin$ ....………..

$\cos 25° = \sin$ ....………..

$\cos 30° = \sin$ ....………..

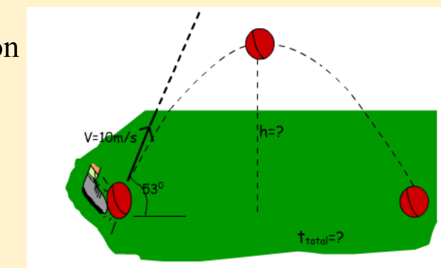
$\cos 45° = \sin$ ....………..

<u>d) Homework addressing students' misconceptions for horizontal range and altitude of a projectile</u>

<u>Homework 4</u>

ក្មេងប្រុសម្នាក់ទាត់បាល់ អោយផ្លាស់ទីជាចលនាគ្រាប់បាញ់ក្រោមមុំ 53° ធៀមនិងទិសដេក និង ល្បឿនដើម 10 m/s។ គណនាកំពស់ឡើងអតិបរមារបស់បាល់ ចម្ងាយធ្លាក់របស់បាល់ និង រយៈពេលធ្លាក់ដល់ដី។

កំណត់តម្លៃមុំបាញ់ដែលធ្លាក់បានចម្ងាយស្មើនិងមុំ 53° (មុំបំពេញ)។ ($sin53° = 0.8$ and $cos53° = 0.6$)



John kicks the ball and the ball does projectile motion at an angle of 53° to horizontal direction.

Its initial velocity is 10 m/s.

-Find the maximum height it can reach, horizontal displacement, and total time required for this motion. ($sin53° = 0.8$ and $cos53° = 0.6$).

-Find another angle launched which is the same horizontal range with 53° angle launched. (complementary angles)

Apply IBL procedure to help students learning on horizontal range and altitude of a projectile

I. The objectives

Knowledge: Students judge the maximum horizontal range and the horizontal range at complementary angles of the projectile following the IBL instruction and the textbook.

Skill: Students reorganize correctly the maximum horizontal range and the horizontal range at its complementary angles of the projectile following the demonstration.

Attitude: Students are interested in a gun shooting to observe the horizontal range, which matches the situation in daily life.

II. Content

Chapter 1: Mechanics, Lesson 1: Motion in space

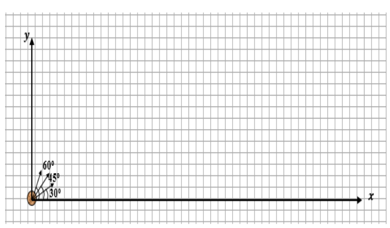
1.2 Projectile motion

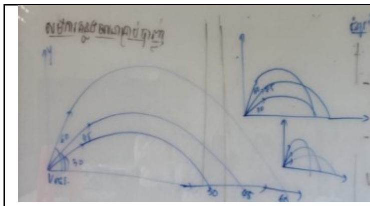
a) Projectile launched at different angles

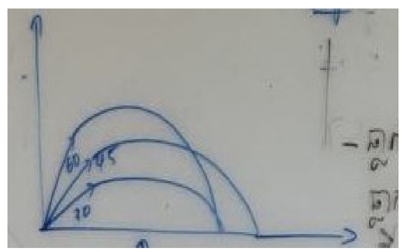
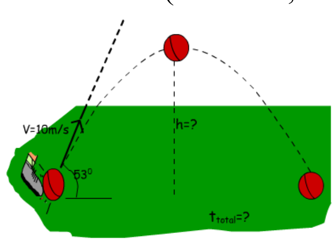
III. Instruments

- Student textbook at page 5-6 published in 2009
- Teacher book and quiz
- Spring gun shooting of the projectile with the same initial velocity at different angles

IV The instruction process (45 minutes)

IBL procedure	Teacher and students' activities
(1) Key questions 1 **Quiz (5 min.)** Draw the parabolic trajectory of the projectile launched with the same initial velocity but at different angles, 30°, 45° and 60° to the horizontal plane.  -What angle of the projectile is projected to get the maximum horizontal range? -What is the complementary angle in the projectile to get the same horizontal range?	Students do the quiz. Teacher asks students to draw on the whiteboard. Students draw the answer on the whiteboard.
(2) Hypothesis (5min.)	- The students' responses in quiz are hypothesis for demonstration. - Teacher asks a few students to draw on

	whiteboard to presents their ideas on quiz.
(3) Investigation (15min.) -Teacher asks students to do the demonstration of gun shooting the ball and others do the investigation. 	- Few students do the demonstration with the guidance from the teacher step by step and others do the investigation. - The demonstration set-up processing 
(4) Analysis (10min.) Teacher asks students to analyze the results from the demonstration. 	Students form into several small group to discuss and analyze the demonstration results. 
(5) Modelling (5min.) After demonstration, a few students are asked to draw on the whiteboard from their analyzing.	- Students draw on whiteboard. - Teacher asks why the projectile launched at 60 degree give similar horizontal range to 30 degree?

	
(6) Evaluation (5 min.) Teacher looks roughly at students' answer sheets and provides the evaluation. -Teacher gives students feedback 	Teacher elicits the range equation of the complementary angles of the projectile. $$x = \frac{2v_0^2\, cos\theta\, sin\theta}{g}$$ $$cos30 = sin60$$ -Students correct their answer and take notes. 
Homework John kicks the ball and ball does projectile motion with an angle of 53º to horizontal. Its initial velocity is 10 m/s, find the maximum height it can reach, horizontal displacement and total time required for this motion. (sin53º=0, 8 and cos53'  	Students do homework at home.

3.2.3 Data collection

In 2017 we applied our IBL procedure and relevant instruction into 3 medium-size high schools located in the city of Cambodia. Around 204 eleventh graders aged 17 were enrolled under topic of the projectile motion following the Cambodian curriculum. Fifty-four students are from Boeung Trabek high school located in the capital city, and 55 students are from Future Bright International School in Siem Reap province. Ninety-five students are from Samdach Decho Hun Sen Suong High School in Tbong Khmum province. Before studying the projectile motion, students have studied the vector concept and one-dimensional motion in grade 10. The researcher obtained IBL procedure of 4 periods (45min per period) instead of teacher in the common classes. Two weeks before and after teaching the students did the Conceptual Questions on Projectile motion as pre-test and post-test.

3.3 Phase-III: Evaluation

To clarify the effectiveness of the IBL procedure on topic of projectile motion in Cambodian high school context in our study, Conceptual Questions on Projectile Motion were used to assess students' understanding. Moreover, two kinds of statistics were used to evaluate the results. The results were discussed in 3 categories by normalized gain, model analysis and patterns of students' ideas, which are described in chapter IV.

Chapter IV
Results and discussion

The results of the IBL procedure are analyzed by applying normalized gain to evaluate students' improvement. Moreover, model analysis is implemented to analyze students' mental models. The diagonals of class density matrix show the percentage of the students choosing each model and model plot shows the movement of the model points before and after teaching. At last, we group students' ideas based on the students telling reasons and their drawings before and after classes.

4.1 Using normalized gain to evaluate the IBL procedure

Average normalized gain (<g>) shows how many times of the maximum possible gain of the learner or the difference between post and pre-tests divided by the difference of total and pre-test scores. It shows the level of students' learning improvement.

In 2017, around 204 students did the Conceptual Questions on Projectile Motion (7 items) two weeks before and after the IBL procedure. IBL procedure was designed to address students' misconceptions related to the drawing velocity components; flight time, splashdown speeds and accelerations of two freely falling objects fly at the same height with the different initial horizontal velocities; the horizontal range and the altitude of a projectile and the projectile trajectory. Hence, we present and discuss only those concepts. The concepts, the list of lesson plans, the teaching instruments, and average normalized gain are shown in Table 4.1.

Table 4.1: Summary of the lesson plans and the instruments addressing students' misconceptions, items for evaluation and average normalized gains

Lesson plans	Concepts	Instruments	Items for evaluation	$\langle g \rangle \pm \langle \Delta g \rangle$
1	The vector components of velocity of the projectile	1) Key question 1 2) Picture of playing baseball and basketball 3) Homework 1	1.1	0.33± 0.02
2	Flight time,	1) Key question 2,	2.1, 2.2,	0.51 ± 0.04

	splash down speed, and accelerations of two freely falling objects flying at the same height with different initial velocity	2) Demonstration set-up of independent of horizontal and vertical motion 3) Worksheet 1 4) Homework 2	2.3	
3	Projectile trajectory and initial concept	1) Key question 3 2) Demonstration set-up of a spring car 3) Worksheet 2 4) Homework 3	3, 4, 7	0.31 ± 0.03
4	The horizontal range and altitude of the projectile	1) Key question 4 2) Demonstration set-up of a spring gun 3) Worksheet 3 4) Homework 4	6	0.34 ± 0.03

In item 1.1, we asked students to draw the velocity components at point A, B, C, D, E along the projectile path (see Appendix A). The horizontal velocity of a projectile is constant along the path. The vertical velocity of a projectile is the change of the position with respect to time. The vertical and horizontal velocities of a projectile are independent from each other. Therefore, we analyzed instantaneous velocities and their components separately vertically and horizontally at each point from point A to E as shown in table 4.2.

In Item 6, students are asked to draw the parabolic trajectory of the projectile launched with the same initial velocity but at different angles, 30°, 45° and 60° to the horizontal plane (Define: g is the magnitude of the acceleration due to gravity). A particle moves in two dimensions (vertical and horizontal directions) during free fall, which is called projectile motion. The vertical motion and horizontal motion are independent of each other. The horizontal range $x = v_x t$, v_x is constant and the vertical altitude $y = -\frac{1}{2}gt^2 + v_{0y}t$. At this point, the two-dimensional projectile motion can be analyzed as one vertical component and one horizontal component in a clearer and easier way to tackle the projectile problems. Therefore, we analyzed our results by separating the horizontal range and the vertical altitude into two groups to probe into student ideas and assess the improvement before and after IBL classes.

Table 4.2: Scoring criteria for the concepts of item 1.1, 2, 6, 3, 4, and 7

Items	Theoretical concepts	Scores	Total scores
1.1 (velocity components)	Draw any arrow	1	5
	Draw a horizontal arrow to present horizontal velocity	1	
	Draw a vertical arrow to present vertical velocity	1	
	Draw correct length of horizontal vector at each point	1	
	Draw correct length of vertical vector at each point	1	
2.1 (flight time)	Both divers reach the water at the same time	1	2
	Because both divers move in the same condition as a free fall motion acted by only gravity or proof by some equations such as $H_A = \frac{1}{2}gt_A^2$, $H_B = \frac{1}{2}gt_B^2 + v_{0y}t$, but $v_{0y} = 0$, and $H_A = H_B \Longrightarrow t_A = t_B$.	1	
2.2 (splash down speeds)	Diver B has greater splashdown speed than A.	1	2
	Because diver B has his horizontal initial velocity or proof some the equations such as $v_A = gt$, $v_B = \sqrt{(gt)^2 + (v_{0B})^2}$, $\Rightarrow\ v_A < v_B$	1	
2.3 (accelerations)	Both divers have the same accelerations.	1	2
	Because both divers have the same ratio of the changed velocities over time or both divers are in free fall motion with the same gravity acceleration.	1	
6 (horizontal	The horizontal range, 45° launched is the	1	2

range and altitude of a projectile)	maximum horizontal range, and if launched at the complementary angles of $30° \, and \, 60°$, the object will fly at the same range but shorter than the range at $45°$ ($x_{45} > x_{30} = x_{60}$) (ignoring air resistance).		
	Altitude of the $60°$ launched higher than the altitude of $45°$ and $30°$ launched respectively ($y_{60} > y_{45} > x_{30}$).	1	
3 (projectile trajectory)	A ball fired in the horizontal direction flies following path B (parabolic path).	1	1
4.1 (projectile trajectory)	An observer standing on the ground views a plane flying in a horizontal direction with a constant speed dropping a ball following path D (parabolic path).	1	1
7 (projectile trajectory)	The ball was thrown by a girl to hit the target following path B (parabolic path).	1	1

Based on the scoring criteria in Table 4.2, results for the concepts of the velocity components; flight time, splashdown speeds, and accelerations of two freely falling objects fly at the same height with different initial horizontal velocities; the altitude and horizontal range of a projectile; and projectile trajectory collected with 204 Cambodian students before and after the IBL instruction are shown in Table 4.3.

Table 4.3: Average % pre-score ± SD, Average % post-score ± SD and <g> ± Δg for item 1.1, (3, 4, 7), 2, and 6 results from the IBL instruction (N=204)

Item		Average %pre-score ± SD	Average % post-score ± SD	<g> ± Δg
1.1		9.9 ± 1.2	39.8 ± 2.1	0.33 ± 0.02
3, 4, 7		31.0 ± 3	52.0 ± 2	0.31 ± 0.03
2	2.1	3.9 ± 1.5	68.4 ± 2.9	0.67 ± 0.03
	2.2	25.0± 2.7	51.0 ± 3.1	0.35 ± 0.05
	2.3	9.0 ± 2.0	55.2 ± 3.0	0.51 ± 0.04
6	6 (Range)	0.5 ± 0.5	47.0 ± 4.0	0.47 ± 0.04
	6 (Altitude)	60.8 ± 3.4	68.2 ± 3.3	0.19 ± 0.01
	6 (Range + Altitude)	0.5 ± 0.5	34.8 ± 3.4	0.34 ± 0.03
$\ll g \gg = 0.39 \pm 0.03$				

4.2 Results for velocity components

4.2.1 Students' correct responses to the direction and magnitude of velocity components

At first, we counted the number of students who drew correctly an arrow to present the directions of horizontal and vertical velocities in Q1.1. The results revealed the difference between pre and post-tests as shown in the graph below:

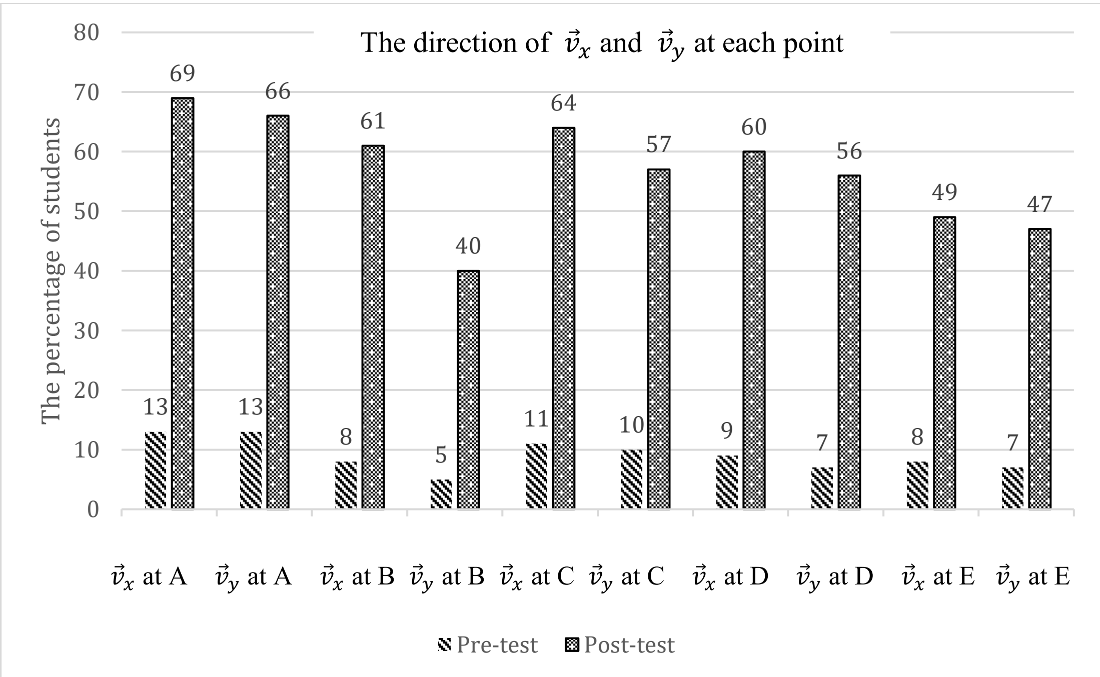


Figure 4.1 The number of students answered correctly the direction of the horizontal and vertical velocity components on pre and post-test at each point (N=204)

As shown by the graph, only 13% of the students on pre-test drew correctly the direction of the horizontal and vertical velocities at point A and it increased to almost 70% of the students after IBL class, which was the highest increase among each point. Moreover, in average of both directions of $\vec{v}_x$ and $\vec{v}_y$, the IBL procedure helped students improve from 15% to almost 50% who drew correctly at every point. First step of designed IBL procedure was to attract students' attention to key questions of the baseball velocity. In the quiz, students were asked to calculate the horizontal and verticle velocities at all points except point E. Teacher would like to challege students on point E. If students understand the concept of the components of the velocity of a projectile well. They will be able to identify correctly at point E. Afterwards, students found that horizontal velocities of a projectile are constant by drawing a horizontal arrow to present the direction and magnitude of a horizontal velocity. In y-axis, students compared the magnitude of vertical velocities at each point. The magnitude of verticle velocities at each point varies following the change of displacement with respect to time. A tangent arrow to the parabolic path is drawn to present the instantaneous velocity. Remarkably, the IBL instruction guided the students to understand better in the direction of $\vec{v}_x$ than the direction of $\vec{v}_y$ at every point. Overall, the IBL procedure attracted students' attention to the direction of $\vec{v}_x$ more than direction of $\vec{v}_y$. It is also possible that Cambodian students had more experiences of motion in x-axis than that in y-axis both in daily life. Further, they had studied one dimensional motion in grade 8 and grade 10.

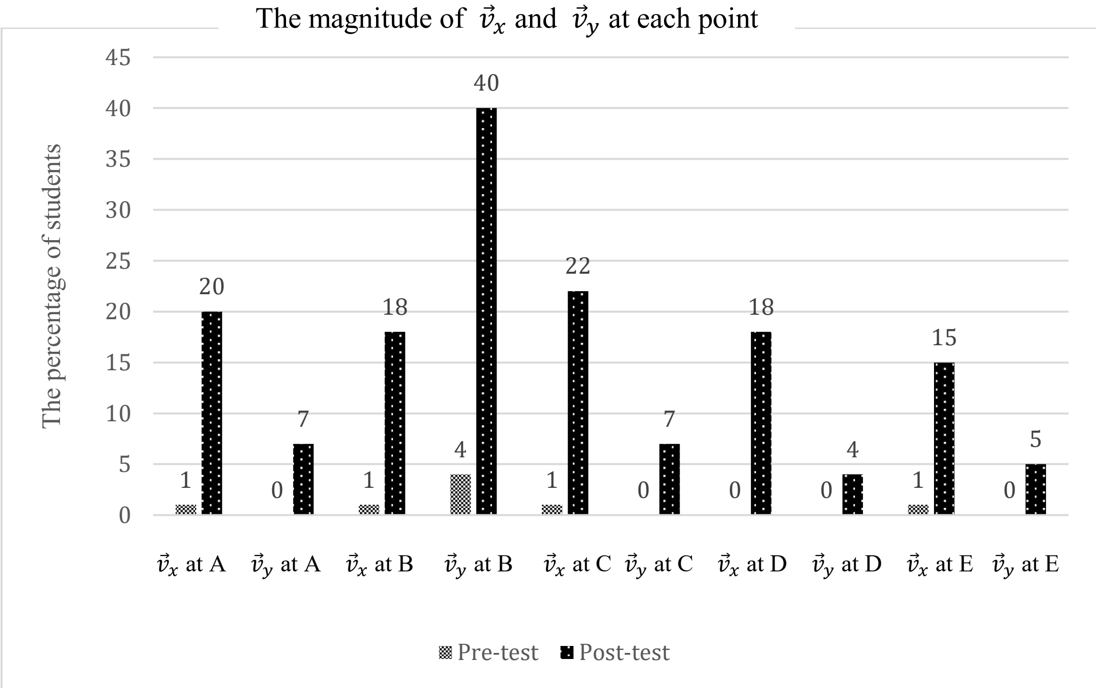


Figure 4.2 The percentage of students drew correctly the magnitude of $\vec{v}_x$ and $\vec{v}_y$ of on pre and post-tests (N=204)

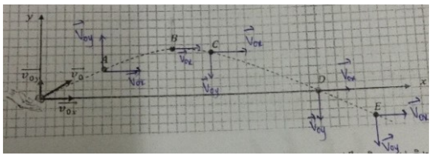
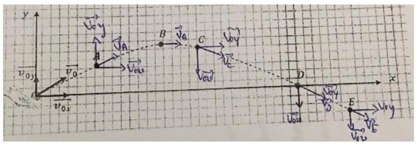
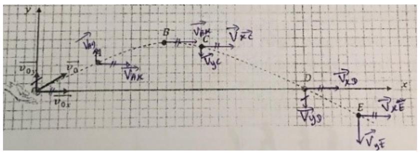
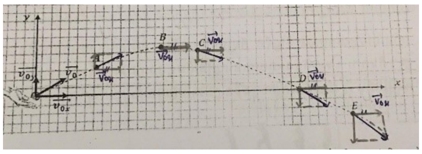
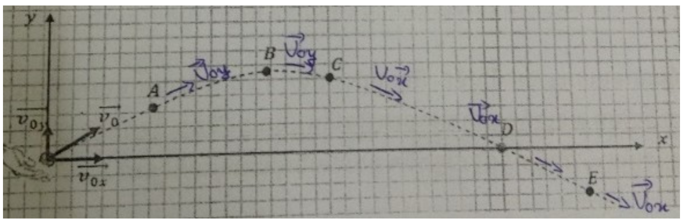
On the other hand, the IBL procedure enhanced students' comprehension with a increase from 4% to 40% of the students who drew the correct magnitude of $\vec{v}_y$ at point B, which is the higest improvement of all points. Students had the idea that no vertical velocity exsists at point B, thus, they drew only one arrow to present the horizontal velocity. Beside this point, we revealed that less than 10% of the students on pre-test drew correcly the magnitude of $\vec{v}_x$ and $\vec{v}_y$, and it still rose to less than 25% of students on post-test. Comparably, only 15% and 5% of the students answerd correctly at point E on the direction of $\vec{v}_x$ and $\vec{v}_y$. It is the smallest percentage of students having the correct answer of all the points.

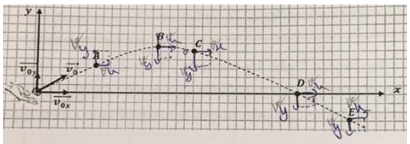
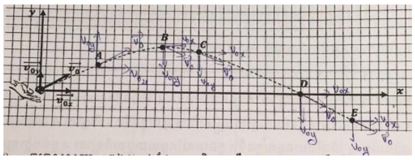
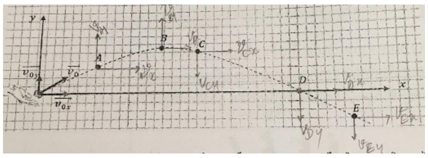
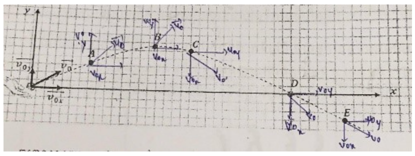
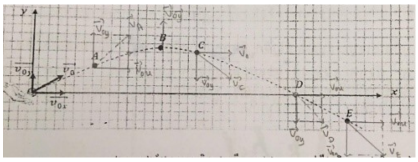
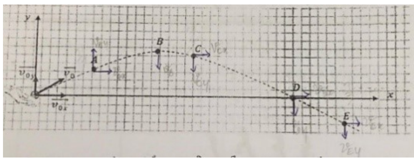
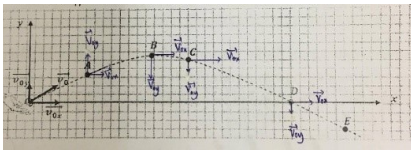
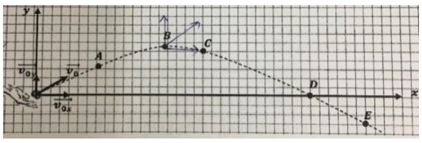
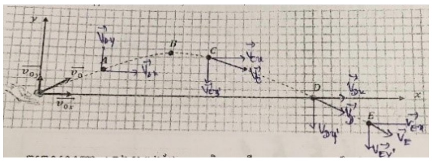
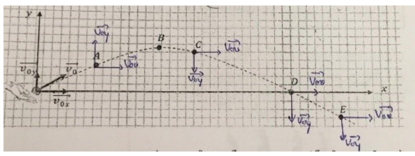
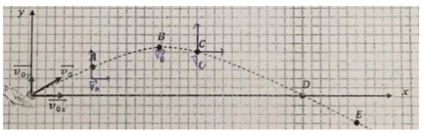
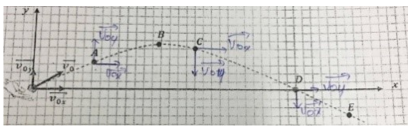
However, the IBL procedures motivated student to understand better in direction of $\vec{v}_x$ and $\vec{v}_y$ than its magnitude.

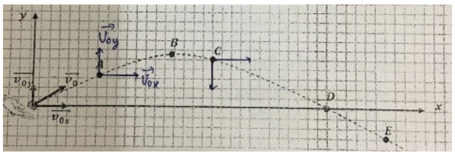
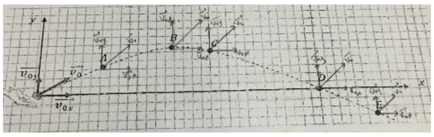
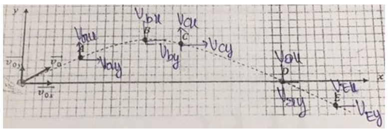
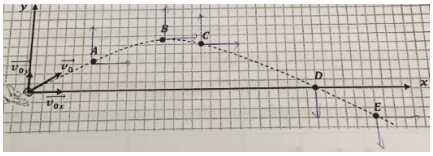
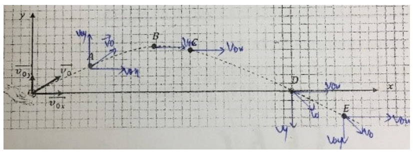
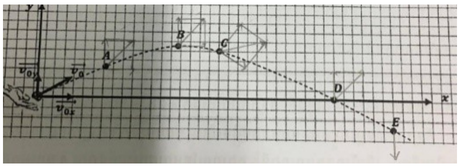
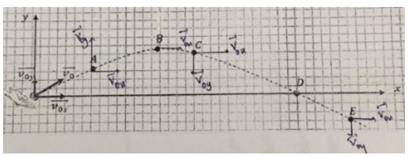
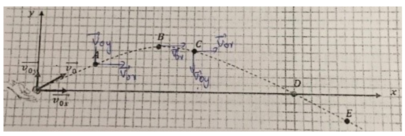
4.2.2 Students' conceptual patterns of velocity components

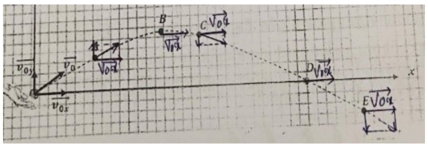
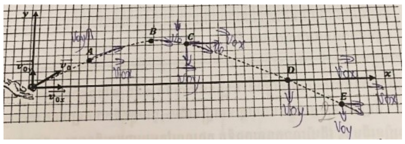
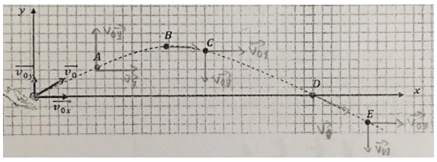
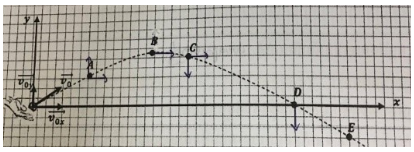
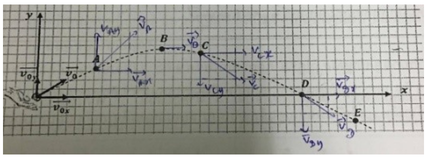
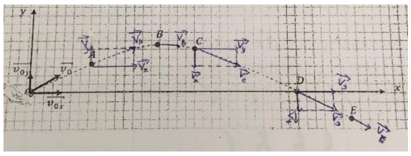
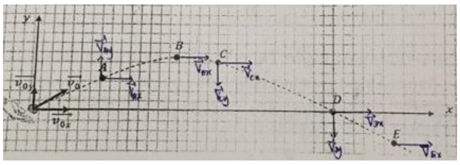
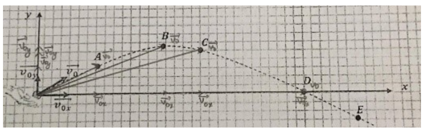
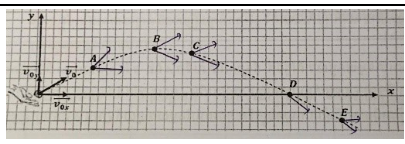
To sum up the results of the vertical velocity direction and the horizontal velocity direction, we group students' patterns on pre and post-tests in order to see overall improvement on both directions. Our result revealed the improvement of students' understanding and several students' misconceptions. We present students' drawing patterns in Table 4.4.

Table 4.4: The patterns of student drawing in direction of $\vec{v}_x$ and $\vec{v}_y$before and after the IBL instruction

Students' patterns of drawing		Pre N=204	Post N=204
Pattern-I Students correctly drew the direction of horizontal and vertical components of the velocity vector at each point but incorrectly drew its length.		2%	20%
 Pre (N=3), Post (N=9) (2 arrows, except point B)	 Pre (N=0), Post (N=31) (3 arrows, except point B)		
Pattern-II Students correctly drew both direction and magnitude of the velocity vector at each point.		0%	2%
 Pre (N=0), Post (N=1)	 Pre (N=0), Post (N=2)		
Pattern-III Students drew one arrow at each point following the curve of the projectile. 		39%	10%
Pattern-IV Students drew downward or upward arrows of v_y at point B		2%	13%

 **Pre (N=0), Post (N=2)**	 Pre (N=0), Post (N=7)		
 **Pre (N=1), Post (N=2)**	 Pre (N=0), Post (N=3)		
 **Pre (N=0), Post (N=3)**	 Pre (N=0), Post (N=2)		
 Pre (N=3), Post (N=0)	 Pre (N=0), Post (N=8)		
Pattern-V Students did not draw at point B		3%	3%
 Pre (N=1), Post (N=1)	 Pre (N=2), Post (N= 0)		
 Pre (N=1), Post (N=0)	 Pre (N=1), Post (N=20)		

<table>
<tr><td colspan="2">
Pre (N=1), Post (N=0)</td><td></td><td></td></tr>
<tr><td colspan="2">Pattern-VI
Students drew the same length and direction of v_x and v_y for all points.</td><td rowspan="2">1%</td><td rowspan="2">6%</td></tr>
<tr><td>
Pre (N=1), Post (N=10)</td><td>
Pre (N=1), Post (N=3)</td></tr>
<tr><td colspan="2">Pattern-VII
Student drew v_y upward at point B and C and downward at D and E</td><td rowspan="3">0%</td><td rowspan="3">3%</td></tr>
<tr><td>
Pre (N=0), Post (N=2)</td><td>
Pre (N=0), Post (N=1)</td></tr>
<tr><td colspan="2">
Pre (N=0), Post (N=2)</td></tr>
<tr><td colspan="2">Pattern-VIII
No drawing at point D</td><td rowspan="2">2%</td><td rowspan="2">6%</td></tr>
<tr><td>
Pre (N=1), Post (N=1)</td><td>
Pre (N=1), Post (N=2)</td></tr>
</table>

 Pre (N=1), Post (N=3)	 Pre (N=0), Post (N=2)		
 Pre (N=1), Post (N=1)	 Pre (N=0), Post (N= 4)		
Pattern-IX Student did not draw any arrow or drew only an arrow following the trajectory or a rightward arrow at point E		3%	11%
 Pre (N=0), Post (N=3)	 Pre (N=0), Post (N=5)		
 Pre (N=0), Post (N=2)			
Pattern-X Other patterns			
		48%	26%

In Table 4.4, on pre-test only 2 % of students drew correctly the direction of horizontal and vertical velocities at each point (pattern I), the designed IBL procedure enhanced students' understanding with the percentage increase to 20% of the students who drew correctly. Moreover, none of the students drew the completely correct arrows before IBL procedure, however, 2% of students at a tiny increase drew the completely correct directions and lengths of the horizontal and vertical velocities (pattern II) after the instruction. Furthermore, the IBL procedure well addressed students' misconceptions about its direction with a drastic decrease from 39% to 10% of students who drew an arrow following trajectory (pattern III) on pre and post-tests.

Interestingly, a slight increase was found from 2% to 13% of students who still drew upward or downward of vertical velocity at point B on pre-and post-tests (pattern IV). Students might have the idea that the object at point B still have vertical velocity by moving upward or downward. It was found that 3% of students still did not draw at point B on pre- and post-tests (pattern V), students thought that the object stops at the highest level at point B without horizontal and vertical velocities. In the IBL class, students were explained that the vertical velocity is 0 ($v_y = 0$) or it stops moving up at the highest point and the object just moves along in x direction with the constant velocity, some students might imagine that $v_x = 0$ and $v_y = 0$ without drawing any arrow to present its direction. Nevertheless, the IBL procedure can help this group of students correct the direction of velocity at all points except point B.

In addition, a small percentage increase was found from 1% to 6% of students who drew the same pattern at each point on pre- and post-tests (pattern VI), the students probably thought that the horizontal and vertical velocities are in identical directions and lengths at each point. On the other hand, only 3% of students were found drawing pattern VII on post-test, they possibly misunderstood that the direction of the vertical velocity follows the level of y-axis (negative vertical velocity if y<0). Besides, a bit increase was discovered from 2% to 6% of students drawing pattern VIII before and after the IBL class, the students perhaps had the misconception that the object hitting x-axis at point D is still with a velocity downward or rightward or following the trajectory. We found that less than 2 % of the students did not draw at point D both on pre and post-tests, they thought that the object stopped at point D when it hit the floor (x-axis). Also, we found that a rise from 3% to11% of the students did not draw at point E (pattern IX). The students might misinterpret that the object reaches and stops at point E which is the last point. Some students drew a rightward arrow or downward arrow or an arrow following trajectory. They thought that at the last point the object has only a rightward or a downward or a following trajectory velocity with no vector components. At the first step (key question) in IBL class students were asked calculated the horizontal and vertical velocities at point A, B, C, and D except point E. The instructor would like to challenge students at point E. However, the challenge was failed and students still remained in guessing at point E. Nevertheless, the IBL procedure was found to help 22% of students to get the sign of learning (Mello et al., 2014) with the evidence of the improvement from their drawing long lines to be the arrows in pattern X. In this case, the students might lack background knowledge of the velocity and vector components, thus, they were not able to draw correct arrows with the right vector concept to represent the velocity.

Overall, the IBL instruction led only 20% of the students drawing correctly both the directions of the vertical and horizontal velocities at all points. It revealed our difficulty to lead the students with low background knowledge of vector concepts and the velocity in one dimension motion to acquire a correct understanding of velocity of projectile motion.

4.2.3 Average normalized gain of directions of velocity components

To examine students' improvement from their initial state, we calculated the average normalized gain based on the scoring criteria for item 1.1 as shown in Table 4.2 above.

After IBL procedure, we revealed the average normalized gain of the direction of velocity components at medium learning gain ($\ll g \gg = 0.5 \mp 0.04$ sd) for item 1.1. To obtain more details, we calculated the average normalized gain of their directions at each point to show students' improvement.

The designed IBL procedure enhanced students' understanding at point A in the upper medium gain region $< g_B >= 0.60 \pm 0.04$, which is the highest among each point by using pair t-test at 0.01 significant level. In this case, the students have the correct idea about the direction of the vertical velocity following the direction of motion by drawing an upward arrow to present vertical velocity ($< g_{Ay} >= 0.61 \pm 0.01$) and a rightward arrow to present horizontal velocity ($< g_{Ax} > = 0.59 \pm 0.01$). In addition, IBL procedure supported students' learning in $\vec{\boldsymbol{v}}_{\boldsymbol{x}}$ direction better than that in $\vec{\boldsymbol{v}}_{\boldsymbol{y}}$ direction.

Table 4.5: The normalized gain of the direction of horizontal and vertical velocities at each point (N=204)

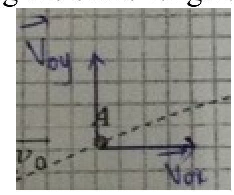
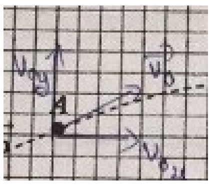
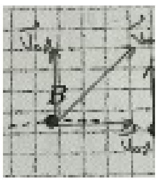
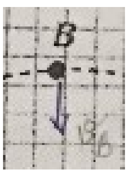
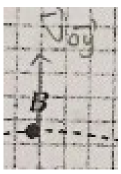
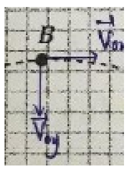
Point	The normalized gain of the direction v_x or v_y	The average normalized gain of the direction of v_x and v_y
A (v_x)	$< g_{Ax} >= 0.59 \pm 0.03$	$< g_A >= 0.60 \pm 0.04$
A (v_y)	$< g_{Ay} >= 0.61 \pm 0.05$	
B (v_x)	$< g_{Bx} >= 0.57 \pm 0.06$	$< g_B >= 0.47 \pm 0.04$
B (v_y)	$< g_{By} >= 0.37 \pm 0.02$	
C (v_x)	$< g_{Cx} >= 0.60 \pm 0.05$	$< g_C >= 0.47 \pm 0.05$
C (v_y)	$< g_{Cy} >= 0.53 \pm 0.04$	
D (v_x)	$< g_{Dx} >= 0.56 \pm 0.03$	$< g_D >= 0.55 \pm 0.03$
D (v_y)	$< g_{Dy} >= 0.53 \pm 0.02$	
E (v_x)	$< g_{Ex} >= 0.45 \pm 0.01$	$< g_E >= 0.44 \pm 0.01$
E (v_y)	$< g_{Ey} >= 0.43 \pm 0.01$	
Average of all points		$\ll g \gg= 0.50 \pm 0.04$

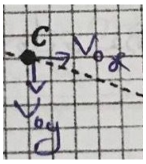
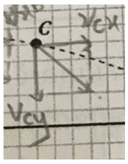
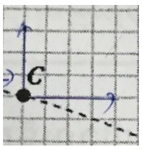
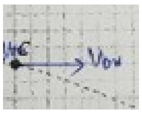
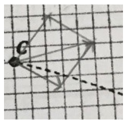
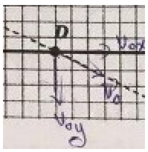
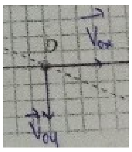
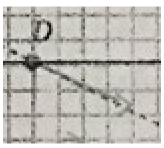
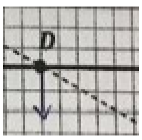
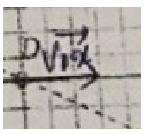
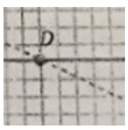
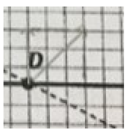
Moreover, at point B ($< g_B >= 0.47 \pm 0.04$), students drew correctly a rightward arrow to represent the horizontal velocity ($< g_{Bx} >= 0.57 \pm 0.06$) and no vertical velocity ($< g_{By} >= 0.37 \pm 0.02$). In this case, the IBL procedure improved students' understanding on the direction of $\vec{v}_x$ better than that of $\vec{v}_y$. It is inferred that students might understand that the object changes its direction at point B and continuing to point C ($< g_C >= 0.47 \pm 0.05$) by drawing a downward arrow to present vertical velocity ($< g_{Cy} >= 0.53 \pm 0.04$) and a right ward arrow to present the horizontal velocity ($< g_{Cx} >= 0.60 \pm 0.05$). It indicated that our teaching method enhanced students' presenting the direction of $\vec{v}_x$ better than that of $\vec{v}_y$. Likewise, when the object continuously drops down at point D and E ($< g_D >= 0.55 \pm 0.03$ and $< g_E >= 0.44 \pm 0.01$), the students drew a downward arrow to present vertical velocity ($< g_{Cy} >= 0.53 \pm 0.01$ and $< g_{Ey} >= 0.43 \pm 0.01$) and a rightward arrow to present horizontal velocity ($< g_{Dx} >= 0.56 \pm 0.01$) and $< g_{Ex} >= 0.45 \pm 0.01$). It revealed that the average normalized gain of direction of $\vec{v}_x$ was greater than that of $\vec{v}_y$ at both point D and E.

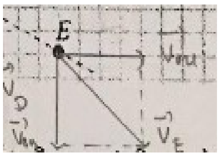
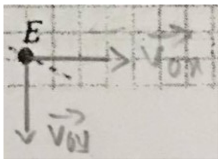
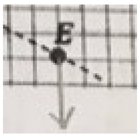
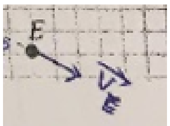
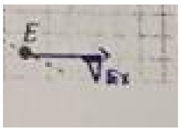
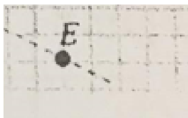
Overall, the results of t-test (p≤ 0.01) showed that the IBL procedure led student improving the best at point A in the medium-gain region in the direction of $\vec{v}_x$ and $\vec{v}_y$, and more interestingly, students performed on direction of $\vec{v}_y$ better than that of $\vec{v}_x$, which is different from point B, C, D, and E, at which students presented the direction of $\vec{v}_x$ better than that of $\vec{v}_y$. On the contrary, at point E students displayed at the moderate level of gain, which is lowest among all points. Therefore, our teaching method remained at medium gain on direction of $\vec{v}_x$ and $\vec{v}_y$.

4.2.4 Studens' conceptual patterns of magnitude velocity components

Table 4.6: The patterns of student drawing in magnitude of $\vec{v}_x$ and $\vec{v}_y$before and after the IBL instruction

Point	Students' drawing	Pre (N=204)	Post (N=204)
A	Pattern I Drew 2 or 3 arrows such as an arrow following the trajectory, a right ward arrow v_x and an upward arrow v_y being the same length.  	4%	23%
	Pattern II Drew an arrow following trajectory.	63%	12%
	Pattern III **Drew correct answer.**	**0%**	**6%**
B	Pattern I Drawing an upward or downward arrow for v_y or, and rightward arrow for v_x (the same length of $v_x$and v_y 6 out of 28 students on post, 12 out of 28 students draw an upward and a rightward arrow)    	6%	17%
	Pattern II **Drew a rightward arrow correctly both direction**	**1%**	**16%**

	and length.		
	Pattern III Drew an arrow following trajectory.	63%	12%
	Pattern IV Did not draw the arrow	6%	4%
C	Pattern I Drew 2 or 3 arrows such as a vector with its xy-components, a right ward arrow v_x and a downward arrow v_y being the same length.  	2%	15%
	Pattern II Students drew an arrow following trajectory	63%	12%
	Pattern III **Correct answer**	**0%**	**7%**
	Pattern IV Other Pre (N=1) Post (N=2)  Pre (N=0) Post (N=1)  Pre (N=0) Post (N=2) 	1%	3%
D	Pattern I Students drew 2 or 3 arrows such as a vector following trajectory and a right ward arrow, a downward arrow that the same length of $v_x$and v_y  	3%	14%
	Pattern II Students drew an arrow following trajectory	63%	12%
	Pattern III **Correct answer**	**0%**	**3%**
	Pattern IV Other     	5%	7%
E	Pattern I	63%	12%

	Students drew an arrow following trajectory		
	Pattern II Students drew 2 or 3 arrows such as a vector following trajectory and a right ward arrow, a downward arrow that the same length of $v_x$and v_y  	0%	11%
	Pattern III **Correct answer**	**0%**	**4%**
	Pattern IV Other	8%	14%
	   		

Before the IBL instruction, 63% of the students drew the arrow following the trajectory without being aware of its magnitude at all points. In contrast, it decreased to 12% of students after the IBL class. At point A, the IBL instruction changed the students' idea to draw a rightward arrow and an upward arrow at the same length to represent the magnitude of the $\vec{v}_x$ and $\vec{v}_y$. The percentage of the students' drawing pattern I increased from 4% to 23%. The students might misunderstand that the magnitude of $\vec{v}_x$and $\vec{v}_y$ is equal. Moreover, only 6% of the students successfully corrected the direction and magnitude of the $\vec{v}_x$ and $\vec{v}_y$. Even though the IBL procedure suggested students calculate the magnitude of $\vec{v}_x$and $\vec{v}_y$ of the projectile at each point (quiz, 5 minutes), the students still lacked their attention to drawing the length of the arrow to present its magnitude. In this case, it pointed out our difficulty that IBL instruction (45 minutes) was still not enough to attract students' attention to drawing the magnitude of $\vec{v}_x$ and $\vec{v}_y$ which is an arrow representing two concepts of its direction and the magnitude. However, IBL procedure helped students' understanding on its direction better than on its magnitude.

At point B, we found another two popular patterns of students' misconceptions after IBL instruction. It increased from 6% to 17% of the students still drawing an upward or a downward arrow to represent the magnitude of $\vec{v}_y$. They might misunderstand that the object moves up or down with the magnitude of $\vec{v}_{0y}$ at the top of the projectile parabola. Moreover, a small reduction from 6% to 4% of the students did not draw the arrow, they perhaps thought that the object would stop at the top of the parabola where the magnitude of $\vec{v}_x$ and $\vec{v}_y$ is zero. Still, the IBL instruction enhanced students from 1% to 16% to draw correctly both the magnitude and the direction of $\vec{v}_y$ which shows greater improvement than that at point A.

At point C, D, and E less than 15% of students on post-test drew the same length of the $\vec{v}_x$and $\vec{v}_y$ in pattern I, which is similar with point A. The students misinterpreted that magnitude of $\vec{v}_x$and $\vec{v}_y$ is equal. Respectively, 3%, 7 %, and 14% of the students on post-test misunderstood that at point C, D, and E remain only magnitude of $\vec{v}_x$ or $\vec{v}_y$ or $\vec{v}$ by drawing only a rightward or upward arrow or an arrow following the trajectory or did not draw in pattern IV. Similarly, the students did not pay attention to its length. Notably, the students thought that the object at point D might hit the ground at x-axis or it might stop at point E which is the last point. And 7%, 3%, and 4% of the students respectively corrected its magnitude at point C, D, and E after the IBL instruction.

To conclude, the IBL instruction motivated students better understanding on magnitude of the $\vec{v}_x$ and $\vec{v}_y$ at point B, but with lower improvement at point A, C, D and E. However, the IBL instruction improved students' understanding on its direction better than its magnitude. We calculate the average normalized gain of it magnitude as shown in the table below.

4.2.5 Average normalized gain of the magnitude of velocity components

Table 4.7: Description of the student's improvement after IBL class on the magnitude of $\vec{v}_x$ and $\vec{v}_y$ (N=204)

Point	The normalized gain of the magnitude of $\vec{v}_x$or $\vec{v}_y$	The average normalized gain of the magnitude of $\vec{v}_x$ and $\vec{v}_y$
A (v_x)	$< g_{Ax} >= 0.19 \pm 0.04$	$< g_A >= 0.13 \pm 0.03$
A (v_y)	$< g_{Ay} >= 0.06 \pm 0.02$	
B (v_x)	$< g_{Bx} >= 0.18 \pm 0.04$	$< g_B >= 0.28 \pm 0.03$
B (v_y)	$< g_{By} >= 0.37 \pm 0.02$	
C (v_x)	$< g_{Cx} >= 0.21 \pm 0.04$	$< g_C >= 0.14 \pm 0.03$
C (v_y)	$< g_{Cy} >= 0.07 \pm 0.02$	
D (v_x)	$< g_{Dx} >= 0.18 \pm 0.03$	$< g_D >= 0.11 \pm 0.02$
D (v_y)	$< g_{Dy} >= 0.04 \pm 0.02$	
E (v_x)	$< g_{Ex} >= 0.15 \pm 0.03$	$< g_E >= 0.10 \pm 0.03$
E (v_y)	$< g_{Ey} >= 0.05 \pm 0.23$	
Average of all points		$\ll g \gg= 0.15 \pm 0.26$

The improvement of understanding on the magnitude of $\vec{v}_x$ and $\vec{v}_y$ at point B is about 0.28 time of maximum possible gain, which is the highest among each point A, C, D, E. In addition, students' improving on the magnitude of $\vec{v}_y$ ($< g_{By} >= 0.37 \pm 0.02$) is much greater than that on the magnitude of $\vec{v}_y$ ($< g_{Bx} >= 0.18 \pm 0.04$). In comparison with point A, C, D, E, students' improving on the magnitude of $\vec{v}_x$ is much greater than that on the magnitude of $\vec{v}_y$.

Overall, the IBL procedure enhanced students' understanding of the directions the magnitude of $\vec{v}_x$ and $\vec{v}_y$ ($\ll g \gg= 0.50 \pm 0.04$) in medium region of gain, however, we met some difficulty in leading students' understanding of its magnitude ($\ll g \gg= 015 \pm 0.02$). Both the directions and magnitude of instantaneous velocity remained in medium gain ($\ll g \gg= 0.33 \pm 0.02$). It reflects that quiz including calculating the magnitude of vertical and horizontal velocities at each point cannot guide students to drawing its direction and its magnitude correctly.

4.3 Average normalized gain of flight time of two freely falling objects at the same height with different initial horizontal velocities

In Table 4.3, we found that our IBL instruction related to flight time of two freely falling objects at the same height with different initial horizontal velocities of item 2.1 improved students' learning 0.67 time of the maximum possible improvement, which is the highest improvement among the items above ($p \leq 0.001$).

In this case, the learning gain of the designed IBL procedure appeared in medium region close to the high region. Therefore, the IBL instruction related to the concept of item 2.1 designed in this study is the one of interactive engagement methods.

At the first step of the designed IBL procedure, we applied a quiz (key question) into classes. The Quiz related to flight time, splashdown speeds, and accelerations of two freely falling objects at the same height with different initial horizontal velocities (concepts of item 2) obtained two purposes

- To elicit students' knowledge, which stimulates our topic.
- To identify students' prior knowledge on the content studied (Hypothesis)

In Cambodian high school context, quiz is a practice testing to attract students' attention. It would be much better than oral questions. Each student in the IBL class used their own ideas considering seriously on the paper-based test because students had their own experiences individually about scores. So they paid much attention to writing down the answer within 5 minutes carefully. Oral test is quite difficult to be integrated into 40-60 students per class. The whole class of students could not answer all of their ideas in oral within 5 minutes. Therefore, we designed the quiz, which included identical concept and different context with the questions as a tool to help teaching and learning. Some researchers also recommended about practice testing such as Roedinger III et al. (2011) who pointed out that testing is not only for assessment but also serves in other purposes such as helping students organize information and form a coherent knowledge. Furthermore, if students are quizzed frequently, they tend to study more and with more regularity. Besides, after students taking a quiz learn more from the relevant step than when they do not take a test. Quizzing also enables better metacognitive monitoring for both students and teacher because it can provide feedback for teacher to identify students' prior knowledge. For students themselves, they can compare their prior knowledge to the context and content study. More importantly, quiz also highlights the gap of the students' knowledge before and after class. For example, if students do the quiz immediately before starting and after finishing the content lesson, the gap improvement of the students will be extracted from the quiz before and after class. It can report how well the class process runs. Moreover, Rawson and Dunlosky (2011) gave a prescription on the basis of the overall patterns of durability and efficiency that students should practice recalling concepts to an initial criterion of 3 correct recalls and then relearn them 3 times at widely spaced intervals. Roediger III and Butler (2011) also reviewed the evidence that retrieval practice occurs during testing and often produces greater learning and long-term retention than studying. Furthermore, Dunloskey et al. (2013) also summarized 10 effective teaching method including practice testing.

In Cambodian context, students were excited to see the independent of vertical and horizontal components. It engaged a few students in doing the demonstration and others did the investigation (step 3), which enhanced students' desire and ability to be self-motivated. It also encouraged students to discover and develop new concepts or new ideas on the concepts of item 2 by analyzing (step 4) the results from the demonstration set-up. In 2014, Zi Shan and colleagues also got the satisfying results of the hands-on experiments which engaged students' intrinsic motivation, commitment, enjoyment and creativity in science. They revealed that hands-on experiments highly benefit students' learning and building on their intrinsic motivation.

Worksheet including concepts of item 2 is a draft facilitating students to take notes or draw a model (step 5) during and after the demonstration step and the investigation step. Student could save the time to take a note or draw on the worksheet. It also facilitated students answer opening questions by filling the gaps and closing questions (problem solving). The designed worksheet consisting of key questions in order to confirm with students' hypothesis and demonstration set-up results. Moreover, modeling equations related to flight time, splashdown speeds and accelerations of two freely falling objects at the same height with the different initial horizontal velocities were provided. Some researchers revealed that the strongest factor perceived by students to impact their learning in a Problem-Based Learning context is the tutoring followed by team and class dynamics, while the influence of the worksheet was rated lowest. They found that student understanding was unaffected by using only worksheet (Choo et al., 2011). However, some other researchers found significant effective learning by applying guided note worksheets as students' facilitator. As the lecture progresses, the guided worksheets provide structure for students to focus on taking notes of the most relevant content. Guided worksheet notes help students better formulate their questions when the lecturers ask questions from the students (Sujarittham et al., 2016; Narjaikaew et al., 2009).

Giving feedback or evaluation (step 6) is an important process for the concepts of item 2 after IBL procedure. Teacher asked students to use the equations to compare flight time of two freely falling objects at the same height with different initial horizontal velocities on the whiteboard. Then teacher gave the feedback by confirming some equations (as shown in the worksheet) related with the demonstration results.

In summary, the designed IBL procedure promoted students learning related to concepts of item 2 (flight time, splash down speed and acceleration of two freely falling objects at the same height with the different initial horizontal velocities) with the effective instruments including a quiz (key questions), a worksheet, and a demonstration set-up.

4.4 Average normalized gain of altitude and horizontal range of a projectile

The IBL procedure, which comprises 6 steps (key question, hypothesize, investigate, analyze, model, evaluate) including quiz, demonstration set-up, worksheet, designed for item 6 in this study, improved students' understanding of the horizontal range and altitude at a low medium gain $\langle g \rangle = 0.34 \pm 0.03$ as interactive engagement. Furthermore, the range of the projectile launched revealed 0.47 time of the maximum possible improvement. It is in a medium gain, a bit higher than 0.3. However, we found that our IBL procedure related to a concept of altitude of the projectile launched at different angles appeared in a low average normalized gain ($\langle g \rangle = 0.19 \pm 0.01$). Students achieved high scores on pre-test for the altitude around 60.8 % compared with the horizontal range 0.5%. Students may have experiences of kicking a ball, spraying water, playing basketball and so on in daily life with the idea that the greater angle the object is launched at, the greater altitude it flies. Students can compare their own height to the ball or water after they kick the ball, spray the water, throw the ball. In this case, the IBL procedure can only motivate students' learning on the horizontal range of the projectile much better than the altitude of the projectile launched at different angles. Based on average normalized gain, students got high score in pre-test (60.8%), which is hard to improve students to 80% or 100% on post-test because from Hake's (1998) empirical data, no course achieved average normalized gain higher than 0.7.

In addition, it is also possible that the object is launched at the greater angle, the greater altitude the object flies, and the idea also guided students to think of the greater horizontal range. After IBL procedure, students got high scores for the projectile horizontal range (47%), which revealed in medium average normalized gain ($<g> 0.47 \pm 0.04$). Clearly, the IBL demonstration set-up (spring gun) for item 6 enabled students to compare the dot on the white paper about the horizontal range by their eyes and the paper reference. Although our spring gun shooting in the air had some bias from horizontal range in the theory, somehow it clearly showed a great difference between the angles of 45 degree and 60 degree in the horizontal range. In the class, students launched a ball at 30 degree and 60 degree angles dropping on the carbon paper to get the dots on the white papers. However, the dots marked by a ball launched at the complementary angles were not at the same point (a very tiny space between the two dots) because of the deficiency of the spring gun and air resistance in the classroom. Then instructor asked students why a projectile launched at 60 degree gives the horizontal range shorter than at 45 degree and it is similar range to 30 degree. Teacher explained the formula $x = \frac{v_0^2(2\sin\theta\cos\theta)}{g}$, and substituted an identical value of the initial velocity at different angles considering the horizontal range. Equations acted as a tool to respond to students' doubts. Students applied their knowledge of equations to identify the target concepts (Teodorescu et al., 2013).

This is a good evidence to convince students by comparing their hypothesis with the theory. Professional physicists conduct experiments to test their own hypothesis or confirm the theory and new discovery (Hu and Zwicke, 2017). The spring gun and the equations were used to confirm the students' hypothesis and confirm with the theory.

The process of launching the ball by spring gun at the different angles is still not enough to visualize the projectile altitude. It did not mark the parabolic altitude on a reference paper. Thus, student could not compare the altitude at different angles. Therefore, students could not confirm their hypothesis with the experiment. We can also try for the next research if we can add one more period doing demonstration about the different angles launched by using this instrument to investigate the projectile altitude and display the equation of projectile altitude $y = \frac{v_0^2 \, sin^2 \, \theta}{2g}$ to confirm with the demonstration set up. It might be better to change students' ideas on the projectile altitude.

Additionally, we will discuss on students' drawings and students' patterns of each answer in the following.

4.5 Patterns of students' responses to the Conceptual Questions on Projectile Motion

4.5.1 Patterns of students' responses to flight time, splashdown of two freely falling objects at the same height with different initial horizontal velocities

Table 4.8: Students' ideas of the flight time of two freely falling objects at the same height with different initial horizontal velocities on pre and post-tests

Group	Students' responses	Pre (N=204) (%)	Post (N=204) (%)
I	In comparison between dropping diver A and running diver B on the cliff at the same time and the same height, both divers spend the same duration of flight time reaching the water because they are both in free fall motion. Although B is faster than A, it takes longer path than A. These parameters make A and B reach the water at the same time in identically initial conditions.	4	59
II	Both divers reach the water at the same time (no	3	15

	reasons).		
III	Diver A reaches the water first because diver A moves in a shorter path than diver B.	20	3
IV (36% pre) (6% post)	Diver A reaches the water first because diver A has no initial velocity, or diver A reaches the water first because B has initial velocity and has longer path than A.	20	2
	Diver B reaches the water first because B has initial velocity.	15	1
	Diver A reaches the water first because diver A has greater velocity than the runner diver B.	1	3
V (13% pre) (4% post)	Diver B reaches the water first because the runner has greater force acting on him than the dropping diver A	5	0
	Diver A reaches the water first because diver A has greater gravitational force than the running diver B.	4	2
	Diver B reaches the water first because diver B has greater gravitational acceleration than the dropping diver A.	3	1
	Diver A reaches the water first because diver A has greater gravitational acceleration than the running diver B.	1	1
VI (1% pre) (4% post)	Both divers reach the water at the same time because both divers have the same velocity and spend the same time.	0	1
	Both divers reach the water at the same time because both divers have the same velocity and move at the same height.	0	1
	Both divers reach the water at the same time because both divers have the same mass.	0	2

	Diver A reaches the water first because diver A drops straight down without air resistance acting on. Diver B runs out off the cliff in a curve path. The air resistance acts on diver B greater than diver A.	1	0
Others	7) Diver A reaches the water first (no reason).	6	5
	8) Diver B reaches the water first (no reason).	7	2
	Other	10	2

The results in the Table 4.8 show that students Group (I) understanding on flight time from 4% of the students on pre-test increasing to 59% of the students on post-test. The students completely corrected the answer and the reasons after the IBL instruction. It reflects that IBL instruction related to flight time helped more than a half of the students move from the incorrect ideas toward the correct ideas.

Notably, an obvious increase was detected from 3% of the students on pre-test to 15% of the students (II) on post-test. More students were aware that both divers reach the water at the same time but they still did not provide any reasons. The IBL procedure for item 2 including a quiz and a demonstration set-up was designed to clarify the vertical and horizontal motions. Students seem to lack the conceptual knowledge that the vertical and horizontal motions are independent of each other, as well as free fall motions. In this case, students lack background concepts of not only two-dimensional motions, but also one-dimensional motion. Thus, the IBL procedure engaged this group of students improving from their initial state to 50% of the question but not completely the whole question.

Students group (IV) 36% and 6% on pre-test and post-test remained misconceptions that the flight time of the objects depends on the paths and the initial horizontal velocities. For example students stated that diver A will reach the water first because diver A moves in a shorter path than diver B. The students' idea was also found in Prescott and Michaelmore (2004). Many researchers also reported that the students holding the misconceptions are difficult to change their ideas to the scientific ideas through traditional teaching methods (Prescott and Mitchelmore, 2004; McCloskey, 1983; Whitaker, 1983).

Students group (V) had the ideas about the impetus theory. It also appeared in Hestenes et al., (1992), McCloskey (1983), Whitaker (1983), and Hallon and Hestenes, (1985). The students thought that the duration of flight time of the divers taking longer or shorter depends on the internal force of the divers. They asserted that diver B reaches the water first because the runner has greater force acting on than diver A who drops. After IBL procedure, the percentage of the students with this idea reduces from 13% to 4%. Our preliminary results did not show ideas about impetus theory in this question. The number of the students participating in designed IBL procedure is greater than common instruction with a difference of around 100 students. The number of the students can be variable for the students' patterns.

Remarkably, around 1% on pre-test increased to 4% of the student (VI) on post-test had the idea that both divers will reach the water at the same time but they provided incorrect reasons. Some reasoned that both divers start at the same height, or the same velocities. Others argued for the causes of the same mass, or with the same time spent. Nevertheless, the IBL procedure guided this group of students moving from their initial state to the confusion state, which is considered a sign of learning (Mello et al., 2014).

To sum up, the IBL procedure enhancing students learning on concepts related to flight time of two freely falling objects at the same height with different initial horizontal velocities is one of the interactive engagement teaching methods, which helps reducing a number of students' misconceptions. Although a small percentage of the students remained in the confusion state after completion of IBL procedure, more than a half of the students acquired the correct ideas

4.5.2 Students' responses to splashdown speeds of two freely falling objects at the same height with different initial horizontal velocities

Table 4.9: Students' patterns of the concept of splashdown speeds of two freely falling objects at the same height with different initial horizontal velocities on pre and post-tests

Group	Students' responses	Pre (N=204) (%)	Post (N=204) (%)
I	1) Diver B has a greater splash down speed than A because B has initial velocity. $v_A = gt < v_B = \sqrt{(gt)^2 + (v_0)^2}$	17	41
II (34 pre) (15 post)	2) Diver B has a greater splash down speed than A because B has initial velocity and stronger force than A or B has a running force producing the greater velocity	33	15
	3) Diver A has greater splash down speed than B because A has no initial velocity.	1	0
III	4) Diver B has greater splash down speed than A because B will reach the water first and B moves in a longer path than A	6	4
IV (3% pre) (6% post)	5) Diver A has greater splash down speed than B because A stand and drops.	2	2
	6) Diver A or B has greater splash down speed because of their mass or pressure, or time or acceleration.	1	4
V	7) Diver B has greater splash down speed than A (no reasons).	19	20
VI	8) Diver A has greater splash down speed than B (no reasons).	1	1
VII	Others	20	13

The IBL procedure included the demonstration set-up of the independent vertical and horizontal components, which addressed students' misconceptions on splashdown speed of two freely falling object at the same height with different initial horizontal velocities. After IBL procedure we got the results as shown in the Table 4.9.

We found that some students' ideas were different from our preliminary results. A large group of students (II) explained that diver B, a runner, has a greater force than diver A who drops, thus, B has a greater splashdown speed than A. The students believed that the internal force imparted to the runner is greater than the one who drops. It implies that the students had ideas about the impetus theory, which were found in some other studies such as Hestenes et al. (1992); Halloun and Hestenes (1985); Whitaker (1983); and McCloskey (1983). The students thought that the splash down speeds depend on the internal force.

Notably, a few students (IV) had the confusing idea by explaining that splash down speed depends on their mass or pressure, or time or acceleration, running or dropping. The group of students increased from 3% on pre-test to 6% on post-test. It indicates that IBL instruction guided the students from their initial state to the confusion state, which is a sign of learning (Mello et al., 2014).

Somehow, after IBL procedure, the percentage of the student rose up from 17% to 41% carrying the correct idea. It reflects the effectiveness of the IBL procedure related to splashdown speeds of two freely falling objects at the same height with different initial horizontal velocities.

4.5.3 Students' responses to accelerations of two freely falling objects at the same height with different initial horizontal velocities

Table 4.10: Students' patterns of accelerations of two freely falling objects at the same height with different initial horizontal velocities on pre and post-tests

Students' responses	Group	Students' reasons	Pre (N=204) (%)	Post (N=204) (%)
Both divers have the same accelerations	I	1) Because both divers are freely falling objects and only gravitational force acts it. (ignore air resistant)	9	42
Both divers have different accelerations	II	2) Because they move in different paths.	9	1
	III (25%	3) Because the diver B has greater velocity than A or the diver A has no	20	5

	pre) (6% post)	initial velocity.		
		4) Because A reaches the water first or A moves faster (4)	3	1
		7) Because B moves with the initial velocity slower than A without initial velocity. (confusion)(4)	2	0
	IV	5) Because diver B has greater force than A (Newton second law)	2	1
	V	6) Because the diver A is dropping and B is running (type of motion)	8	1
	Other	(No reason)	26	2
	Other	8) Because the gravity acting on A is smaller than B. (confusion)	1	0
	Other	10) Because A is heavier than B or they move out of the cliff at different time. (Other)	2	1
Both divers have the same accelerations	VI	Both divers have the same accelerations because they move out of the cliff at the same time.	1	7
		Both divers have the same accelerations (no reason)	1	26
		Other	16	13

In 2017, the IBL procedure was applied into classes to enhance students' learning in the concept of accelerations of two freely falling objects at the same height with different initial horizontal velocities, which asks whether the acceleration of the independent of vertical and horizontal components are equal or different from each other and asks students to explain the reasons. Students' responses are described in the table 4.10. In our preliminary results, students misjudged that (a) the horizontal and vertical motions have different vertical accelerations when they have different initial horizontal velocities. Some students believed that (b) two objects hitting the ground at the same time have the same accelerations (Piten et al., 2017).

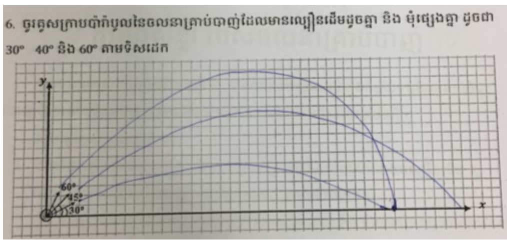
It was revealed that students (III) holding the misconception (a) mentioned above reduced from 25% to 6%. Particularly, we found some more misconceptions in 2017 but after IBL instruction the percentage of the students holding the misconceptions decreased. For instance, before IBL instruction, students in Group (II) and (V) believed that the simultaneous vertical and horizontal motions fly in the different paths or different types of motions will have the different accelerations. Besides, students in Group (IV) carried ideas of the impetus theory that the different internal force will produce the different accelerations. It clarifies that IBL instruction related to the concept of item 2.3 is more effective than traditional instruction to address students' misconceptions.

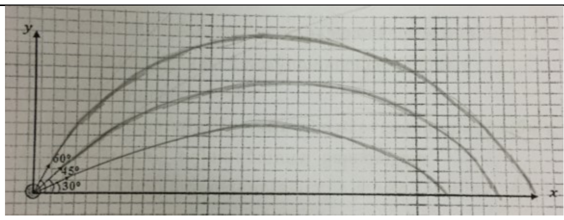
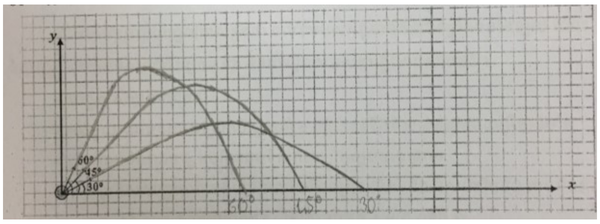
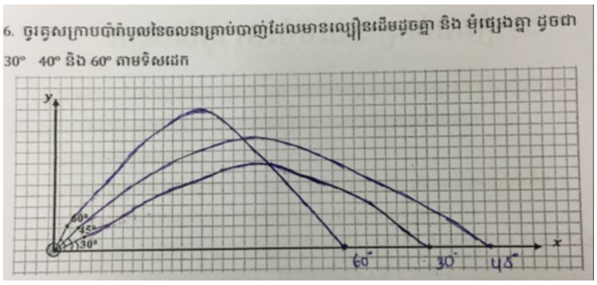
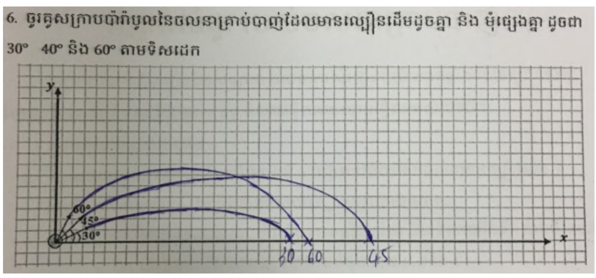
Noticeably, students in Group (VI) carrying the ideas (b) as discussed above increased from 1 to 7%. The students realized that both motions have the same accelerations but they still held some confusing reasons and some did not provide any reasons.

In summary, after IBL instruction, some students still remained in confusion state on concept of acceleration of two freely falling objects at the same height with different initial horizontal velocities with a small percentage of the students still holding misconceptions. However, almost half of the whole students obtained the correct idea. It indicates that IBL instruction strengthened students' understanding.

4.5.4 Students' responses to the altitude and horizontal range of a projectile

Table 4.11: The students' drawing patterns for the altitude and horizontal range of a projectile on pre and post tests

Group	Students' patterns	Pre (N=204) (%)	Post (N=204) (%)
I	Correct answer Draw the parabolic paths with (x_{30}= x_{60}< x_{45}) and (y_{30} < y_{45} < y_{60}) 	1	36
II	Draw the parabolic paths with (x_{30}< x_{45}< x_{60}) and (y_{30} < y_{45} < y_{60})	33	12

			
III	Draw the parabolic paths with (x_{30}> x_{45}> x_{60}) and (y_{30} < y_{45} < y_{60}) 	18	9
IV	Draw the parabolic paths with (x_{60}< x_{30}< x_{45}) and (y_{30} < y_{45} < y_{60}) 	5	10
V	Draw the parabolic paths with (x_{30}< x_{60}< x_{45}) and (y_{30} < y_{45} < y_{60}) 	7	5
VI	Others such as: Draw the parabolic paths with (x_{30}> x_{60}> x_{45}) and (x_{30}=x_{45}< x_{60}), (x_{30}>x_{45}= x_{60}), (y_{30} < y_{45} < y_{60})	2	15
Other		34	13

Our results revealed that IBL class addressed students' misconceptions on the horizontal range better than traditional teaching methods. The percentage of the students having correct idea increased significantly. Although IBL instruction could not shift student ideas on vertical altitude but it shifted a big gap on horizontal range.

In Table 4.11 the percentage of the students in Group (I) holding the correct idea is high. As we discussed on average normalized gain for altitude and horizontal range of a projectile above students might have a lot experiences in daily life about the vertical altitude. Therefore, their judging is correct.

In addition, IBL instruction shifted students (II) from their initial state to confusion state. Moreover, IBL instruction revealed students' misconceptions as described in table 4.11 of students group III, IV, and V. It reflected our difficulty of altitude concept.

Table 4.12: Students' drawing patterns of altitude of a projectile on pre and post-tests

Group	Students' drawing patterns	Pre (N=204) (%)	Post (N=204) (%)
I	Correct answer Draw the parabolic paths with ($y_{30} < y_{45} < y_{60}$)	61	68
II	Draw the parabolic paths with ($y_{45} > y_{60} > y_{30}$)	0	15
III	Draw the parabolic paths with ($y_{60} = y_{45} > y_{30}$)	3	2
IV	Draw the parabolic paths with ($y_{60} = y_{45} = y_{30}$)	1	2
V	Draw the parabolic paths with ($y_{60} > y_{45} = y_{30}$)	1	1
	Other	34	12

Table 4.13: Students' drawing patterns of horizontal range of a projectile on pre and post-tests

Group	Students' drawing patterns	Pre (N=204) (%)	Post (N=204) (%)
I	Correct answer Draw the parabolic paths with ($x_{30} = x_{60} < x_{45}$)	1	47

II	Draw the parabolic paths with (x_{30}< x_{45}< x_{60})	33	12
III	Draw the parabolic paths with (x_{30}> x_{45}> x_{60})	18	9
IV	Draw the parabolic paths with (x_{60}< x_{30}< x_{45})	5	10
V	Draw the parabolic paths with (x_{30}< x_{60}< x_{45})	7	5
VI	Draw the parabolic paths with (x_{30}> x_{60}> x_{45}) and (x_{30}=x_{45}< x_{60}), (x_{30}>x_{45}= x_{60}),	2	9
	Other	34	12

As we discussed on average normalized gain in table 4.3 for the altitude and horizontal range of a projectile the results shown in two tables of altitude and horizontal range (tables 4.12 and 4.13) to support each other. We also extracted students' misconception from table 4.12 and 4.8 to show the patterns of concepts.

4.6 Model Analysis

In this study, we applied model analysis techniques to investigate the change of the students' model state in the IBL class. Three questions of the concept with 3 different contexts were discuss in the publication Piten and Rakkapao (2018) focusing on the students' comprehension of projectile trajectory concept.

Table 4.14 shows the results of the model analysis, and as can be seen from the diagonal elements of the pre- and post-tests class matrices, the percentage of students, who selected the correct model (model 1), was 41% before instruction, which increased to 62% after the IBL instruction. In contrast, the percentage of students, who selected the incorrect model (model 2), decreased from 55% to 34% after the instruction. Similarly, the off-diagonal elements of the class density matrices revealed significant mixing in model 1 and model 2 before (ρ_{12}=78%) and after (ρ_{12}=70%) instruction.

Table 4.14: Class density matrices, eigenvalue, eigenvectors and model point in this study (N= 204)

	Pre	Post
Class density matrix	$\begin{bmatrix} 0.41 & 0.37 & 0.02 \\ 0.37 & 0.55 & 0.03 \\ 0.02 & 0.03 & 0.04 \end{bmatrix}$	$\begin{bmatrix} 0.62 & 0.32 & 0.05 \\ 0.32 & 0.34 & 0.02 \\ 0.05 & 0.02 & 0.04 \end{bmatrix}$
Dominant eigenvalue	0.86	0.84
Primary eigenvector	$\begin{bmatrix} 0.64 \\ 0.77 \\ 0.04 \end{bmatrix}$	$\begin{bmatrix} 0.84 \\ 0.55 \\ -0.07 \end{bmatrix}$
(P2, P1)	(0.51, 0.35)	(0.25, 0.59)

The IBL approach designed in this study was based on the preliminary results of Cambodian students' misconceptions in the year 2016. Most misconceptions agree with those previously reported of McCloskey (1983), Whitaker (1983), and Halloun et al., (1992).

The most popular misconception about the parabolic trajectory of a projectile is that the impetus makes the projectile move in a curve or a straight line that the projectile travels and lands behind the point of its release. In this study, the demonstration set was developed to help the students to easily visualize the trajectory of the projectile. The students were engaged by using the hypothesis step, and they were asked to await the demonstration results in order to check their hypotheses. Overall, the classroom environment was interactive and the students enjoyed discussing with their friends and the teacher before and after the investigation step. The steps of the IBL approach help students to learn and transfer what they have learned to new contexts (Cahill and Bloch-Schulman, 2012). Moreover, in this study we found that most students were excited by and interested in our instrument since they had never seen it before. Many students paid a lot of attention to the instrument and the *key question*. They came to discuss with the teacher after the class, which is quite unusual in the atmosphere of a classroom in a high school in Cambodia. Based on the researcher's more than ten-years' experience in teaching high schools, normally after the class most children simply return home to help their parents work, with a few of them going to a tutoring school.

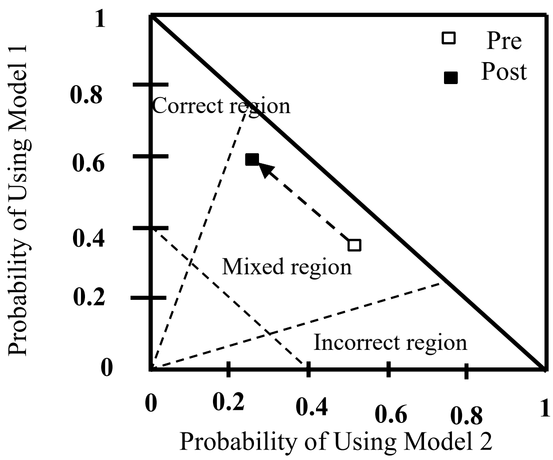


Figure 4.3: Model plot on the concept of the parabolic trajectory of the projectile taught by the IBL approach

Moreover, as revealed by the model plot in Figure 4.1, there was a slight improvement in the mixed model states of the students' understanding after the IBL instruction. This reflected some difficulties in this work since, the projectile topic is strongly associated with the vector, and the force and motion concepts, and the students' understanding of those concepts impacted what and how the students learned. Further studies together with active learning activities and proper instructional instruments for Cambodian contexts are necessary to improve the science abilities and skills of learners.

In brief, a small movement of the model states was found in the mixed region. Yet the approach may not have enabled the students to progress to learning a completely a correct model, it was able to change some of the confused states, which is a sign of learning (Melloa et al., 2014).

Chapter V

Conclusion

In this chapter, we conclude the holistic completion of our current research. The following gives an emphasis on how we conducted the research, what we have achieved, what are our difficulties, and what we can still do for future studies. Interesting findings and contributions of our research are highlighted to enlighten both instructors and scholars.

5.1 A retrospect of the whole research

To support the quality of high school students in science learning which is fundamental in education, the focus of this research is on the projectile motion topic in physics. It is also a significant way to help Cambodian students grow up with scientific ideas. We developed IBL procedure consisting of 6 steps: key question, hypothesize, investigate, analyze, model, and evaluate. To design a practical IBL procedure, CQPM was applied to survey and identify Cambodian high school students' misconceptions of projectile motion including the direction of velocity and the direction and magnitude of acceleration of the projectile, direction and magnitude of force acting on projectile, the time interval of the simultaneous vertical and horizontal motions, the splash down speed and the acceleration of vertical and horizontal motion, the horizontal distance and final velocity of the projectile when the time interval changes, projectile trajectory, the acceleration of linear motion, and the acceleration of circular motion (Piten et al., 2017). The tailored IBL procedure embedded with the inquiry cycle was found to be an interactive-engagement teaching method, enhancing students' correct comprehension of key concepts for some items.

Moreover, the average normalized gains of students' understanding of each individual concept are different because demonstration set-up plays a significant role in showing convincing evidence to the misconceptions or hypotheses they hold. Additionally, quizzes which are found being beneficial in many studies for the students at the beginning of each class account for their learning improvement. On the other hand, it is interpreted that the frequency of providing confirming feedback contributes to students' gain of comprehending key concepts of projectile motion at the final evaluation stage in the IBL procedure. Interestingly, the influence of worksheets distributed to the students in the research still needs further investigation to gauge how beneficial the worksheets are for improving students' learning. The effectiveness of IBL procedure really needs the cooperation of all the instruments above. In addition, IBL procedure enhances students' learning at medium gain on overall.

However, we revealed that there were low gains on some concepts such as drawing a vector to represent the magnitude of velocity and altitude of the projectile. We found that Cambodian students had low background not only on the vector concept but also their content knowledge on one-dimensional motion. For these concepts, it is difficult to design demonstration set-ups in the Cambodian high school context because of the lack of teaching media such as computer and projector screen presentation.

In addition, the model analysis showed that students' model state changes varied on different concepts. In certain concepts of projectile trajectory, students did move their model state from the incorrect region to the mixed region. The shift from the incorrect region to the mixed region in the model plot indicates a sign of learning improvement (Piten and Rakkapao, 2018).

5.2 Contributions of the research

5.2.1 Contributions to physics education in Cambodia

a. It provides a piece of convincing evidence that IBL approach has potential feasibility to be adopted in physics learning and teaching at high school level in Cambodia. Therefore, education policy makers may consider introducing IBL approach to replace some conventional teaching methods if revising the new curriculum for high school physics education.

b. The identified misconceptions of the Cambodian high school students can be a useful source to make physics teachers aware of students' misunderstanding of projectile motion before they design any lesson plan. Thus, these misconceptions assist the physics teachers in Cambodian high school to better guide their students to obtain a correct idea about the projectile motion concept. These misconceptions also benefit teachers who teach projectile motion in some other developing countries whose conditions are similar with Cambodia. For example, the tables below represent students' misconception on item 2 and item 6.

Table 5.1: Students' misconceptions of the flight time of two freely falling objects at the same height with different initial horizontal velocities found in this study

Group	Students' ideas from pre- and posttests	Other references
I	Flight time of two objects freely falling at the same height with different initial horizontal velocities depends on the paths (straight or curve) or the initial horizontal velocity.	Prescott and Michaelmore , 2004
II	The greater internal force is acted on the object, the shorter time it spends reaching the ground.	Hestenes et al., 1992; McCloskey 1983; Whitaker 1983; and Halloun and Hestenes, 1985

Table 5.2: Students' misconceptions for splashdown speeds of two freely falling objects at the same height with different initial horizontal velocities found in this study

Group	Students' ideas from pre- and posttests	Other references
I	The greater the internal force acts on the object, the greater splashdown speed it has.	Hestenes et al., 1992; McCloskey 1983; Whitaker

		1983; and Halloun and Hestenes, 1985
II	Splashdown speeds of two objects freely falling at the same height with different initial horizontal velocities depend on their paths (straight or curve).	-
	Splashdown speeds of two objects freely falling at the same height with different initial horizontal velocities depend on the type of motion (projectile or free fall).	-

Table 5.3: Students' misconceptions for acceleration of two freely falling objects at the same height with different initial horizontal velocities found in this study

Group	Students' ideas from pre- and posttests	Other references
I	Accelerations of two objects freely falling at the same height with different initial horizontal velocities depend on their paths (straight or curve) and initial horizontal velocity.	-
II	Accelerations of two objects freely falling at the same height with different initial horizontal velocities depend on the internal force.	Hestenes et al., 1992; McCloskey 1983; Whitaker 1983; and Halloun and Hestenes, 1985
III	Acceleration of two objects freely falling at the same height with different initial horizontal velocities depend on the type of motion (projectile or free fall).	-

Table 5.4: Students' misconceptions for altitude and horizontal range of a projectile found in this study

Group	Students' ideas from pre- and posttests	Other references
I	The greater angle the projectile is launched at, the greater horizontal range the projectile reaches.	-

c. Three demonstration set-ups were developed by the researchers to better address students' misconceptions of projectile motion. The self-designed demonstration set-ups are effective to enhance students' correct understanding of projectile motion concept. These demonstration set-ups are not complicated to be designed by teachers and the cost is at an affordable price when considering the economic conditions in Cambodia or in some other similar developing countries.

5.2.2 Implications for physics education research

a. Future research can still be conducted to further examine the effectiveness and feasibility of IBL procedure in Cambodia or some other developing countries in a similar educational context. Hence, researchers are indeed encouraged to carry out more research through trying the IBL procedure to address students' misconceptions of projectile motion at the high school level.

b. The Conceptual Questions on Projectile Motion is a reliable research instrument for researchers who are interested in conducting relative research on this topic.

c. Students' misconceptions of projectile motion are used as preliminary resource to design other teaching methods.

5.3 Challenges of the current research

a. The researcher did not test the level of students' background knowledge. Later, it turned out that many students have very low background knowledge in some content that students had learned in grade 10, which became a great challenge (even obstacles) for implementing IBL approach in the research.

b. Due to the limited conditions (eg. difficulty in creating a vacuum environment), our demonstration set-ups are still not efficient enough to guide the students to a holistic correct understanding of projectile motion concept.

c. The teaching infrastructures are far from enough for teachers and students to make a good use, especially lacking modern teaching media and computer technology devices.

d. Some uncontrolled factors such as student withdrawal or dropout affected data collection, which made the data cases not completely matched on the pre- and posttests.

5.4 Suggestions for further studies

a. It is suggested that a quick evaluation of students' background knowledge is necessary before starting the research.

b. Demonstration set-ups for altitude and horizontal range of projectile motion are recommended to be adjusted or improved to make it better address students' misconceptions of projectile motion in future research.

c. Further investigation can concentrate on the effectiveness of different specific teaching techniques (e.g. quiz, worksheet, proving feedback) on improving students' learning gain on understanding the projectile motion concept.

References

Ahea, M.A.B., Ahea, K. R., & Rahman, I. (2016). The value and effectiveness of feedback in improving students' learning and professionalizing teaching in higher education. *Journal of Education and Practice*, *7*(16), 38-41.

Bao, L. (2006). Theoretical comparisons of average normalized gain calculations. *American Journal of Physics*, *74*, 917-922.

Bao, L., & Redish. F. E. (2001). Concentration analysis: A quantitative assessment of student states. *American Journal of Physics*, *69*, S45, 45-53.

Bao, L., & Redish. F. E. (2006). Model analysis: Respresenting and assesing the dynamics of student learning. *Physical Review Physics Education Research*, *2* (1), 1-16.

Bao, L., Hogg, K., & Zollman, D. (2002). Model analysis of fine structures of student models: An example with Newton's third law. *American Journal of Physics*, *70*, 766-778.

Choo, S. Y. S., Rotgans, I. J., Yew, H. J. E., & Schmidt, G. H. (2011). Effect of worksheet scaffolds on student learning in problem-based learning. *Advances in Health Sciences Education*, *16* (4), 517–528.

Coletta, P. V., & Phillips, A. J. (2005). Interpreting FCI scores: Normalize gain, pre-instruction score, and scientific reasoning ability. *Physical Reviews Special Topics - Physics Education Research*, *3* (1), 1172-1182.

CSMEE (The Center for Science, Mathematics, and Engineering Education). (1995). *Inquiry and the National Science Education Standards.*

Cummings, K., Marx, J., Thornton, R., & Kuhl, D. (1999). Evaluating innovation in studio physics. *American Journal of Physics*, *67*, 38-44.

Dhanapal, S., & Shan, W. Z. (2014). A study on the effectiveness of hands-on experiment in learning science among year 4 students. *International Online Journal of Primary Education*, *3*(1), 29-40.

Dy, S. S. (2003). Basic education in Cambodia: The impact of UNESCO on polices in 1990s. *Education Policy Analysis Archives*, 1-20.

Educational Development Center. (2001). *An Introduction to Inquiry-based Learning.* Retrieved from http://youthlearn.org/wpcontent/uploads/Inquiry_Based_Learning.pdf

Force and Motion during Computer-Supported Physics Instruction. *Journal of Research in Science Teaching, 36* (7), 859-882.

Gaffney, D. H. J. (2013). Education majors' expectations and reported experiences with inquiry-based physics: Implications for student affect. *Physical Review Physics Education Research*, *9*, 1-16.

Hake, R. R. (1997). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics course. *American Journal of Physics*, *66*(1), 64-74.

Halloun, A. I., & Hestenes, D. (1985). Common sense concepts about motion. *American Journal of Physics*, 1056-1065.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics*, *55*, 440-454.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher*, *30,* 141-158

Hu, D., Zwickl, M. B., & Wilcox, R. B. (2017). Qualitative investigation of students' views about experimental physics. *Physical Review Special Topic-Physic Education Research*, *13*, 1-12.

Khieng, S., Srinivasa, M., & Chhem, R. (*Eds*.) (2015). *Cambodia education 2015: Employment and empowerment*. Phnom Penh: Cambodia Development Resource Institute.

Lalley, J. P., & Miller, R. H. (2007). The learning pyramid: Does it point teachers in the right direction? *Education, 128* (1), 64-79.

Lindsey, A. B., Hsu, L., Sadaghiani, H., Taylor, W. J., & Cummings, K. (2012). Positive attitudinal shifts with the physics by inquiry curriculum across multiple implementations. *Physical Review Special Topics- Physics Education Research*, 1-8.

Loverude, E. M., Gonzalez, L. B., & Nanes, R. (2011). Inquiry-based course in physics and chemistry for preservice K-8 teachers. *Physical Review Special Topics- Physics Education Research, 7*, 1-18.

McCloskey, M. (1983). Intuitive Physics. *Scientific American*, 122-130.

McDermott, C. L., & Shaffer, S. P. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics*, *60* (11), 994-1003.

McGinness, P. L., & Savage, C. M. (2016). Develop an action concept inventory. *Physics Education Research Physical Review*, *12* (1), 1-6.

MOEYS (Ministry of Education, Youth and Sport) (2014). *Education strategic plan 2014-2018*. Phnom Penh.

Mudau, A. V. (2014). Programatic review of literature associated with projectile motion perceived as difficult to teach by some South African teachers. *Mediterranean Journal of Social Sciences*, *5*(8), 441-445.

Narjaikaew, P., Emarat, N., & Cowie, B. (2009). The effect of guided note taking during lectures on Thai university students' understanding of electromagnetism. *Research in Science & Technological Education, 27* (1).

Phin, C. (2014). Challenges of Cambodia Teachers in Contributing to Human and Social Development: Are They Well-Trained? *International Journal of Social Science and Humanity*, 344 -348.

Piten, S. & Rakkapao, S. (2018). Evaluation of high school Cambodian students' comprehension of the projectile trajectory using the model analysis technique. *Proceedings of the Physics Education Research Conference 2017*. DOI: 10.1119/perc.2017.pr.072.

Piten, S., Rakkapao, S., & Prasitpong, S. (2017). Cambodian students' prior knowledge of projectile motion. *Journal of Physics: Conference Series*, *901*, conference 1. 1-5.

Posner, J.G., Strike, A. K., Hewson, W. P., & Gertzog, A. W. (1982). *Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education*, *66* (2), 211-227.

Prescott, A., & Mitchelmore, M. (2004). *Student misconceptions about projectile motion.* Doctoral dissertation, University of Technology, Sydney.

Prescott, A., & Mitchelmore, M. (2005). Teaching projectile motion to eliminate misconceptions. *Proceedings of the 29th conference of the International Group for the Psychology of Mathematics Education*, 97-104. Melbourne.

Rakkapao, S., Pengpan, T., Srikeaw, S., & Prasitpong, S. (2014). Evaluation of POE and instructor-led problem-solving approaches integrated into force and motion lecture classes using a model analysis technique. *European Journal of Physics*, *35*(1), 1-10.

Rany, S., Md Zain,N.A., & Jamil, H. (2012). Cambodia's Higher Education Development in Historical Perspectives (1863-2012). *International Journal of Learning and Development, 2* (2), 224-241.

Redish, F. E., Saul, M. J., & Steinberg, N. R. (1998). Student expectation in introductory physics. *American Journal of Physics*, *66,* 212-224.

Ross, R. R. (1987). *Cambodia: A country study.* Federal Research Diversion Library of Congress. https://www.loc.gov/resource/frdcstdy.cambodiacountrys00ross/?sp=167.

SEAL (Science, Environmental and Agricultural Life skills Programme) (2013). *Cambodia - Science and Life Skills in Teacher Training.* Retrieved from http://www.vvob.be/vvob/en/programmes/cambodia-science-and-life-skills-teacher- training.

Smith, I. T. & Wittmann, C. M. (2008). Applying a resources framework to analysis of the Force and Motion Conceptual Evaluation. Physical Review Special Topics- Physics Education Research, 1-11.

Smith, I. T., Wittmann, C. M., & Carter, T. (2014). Applying model analysis to a resource-based analysis of the force and motion conceptual evaluation. *Physical Review Special Topics- Physics Education Research*, *4*, 1-17.

Smith. I. T. (2016). Representing uncertainty on model analysis plots. *Physical Review Physics Education Research*, *12* (2), 1-5.

Sujarittham, T., Emarat, N., Arayathanitkul, K., Sharma, M. D., Johnston, I., & Tanamatayarat, J. (2016). Developing specialized guided worksheets for active learning in physics lectures. *European Journal of Physics, 37*, 1-17.

Tao, P. K. & Gunstone, F. R. (1999). The Process of Conceptual Change in in Force and Motion during Computer-Supported Physics Instruction

Tao, P. K. (1997). Confronting students' alternative conception in mechanics with the force and motion micro-world. *AIP Computers in Physics*, 11(2), 199-207.

Teodorescu, E. R., Bennhold, C., Feldman, G. & Medsker, L. (2013). New approach to analyzing physics problems: A taxonomy of introductory physics problems. *Physical Review Special Topic-Physics Education Research, 9*, 1-12.

Thornton, K. R. & Sokoloff. R. D. (1998). Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, *66* (4) 338-352.

Thornton, K. R., Kuhl, D., Cummings, K., & Marx, J. (2009). Comparing the force and motion conceptual evaluation and the force concept inventory. *Physical Review Special Topics- Physics Education Research*, *5*(1), 1-8.

Whitaker, J. R. (1983). Aristotle is not dead: student understanding of trajectory motion. *American Journal of Physics*, *51* (4), 352-357.

White,Y. B., Todd A. Shimoda, A. T., & Frederiksen, R. J. (1999). Enabling students to construct theories of collaborative inquiry and reflective learning: Computer-support for metacognitive development. *International Journal of Artificial Intelligence in Education*, 151-182.

Appendices

Appendix A
Conceptual Questions on Projectile Motion

Conceptual Questions on Projectile Motion

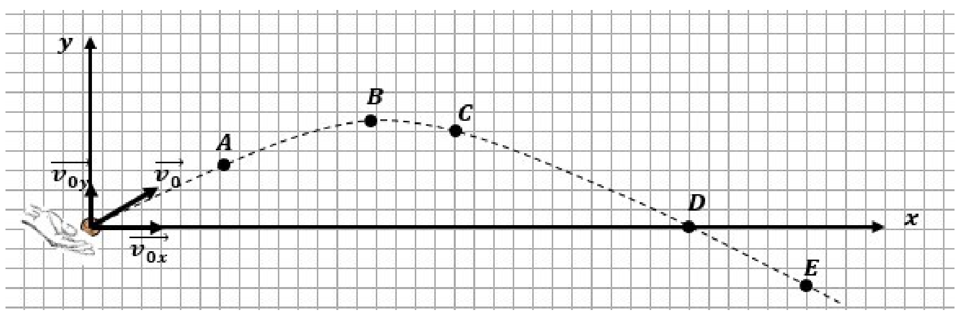
Directions: These projectile motion questions are designed based on the assumptions that air resistance is negligible, the acceleration due to gravity is constant and downward direction, and the Earth's rotation does not affect the motion.

Please write your answers in the test.

1. A ball is thrown upward, at an angle, with the initial velocity $\vec{v}_0$.

The horizontal component $\vec{v}_{0x}$ and vertical component $\vec{v}_{0y}$ of $\vec{v}_0$ are depicted in the figure below.

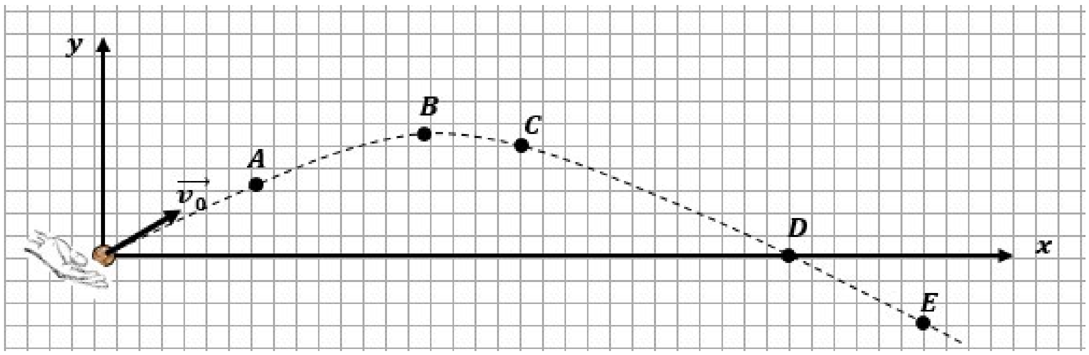
1.1) Draw arrows to indicate the horizontal and vertical components of the ball's velocity at position A, B, C, D and E.



1.2) Mark √ in the table that agree with the magnitude and direction of the ball's acceleration ($\vec{a}_{ball}$) at position A, B, C, D, and E, and give your reasons. (Define: g is the magnitude of the acceleration due to gravity)

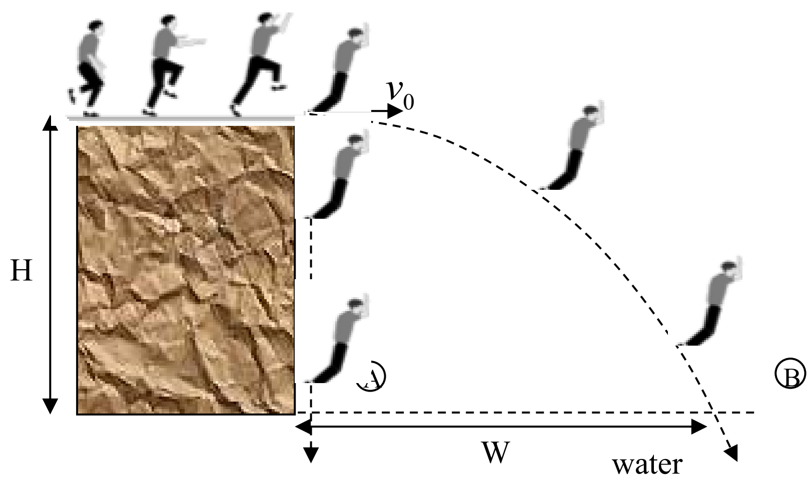
Position	Magnitude of ($\vec{a}_{ball}$)					Direction of ($\vec{a}_{ball}$)			
	$= 0$	$= g$	$< g$	$> g$	Give Reasons	upward	downward	none	Give Reasons
A									
B									
C									
D									
E									

1.3) Identify and draw arrows to indicate the direction and magnitude of the <u>force(s)</u> acting on the ball at position A, B, C, D and E.



Force(s) acting on the ball is (are)...

2. Two identical divers plan to dive off a cliff into the water. Diver A drops straight down. Diver B runs off the cliff with an initial horizontal speed v_0 , as shown in the figure below. (Simultaneous events)



2.1) Which of the diver will reach the water first? Give your reasons.

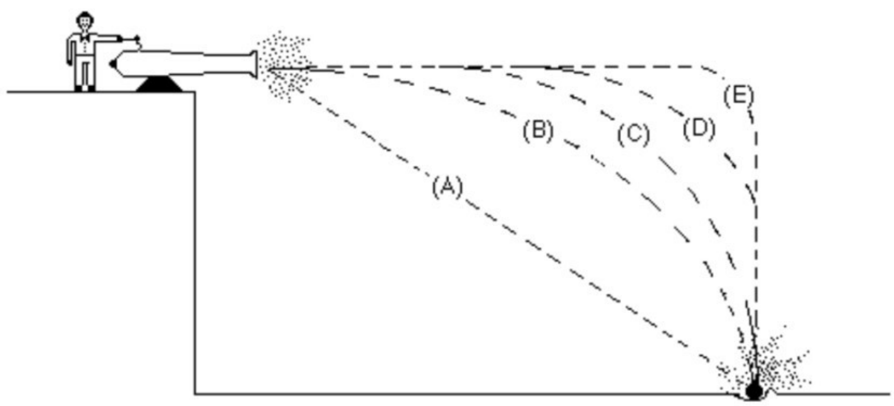
2.2) Which diver exist the <u>greater</u> splashdown speed? Give your reasons.

2.3) For both divers, are the accelerations of the diver equal? Give your reasons.

2.4) For diver Ⓑ, if the height *H* of the cliff is increased, when the diver runs off with thesame initial horizontal speed v_0, the distance *W* and the splashdown velocity will <u>greater than</u>, <u>less than</u>, or <u>equal</u> to the former? Give your reasons.

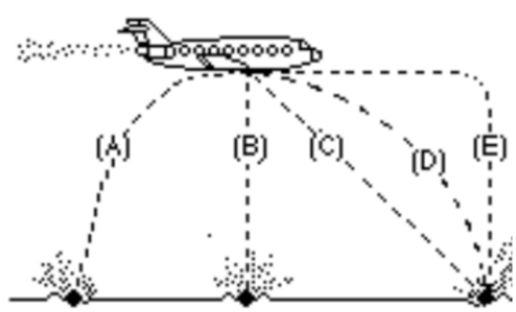
Distance *W*	Splashdown Velocity

3. A ball is fired by cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?



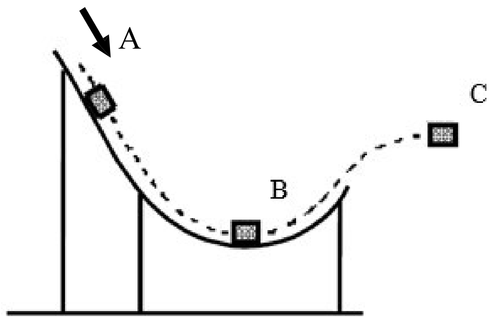
4. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction with a constant speed.

4.1 The path would the ball most closely follow after leaving the airplane, <u>observed by a person standing on the ground</u> and viewing the plane, is………………………………………



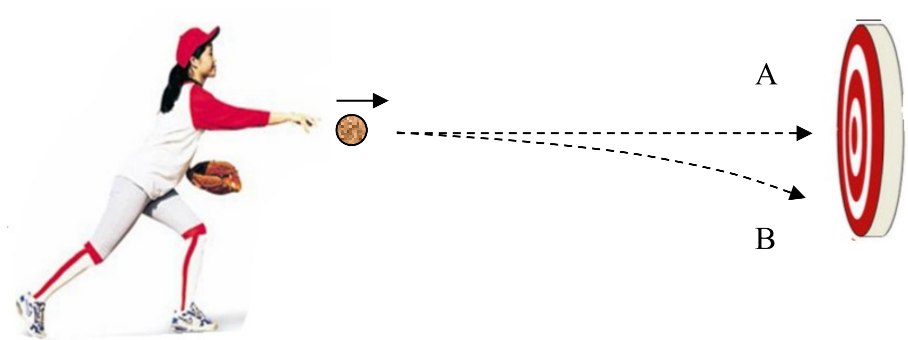
4.2 The path would the ball most closely follow after leaving the airplane, observed by a pilot sitting on the airplane is…………………………….... (Choose a choice from the right figure)

5. A block slides along a frictionless ramp. Draw the arrow to represent the direction of the acceleration of the block at position A, B and C (after leaving the ramp).



6. Draw the parabolic trajectory of the projectile launched with the same initial velocity but different angles, 30°, 45° and 60° to the horizontal plane.

7. A girl throws a ball in the horizontal direction as shown in the figure below. Which of the paths would the ball most closely follow?



Appendix B

A Form for Evaluating the Item-Objective Congruence (IOC)

Appendix B
A form for evaluating the Item-Objective Congruence (IOC)

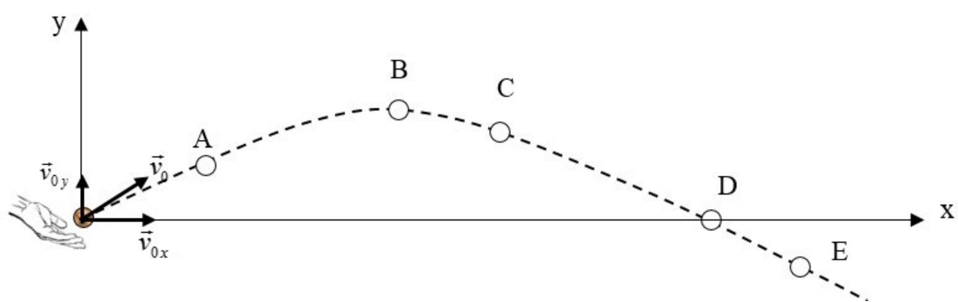
Directions: This form provides for experts. Please verify the agreement between items and behavioral objectives, and mark in a column of levels of consistency, as +1 if you are confident that the item agrees with its objective, as 0 if you are not confident, as -1 if you are confident that the item disagrees with its objective.

Conceptual Questions on Projectile Motion

These projectile motion questions are designed based on the assumptions that air resistance is negligible, the acceleration due to gravity is constant and downward direction, and the Earth's rotation does not affect the motion.

1. A ball is thrown upward, at an angle, with the initial velocity $\vec{v}_0$. The horizontal component $\vec{v}_{0x}$ and vertical component $\vec{v}_{0y}$ of $\vec{v}_0$ are depicted in the figure below.

1.1) Draw arrows to indicate the horizontal and vertical components of the ball's velocity at position A, B, C, D and E.

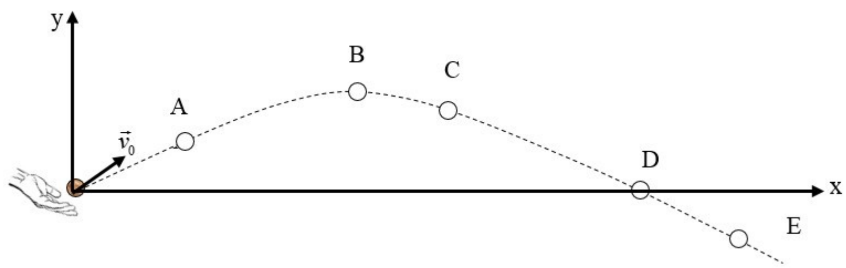


1.2) Mark √ in the table that agree with the magnitude and direction of the ball's acceleration ($\vec{a}_{ball}$) at position A, B, C, D, and E, and give your reasons.

(Define: g is the magnitude of the acceleration due to gravity)

Position	Magnitude of ($\vec{a}_{ball}$)					Direction of ($\vec{a}_{ball}$)			
	$= 0$	$= g$	$< g$	$> g$	Give Reasons	upward	downward	none	Give Reasons
A									
B									
C									
D									
E									

1.3) Identify and draw arrows to indicate the direction and magnitude of the force(s) acting on the ball at position A, B, C, D and E.

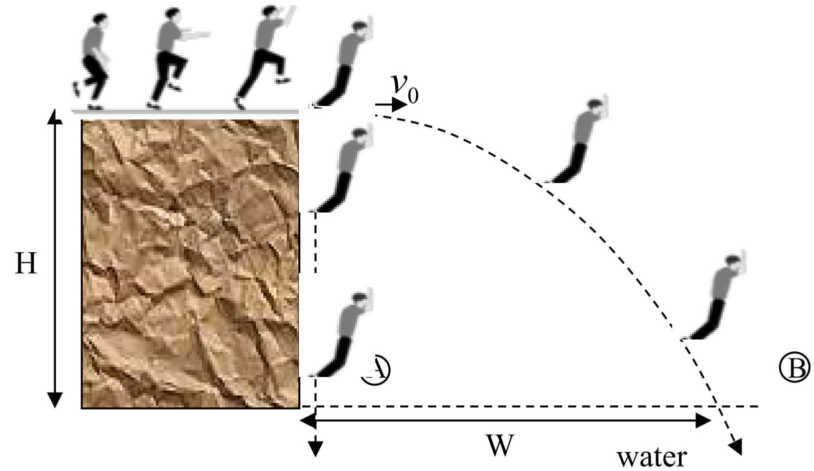


Force(s) acting on the ball is (are)...

For Experts

Item 1	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
1.1	Students are able to identify magnitude and direction of velocity of the projectile at different positions.			
1.2	Students are able to identify magnitude and direction of acceleration of the projectile.			
1.3	Students are able to identify magnitude and direction of force acting on the projectile.			

2. Two identical divers plan to dive off a cliff into the water. Diver A drops straight down. Diver B runs off the cliff with an initial horizontal speed v_0 , as shown in the figure below. (Simultaneous events)



2.1) Which of the diver will reach the water first? Give your reasons.

2.2) Which diver exist the <u>greater</u> splashdown speed? Give your reasons.

2.3) For both divers, are the accelerations of the diver equal? Give your reasons.

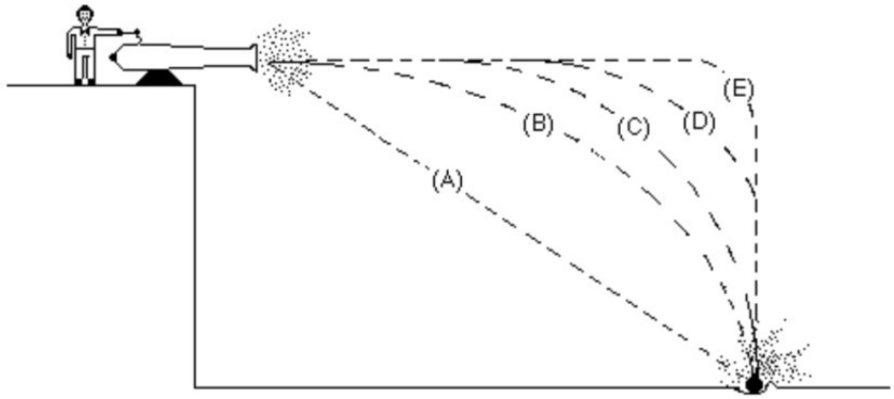
2.4) For diver Ⓑ, if the height *H* of the cliff is increased, when the diver runs off with thesame initial horizontal speed v_0, the distance *W* and the splashdown velocity will <u>greater than</u>, <u>less than</u>, or <u>equal</u> to the former? Give your reasons.

Distance *W*	Splashdown Velocity

For Experts

Item 2	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
2.1	Students are able to compare the time interval between the projectile motion and the free fall.			
2.2	Students are able to compare the final velocity between the projectile motion and the free fall.			
2.3	Students are able to compare the acceleration between the projectile motion and the free fall.			
2.4	Students are able to identify the horizontal distance, and final velocity of the projectile when the time interval changes.			

3. A ball is fired by cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?

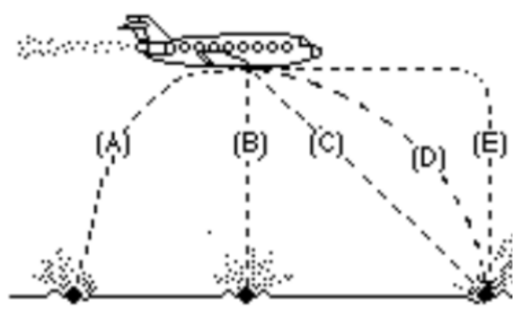


For Experts

Item 3	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
	Students are able to identify the parabolic trajectory of the projectile.			

4. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction with a constant speed.

4.1 The path would the ball most closely follow after leaving the airplane, <u>observed by a person standing on the ground</u> and viewing the plane, is……………………………………

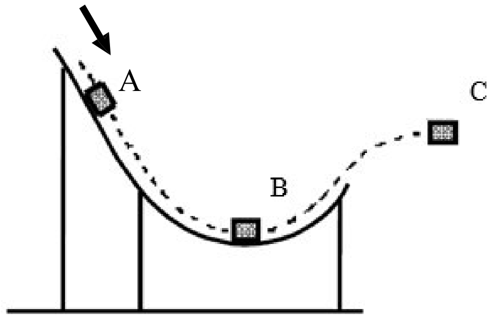


4.2 The path would the ball most closely follow after leaving the airplane, observed by a pilot sitting on the airplane is…………………………….... (Choose a choice from the right figure)

For Experts

Item 4	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
	Students are able to identify the parabolic trajectory of the projectile.			

5. A block slides along a frictionless ramp. Draw the arrow to represent the direction of the <u>acceleration</u> of the block at position A, B and C (after leaving the ramp).



For Experts

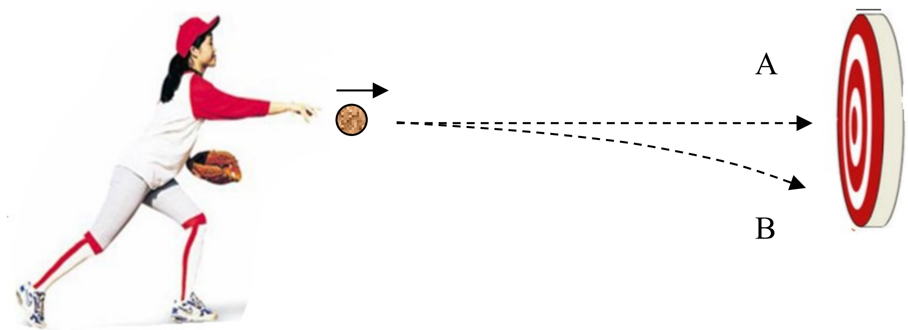
	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
Item 5	Students are able to distinguish three kinds of motions: linear motion, circular motion, and projectile motion.			

6. Draw the parabolic trajectory of the projectile launched with the same initial velocity but different angles, 30°, 45° and 60° to the horizontal plane.

For Experts

	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
Item 6	1) Students are able to identify the maximum horizontal distance of the projectile of angle 45°. 2) Students are able to identify the same horizontal distance of the two complementary angles.			

7. A girl throws a ball in the horizontal direction as shown in the figure below. Which of the paths would the ball most closely follow?



For Experts

Item 7	Behavioral Objectives	Levels of Consistency		
		+1	0	-1
	Students are able to identify the parabolic trajectory of the projectile.			

Other Suggestions

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Signature………………

…………………

(Expert's name)

Date……………………

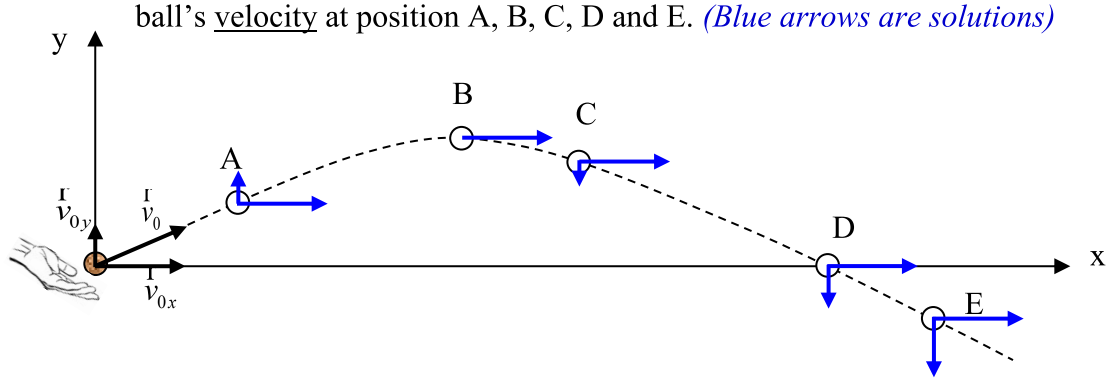
Appendix C

Details of Preliminary Results

Appendix C

Details of Prelimenary Results

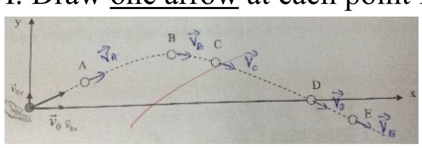
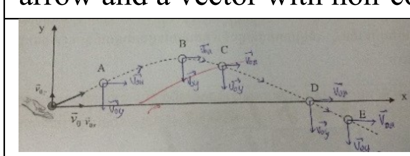
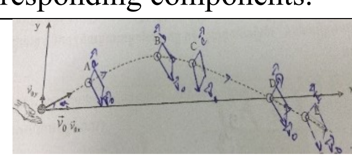
1. A ball is thrown upward, at an angle, with the initial velocity $\vec{v}_0$. The horizontal component $\vec{v}_{0x}$and vertical component $\vec{v}_{0y}$ of $\vec{v}_0$ are depicted in the figure below.
   1.1) Draw arrows to indicate the horizontal and vertical components of the ball's <u>velocity</u> at position A, B, C, D and E. *(Blue arrows are solutions)*



Results for item 1.1

When we considered students' drawings in item 1.1 we found that only 21 out of 81 students in pre-test and 20 out of 75 students in post-test filled out every position. Moreover, over 80% of these students drew arrows follow the trajectory, as shown in Table A1.1.1

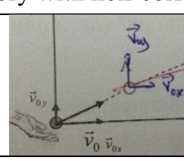
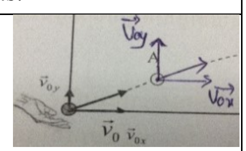
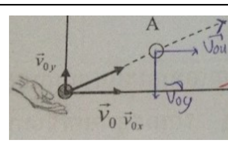
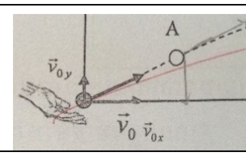
Table A1.1.1: Patterns of students' drawings for item 1.1 as the results from students who filled out every position asked by the question.

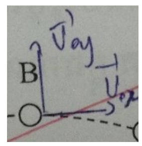
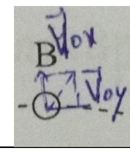
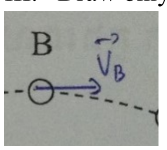
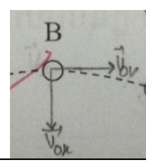
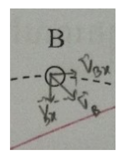
Pre-test (N=21)	Patterns of students' drawings	Post-test (N=20)
(N=19) (90%)	I. Draw <u>one arrow</u> at each point following the trajectory. 	(N=17) (85%)
(N=2) (10%)	II. Draw <u>2 or 3 arrows</u> at each point, such as an arrow following the trajectory, a rightward arrow, a downward arrow and a vector with non-corresponding components.  	(N=3) (15%)

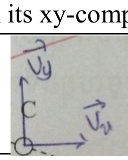
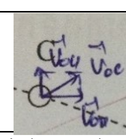
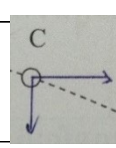
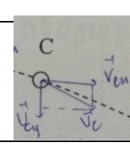
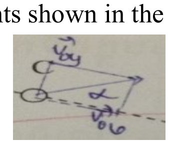
This showed that more than 80% of the students had low background knowledge not only the projectile motion but also the vector concepts, even though they were taught. They had the misconception that a velocity vector followed the trajectory. In fact, a velocity vector just contacts the parabolic path at a given point. Moreover, the students did not realize about the length of each arrow, which represented the magnitude of the vector. They just drew the same pattern of arrows at every point without the vector concept. In pattern II, they drew 2 or 3 arrows with the same shape at every point. Mostly, in a given point students just drew different lengths of a rightward arrow and a downward arrow. It displayed the low basic understanding of finding the components of vectors. Overall, this indicates that the students have to be improved the understanding of the vector concepts before the projectile motion class.

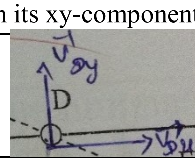
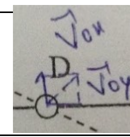
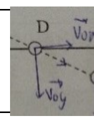
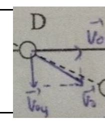
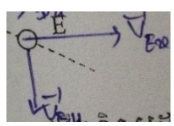
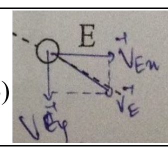
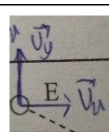
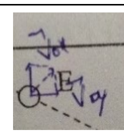
Moreover, to study for more details we focus on the students' drawings at each position. Results are shown in Table A1.1.2.

Table A1.1.2: Patterns of students' drawings for item 1.1 at position A, B, C, D and E.

<table>
<tr><td colspan="4">Table 2</td></tr>
<tr><td>Pre-test
(N=56)</td><td colspan="2">Patterns of students' drawings at position A</td><td>Post-test
(N=88)</td></tr>
<tr><td rowspan="2">(N=35)
(63%)</td><td colspan="2">I. Draw 2 or 3 arrows, such as an <u>upward</u> arrow, a rightward arrow and a vector following the trajectory with non-corresponding components.</td><td rowspan="2">(N=66)
(75%)</td></tr>
<tr><td>I(a)
Pre-test(N=11)
Post-test(N=33)
</td><td>I(b)
Pre-test(N=24)
Post-test(N=33)
</td></tr>
<tr><td>(N=19)
(34%)</td><td colspan="2">II. Draw one arrow following the trajectory.</td><td>(N=17)
(19%)</td></tr>
<tr><td rowspan="2">(N=0)</td><td colspan="2">III. Draw 2 arrows, such as a <u>downward</u> arrow, a rightward arrow and an arrow following the trajectory.</td><td rowspan="2">(N=2)
(2%)</td></tr>
<tr><td>III(a)
Pre-test(N=0)
Posttest(N=1)
</td><td>III(b)
Pre-test(N=0)
Post-test(N=1)
</td></tr>
<tr><td>N=2</td><td colspan="2">IV. Other.</td><td>N=3</td></tr>
<tr><td colspan="4"></td></tr>
</table>

Pre-test (N=49)	Patterns of students' drawings at **position B**	Post-test (N=82)
(N=19) (39%)	I. Draw one arrow following the trajectory.	(N=17) (21%)
(N=12) (24%)	II. Draw 2 or 3 arrows, such as an upward arrow, a rightward arrow, and a vector with its xy-components. II(a) Pre-test(N=6) Post-test(N=23)  II(b) Pre-test(N=6) Post-test(N=12) 	(N=35) (43%)
(N=9) (18%)	III. *Draw only a rightward arrow. 	(N=13) (16%)
(N=3) (6%)	IV. Draw 2 or 3 arrows, such as a rightward arrow, a downward arrow and a vector with its xy-components. IV(a) Pre-test(N=3) Post-test(N=5)  IV(b) Pre-test(N=0) Post-test(N=5) 	(N=10) (12%)
(N=6) (12%)	V. Other	(N=7) (9%)

Pre-test (N=50)	Patterns of students' drawings at **position C**	Post-test (N=76)
(N=19)(38%)	I. Draw one arrow following the trajectory.	(N=17)(22%)
(N=16)(32%)	II. Draw 2 or 3 arrows, such as an upward arrow, a rightward arrow, and a vector with its xy-components. II(a) Pre-test(N=6) Post-test(N=16)  II(b) Pre-test(N=10) Post-test(N=10) 	(N=26)(34%)
(N=8)(16%)	III. Draw 2 or 3 arrows, such as a downward arrow, a rightward arrow and a vector following the trajectory with its xy-components. III(a) Pre-test(N=5) Post-test(N=12)  III(b) Pre-test(N=3) Post-test(N=8) 	(N=20)(26%)
(N=4)(8%)	IV. Draw a vector with its components shown in the following figure. 	(N=5)(7%)

(N=3)	V. Other.	(N=8)
Pre-test (N=47)	Patterns of students' drawings at **position D**	Post-test (N=63)
(N=19)(40%)	I. Draw one arrow following the trajectory.	(N=17)(27%)
(N=9)(19%)	II. Draw 2 or 3 arrows, such as an upward arrow, a rightward arrow and a vector with its xy-components.	(N=17)(27%)
	II(a) Pre-test(N=4) Post-test(N=11)  II(b) Pre-test(N=5) Post-test(N=6) 	
(N=7)(15%)	III. Draw 2 or 3 arrows, such as a downward arrow, a rightward arrow and a vector following the trajectory with its xy-components.	(N=17)(27%)
	III(a) Pre-test(N=4) Post-test(N=11)  III(b) Pre-test(N=3) Post-test(N=6) 	
(N=12)	IV. Other.	(N=12)
Pre-test (N=45)	Patterns of students' drawings at **position E**	Post-test (N=59)
(N=19)(42%)	I. Draw one arrow following the trajectory	(N=17)(29%)
(N=9)(20%)	II. Draw 2 or 3 arrows, such as a downward arrow, a rightward arrow and a vector following the trajectory with its xy-components.	(N=18)(31%)
	II(a) Pre-test(N=7) Post-test(N=4)  II(b) Pre-test(N=2) Post-test(N=14) 	
(N=8)(18%)	III. Draw 2 or 3 arrows, such as an upward arrow, a rightward arrow and a vector with its xy-components.	(N=13)(22%)
	III(a) Pre-test(N=4) Post-test(N=9)  III(b) Pre-test(N=4) Post-test(N=4) 	
(N=9)	IV. Other.	(N=11)

There are three main patterns of students' drawings at point A shown in table A2. We found that most students (63% before instruction and 75% after instruction) knew that the ball was going up by drawing an upward arrow (pattern I). However, they were careless of the vector's length. Most students drew a vertical arrow at position A longer than that of the starting vector presented in the item. Many students drew a vector following the trajectory with non-corresponding xy-components (pattern I(b)). Correctly, they have to draw the shorter upward arrow and the identical rightward arrow with the starting arrows.

At position B, the highest point of the projectile motion, we found that fewer than 20% of these students correctly understood that the vertical velocity at this point is zero. They drew only one rightward arrow, but different lengths with the starting vector (pattern III) representing prior knowledge of horizontal velocity vector. Both before and after the instruction, many students drew one arrow following the trajectory (pattern I), and two or three arrows with at least one upward arrow (pattern II).

At point C, before the instruction, the first two students' popular ideas were pattern I (38%) and II (32%), similar to those of point A and B. But after the instruction, 26% of the students knew that the ball moved downward (pattern III). Similarly, at point D in pre-test many students drew one arrow following the trajectory (pattern I, 40%), and two or three arrows with at least one upward arrow (pattern II, 19%). In post-test, of about 27% of the students knew that the ball moved downward (pattern III). Three main patterns of the students' drawings in every position are 1) drawing one arrow following the trajectory; 2) drawing two or three arrows with at least one upward arrow; and 3) drawing two or three arrows with at least one downward arrow. Overall, the misconception involving a velocity vector followed the trajectory of the projectile still remained after the instruction. Moreover, we found that in post-test only 19% of these students knew that at point C, D and E the ball moved downward. Of about 30% of the students in post-test correctly drew the xy-components of a vector. Our results indicated that the students strongly held their prior knowledge after the traditional teaching method. This is ineffective of traditional physics instruction as mentioned by several works in physics education research (Hestenes, 1987; Thornton and Sokoloff, 1998; McDermott and Shaffer, 1992).

1.2) Mark √ in the table that agrees with the magnitude and direction of the ball's <u>acceleration</u> ($\vec{a}_{ball}$) at position A, B, C, D and E, and give your reasons.
(Define: g is the magnitude of the acceleration due to gravity)

Position	Magnitude of $\vec{a}_{ball}$					Direction of $\vec{a}_{ball}$			
	= 0	= g	< g	> g	Give reasons	upward	downward	none	Give reasons
A		√			Only a force due to gravity acting on the projectile.		√		Acceleration due to gravity is downward direction.
B		√					√		
C		√					√		
D		√					√		
E		√					√		

Results for item 1.2

We found that after the instruction only 4 out of 67 students correctly identified that at every position the ball's acceleration is equal to the gravitational acceleration, marked $a_{ball} = g$ and point downwards and gave correct reason. Other students' responses with or without explanations were categorized and shown in table A1.2.

Table A1.2: Students' answers for item 1.2 at position A, B, C, D, and E in pre-and post-tests.

Position	Students' answers about magnitude and direction of $\vec{a}_{ball}$ with/without reasons				
A	Pre-Test (N=57)	$a_{ball} = 0$ (N=12)	$a_{ball} = g$ (N=1)	$a_{ball} < g$ (N=23)	$a_{ball} > g$ (N=21)
		Upward direction (N=37)			
		(N=6)	(N=1)	(N=17) It moves up.	(N=13)

		Not mark direction (N=20)			
		(N=6)	(N=0)	(N=6)	(N=8)
	Post-Test (N=67)	$a_{ball} = 0$ (N=14)	$a_{ball} = g$ (N=7)	$a_{ball} < g$ (N=11)	$a_{ball} > g$ (N=35)
		Upward direction (N=42)			
		(N=5)	(N=1)	(N=3)	(N=18)
		(N=1) There is only gravitational force acting on it.	(N=1) It has different gravitational forces acting on each position.	(N=2) It moves up.	(N=5) It moves up.
				(N=3) It moves against the gravitational force.	(N=3) It has no gravitational force acting on it.
		Not mark direction (N=15)			
		(N=5)	(N=0)	(N=1)	(N=9)
		Downward direction (N=9)			
		(N=0)	(N=2)	(N=0)	(N=0)
		(N=2) There is an identical gravitational force acting on it every position.	(N=3) There is an identical gravitational force acting on it every position.	(N=2) It is accelerated.	(N=0)
		No direction (N=1)			
		(N=1) It is moving up.	(N=0)	(N=0)	(N=0)

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="17">B</td><td rowspan="9">Pre-Test
(N=52)</td><td>$a_{ball} = 0$ (N=10)</td><td>$a_{ball} = g$ (N=20)</td><td>$a_{ball} < g$ (N=12)</td><td>$a_{ball} > g$ (N=10)</td></tr>
<tr><td colspan="4">Not mark direction (N=20)</td></tr>
<tr><td>(N=4)</td><td>(N=9)</td><td>(N=4)</td><td>(N=3)</td></tr>
<tr><td colspan="4">No direction (N=18)</td></tr>
<tr><td>(N=6) It is at the maximum position of the parabolic path.</td><td>(N=8) It is at the maximum position of the parabolic path.</td><td>(N=2)</td><td>(N=2)</td></tr>
<tr><td colspan="4">Upward direction (N=10)</td></tr>
<tr><td>(N=0)</td><td>(N=3)</td><td>(N=4) It moves upward.</td><td>(N=3)</td></tr>
<tr><td colspan="4">Downward direction (N=4)</td></tr>
<tr><td>(N=0)</td><td>(N=0)</td><td>(N=2)</td><td>(N=2)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="7">Post-Test
(N=63)</td><td>$a_{ball} = 0$ (N=21)</td><td>$a_{ball} = g$ (N=22)</td><td>$a_{ball} < g$ (N=6)</td><td>$a_{ball} > g$ (N=14)</td></tr>
<tr><td colspan="4">No direction (N=24)</td></tr>
<tr><td>(N=4)</td><td rowspan="5">(N=7)</td><td rowspan="5">(N=0)</td><td>(N=3)</td></tr>
<tr><td>(N=4) Its velocity is zero.</td><td rowspan="4">(N=1) It is at the maximum position of the parabolic path.</td></tr>
<tr><td>(N=3) It is at the maximum position of the parabolic path.</td></tr>
<tr><td>(N=1) It stops.</td></tr>
<tr><td>(N=1) It is a</td></tr>
</table>

		uniform motion			
		Upward direction (N=16)			
		(N=2)	(N=3)	(N=1)	(N=5)
		(N=1) There is only gravitational force acting on it.		(N=1) It moves up and the gravitational force acts on it.	(N=1) It moves up.
					(N=1) It moves against the gravitational force.
					(N=1) It is at the maximum position.
		Downward direction (N=12)			
		(N=3) Identical gravitational force acts on it every position.	(N=2)	(N=2) It moves down.	(N=1)
			(N=3) Identical gravitational force acts on it every position.		(N=1) It is above the X-axis.
		Not mark direction (N=11)			
		(N=2)	(N=7)	(N=2)	(N=0)
C	Pre-Test (N=50)	$a_{ball} = 0$ (N=1)	$a_{ball} = g$ (N=12)	$a_{ball} < g$ (N=20)	$a_{ball} > g$ (N=17)
		Downward direction (N=29)			
		(N=0)	(N=12)	(N=0)	(N=17)

		Upward direction (N=10)			
		(N=0)	(N=0)	(N=10)	(N=0)
		No direction (N=3)			
		(N=0)	(N=0)	(N=3)	(N=0)
		Not mark direction (N=8)			
		(N=1)	(N=0)	(N=7)	(N=0)
	Post-Test (N=63)	$a_{ball} = 0$ (N=4)	$a_{ball} = g$ (N=14)	$a_{ball} < g$ (N=30)	$a_{ball} > g$ (N=15)
		Downward direction (N=46)			
		(N=2) There is only gravitational force acting on it.	(N=5)	(N=11)	(N=9)
			(N=4) Identical gravitational force acts on it every position.	(N=6) It moves down.	(N=2) There is only gravitational force acting on it.
			(N=2) It moves down like a free fall motion.	(N=3) It is not acted by gravitational force.	(N=1) It moves down.
				(N=1) It moves against the gravitational force.	
		Upward direction (N=3)			
		(N=1)	(N=1)	(N=0)	(N=0)

		(N=1) There is only gravitational force acting on it.			
		Not mark direction (N=14)			
		(N=0)	(N=2)	(N=9)	(N=3)
D	Pre-Test (N=51)	a_{ball} = 0 (N=27)	$a_{ball} = g$ (N=15)	$a_{ball} < g$ (N=6)	$a_{ball} > g$ (N=3)
		Downward direction (N=21)			
		(N=12) It moves along the curve to the same level that it was launched.	(N=7) It moves down.	(N=2) It moves down.	(N=0)
		No direction (N=11)			
		(N=9)) It moves along the curve to the same level that it was launched.	(N=2) It moves along the curve to the same level that it was launched.	(N=0)	(N=0)
		Not mark direction (N=19)			
		(N=6)	(N=6)	(N=4)	(N=3)
	Post-Test (N=61)	a_{ball} = 0 (N=21)	$a_{ball} = g$ (N=26)	$a_{ball} < g$ (N=12)	$a_{ball} > g$ (N=2)

		Downward direction (N=35)			
		(N=7)	(N=9)	(N=4)	(N=0)
		(N=2) There is only gravitational force acting on it.	(N=4) There is only gravitational force acting on it.	(N=4) It moves down.	(N=1) It moves down.
		(N=1) It arrives the floor.	(N=1) It moves down.	(N=1) It is projectile motion.	(N=1) It has parallel direction with the gravitational force.
		No direction (N=14)			
		(N=2)	(N=7)	(N=0)	(N=0)
		(N=2) It moves along the curve to the same level that it was launched.	(N=2) It moves along the curve to the same level that it was launched.		
			(N=1) It has no gravitational force.		
		Upward direction (N=4)			
		(N=2)	(N=2)	(N=0)	(N=0)
		Not mark direction (N=8)			
		(N=5)	(N=0)	(N=3)	(N=0)
E	Pre-Test (N=53)	$a_{ball} = 0$ (N=15)	$a_{ball} = g$ (N=8)	$a_{ball} < g$ (N=17)	$a_{ball} > g$ (N=13)
		Downward direction (N=24)			

		(N=1)	(N=1)	(N=5)	(N=2)
		(N=2) It is the final position.	(N=7) It moves down.	(N=3) It falls below x-axis.	(N=3) It is falling down.
		No direction (N=11)			
		(N=6)	(N=0)	(N=2)	(N=2)
		(N=1) It arrives the floor.			
		Not mark direction (N=18)			
		(N=5)	(N=0)	(N=7)	(N=6)
	Post-Test (N=60)	$a_{ball} = 0$ (N=16)	$a_{ball} = g$ (N=10)	$a_{ball} < g$ (N=26)	$a_{ball} > g$ (N=8)
		Downward direction (N=32)			
		(N=2)	(N=7)	(N=8)	(N=3)
		(N=3) There is only gravitational force acting on it.		(N=3) It falls below x-axis.	(N=1) Its direction is parallel to the gravitational force direction.
				(N=1) There is only gravitational force acting on it.	(N=1) It moves down.
				(N=1) It is projectile motion.	
				(N=1) It is free	

				fall motion.	
				(N=1) It moves down.	
		Not mark direction (N=13)			
		(N=4)	(N=2)	(N=4)	(N=3)
		No direction (N=13)			
		(N=5)	(N=1) It arrives the floor.	(N=7)	(N=0)
		Upward direction (N=2)			
		(N=1)	(N=0)	(N=0)	(N=0)
		(N=1) There is only gravitational force acting on it.			

At position A, in the pre-test, 40% of the students marked the magnitude of a_{ball}<g and .pointed upward. After the instruction, most of them (63%) still believed that the direction of a_{ball} was upward. Some said because the ball moved up or against the gravitational force. This indicated the misconception that the direction of acceleration follows the direction of motion. Moreover, 52% of them claimed that the magnitude of a_{ball}>g using similar reasons.

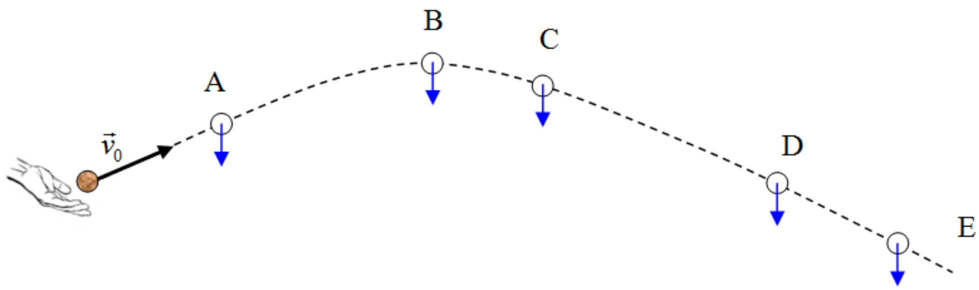
At point B, both before and after instruction, around 35% of the students marked $a_{ball} = g$, which is the correct magnitude, but only 8% of them in post-test knew that the direction of a_{ball} was downward. Furthermore, many students (19% in the pre-test, and 33% in the post-test) believed that at point B $a_{ball} = 0$. Some explained that because it is the highest point of the projectile path, the ball's velocity is zero or it stops for a while at that point. With very similar reason, many students said there was no direction of a_{ball}. These students' responses point to the misconception that the acceleration and the instantaneous velocity are always the same parameter (velocity-acceleration undiscriminated). Clearly, they believe that at point B the ball temporarily stops (velocity is zero), so the a_{ball} is zero, with no direction.

Students' responses at point C are quite similar to point A with a different direction. Many students (58% in the pre-test, and 73% in the post-test) said the direction of a_{ball} was downward. The popular reason was that because it moved downward. With the same idea, some claimed the magnitude of $a_{ball} < g$, or $a_{ball} > g$.

For position D, which is the same level with the starting point, we found that many students believed $a_{ball} = 0$ because the ball returned to the same level. This implies to the misconception that the acceleration is the displacement. When the ball goes and returns to the same position, its displacement will be zero.

At point E, we found that many students still believed that the direction of a_{ball} was downward because it moved down. Moreover, many students (32% in the pre-test, and 43% in the post-test) marked the magnitude of $a_{ball} < g$. Some gave the reason that because the ball was below the x-axis. It reflects the confusion ideas about the number over and below the x-axis, and the position of the ball.

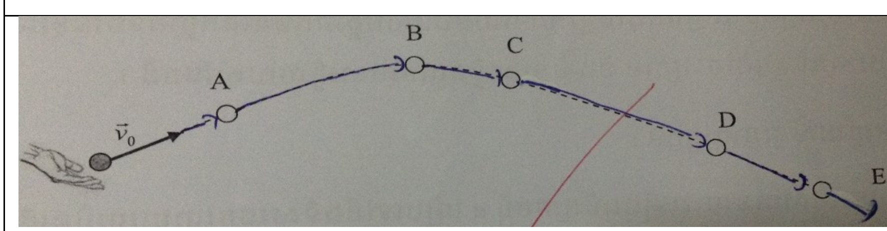
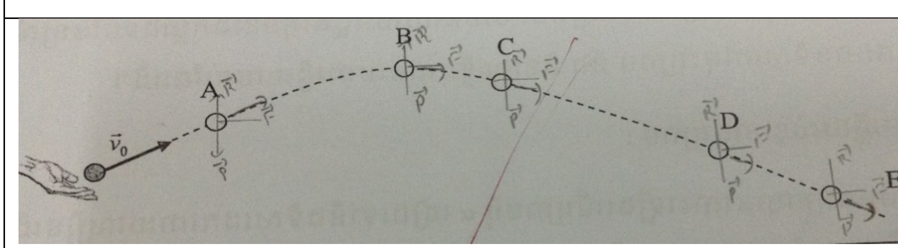
1.3) Identify and draw arrows to indicate the direction and magnitude of the <u>force(s)</u> acting on the ball at position A, B, C, D and E.

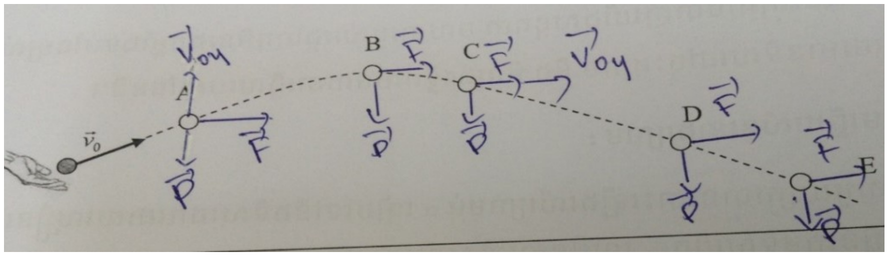
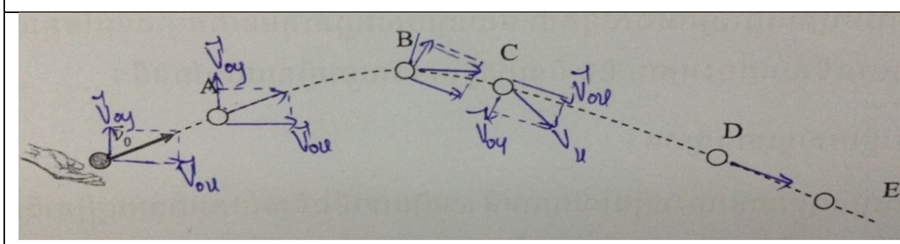
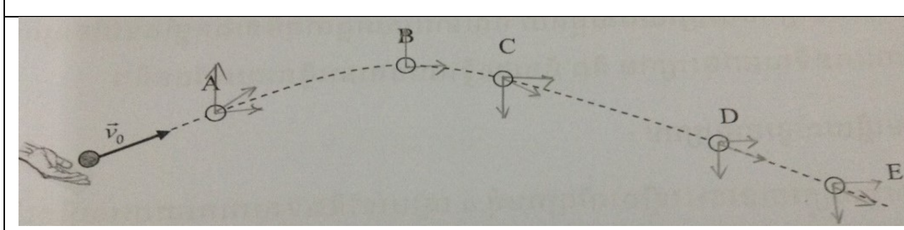


Force(s) acting on the ball is(are)......... a force due to gravity................................

Results for item 1.3

Table A1.3.1: Students' responses for item 1.3 in pre-and post-tests.

Pre-Test (N=35)	Patterns of students' drawings	Post-test (N=62)
(N=25) (71%)	I. Draw one arrow at each point following the trajectory. 	(N=24) (39%)
(N=2) (6%)	II. Draw two or three arrows, such as a rightward arrow, a downward/upward arrow and an arrow following the trajectory and indicate as a hand force, a gravitational force, and a reaction force. 	(N=6) (10%)

		
(N=0)	III. Draw two or three arrows, such as a rightward arrow, a downward/upward arrow and an arrow following the trajectory and name "v". 	(N=16) (26%)
(N=8) (23%)	IV. Draw two or three arrows, such as a rightward arrow, a downward/upward arrow and an arrow following the trajectory <u>without name</u>. 	(N=14) (23%)

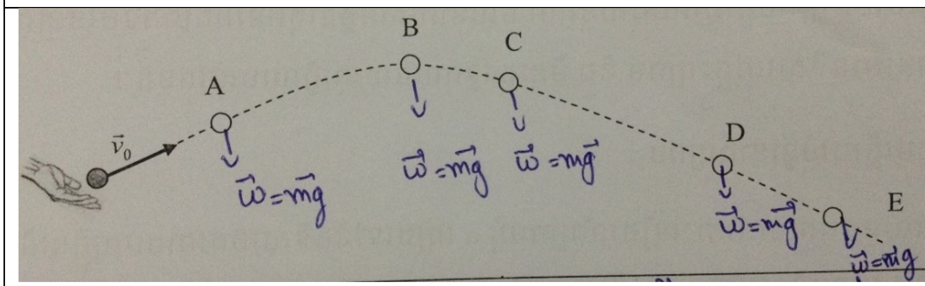
(N=0)	*V. Draw an arrow of gravitational force. 	(N=2) (3%)

Table A1.3.2: Forces which students write for item 1.3 in pre-and post-test.

Pre-test (N=21)		Post-test (N=58)	
Student's answer	Percent of students	Student's answer	Percent of students
Hand force	43	*Gravitational force	43
Hand force, gravitational force and reaction force	33	Gravitational force and hand force	24
*Gravitational force	24	Applied force	10
		Projectile force	10
		Gravitational force and its weight	7
		Net force	5

Results for item 1.3 in table A1.3.1 showed that many students (71% in the pre-test, and 39% in the post-test) drew an arrow at every position of the ball following the trajectory to identify a force. It is possible that the students believe the force is in the direction of the motion. The misconception, involving a moving object always has a force acting on it in the direction of motion, was also reported by Toa and Gunstone in1999, and Prescott and Mitchelmore in 2005.

Moreover, students' drawings in pattern II showed the belief that if we draw the gravitational force, we have to draw the reaction force in the opposite direction. This may be from the misunderstanding of a free-body diagram concept, or the unclear idea of the third Newton's law of motion. In pattern III, after the instruction, 26% of the students named an arrow that they drew as "a velocity". It points to the confusion between the acceleration and velocity of the students, or the careless in reading the question. Moreover, results in table A1.3.2 displayed that many students had the misconception that a force is needed to maintain the motion of an object. They then created a hand force (76% in the pre-test, and 24% in the post-test), an applied force (10% in the post-test), and a projectile force (10% in the post-test). They believed that this force sticks with the ball and make the ball move following the path. This misconception also found in a research of Prescott and Michelmore in 2004; Hestenes, Wells, and Swackhamer in 1992; Tao in 1997.

3. A ball is fired by cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?

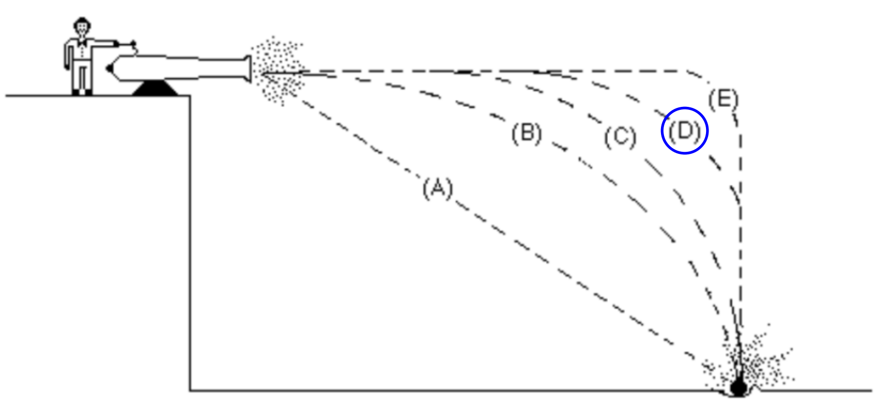


Table A3 Students' responses to item 3 on pre-post tests

Paths	Pre-test (N=93) % of students' answer	Post-test (N=119) % of students' answer
A	1	0
*B	41	38
C	46	55
D	7	5
E	2	0

This item was taken from a well-known conceptual assessment instrument called the Force Concept Inventory (FCI) developed by Hestenes and colleagues in 1992. Choices of the FCI were from responses to open-ended questions. They found that students often drew path C, D or E to display their misunderstanding. They believed that in the firing of a cannon ball, the force of cannon (impetus) is greater than the weight of the ball so it makes the ball moves in a straight line. After that, the initial impetus slowly reduces and the downwards gravitational force gradually acts on the ball so the net force makes the ball moves as a curve. Ultimately, the impetus lost, the only downward force acts on the ball so it makes the ball falls straight down. This is the Albert of Saxony idea in the 14th century, presented by Prescott (2004). In our study, we found that path C is the most popular choice, with 46% (55%) of the students' responses on pre-and post-tests. In fact, the fired ball follows path B and there is only gravitational force always acting on it. Moreover, we found that after the traditional instruction most students still unchanged their misconception, and the amount of students who selected the correct answer decreased. This implies to the ineffective teaching and learning methods used in the classroom (Hestenes, Wells, and Swackhamer, 1992).

4. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction with a constant speed.

4.1 The path would the ball most closely follow after leaving the airplane, <u>observed by a person standing on the ground</u> and viewing the plane, is……D……………………………………..

4.2 The path would the ball most closely follow after leaving the airplane, <u>observed by a pilot sitting on the airplane</u>, is……B………………

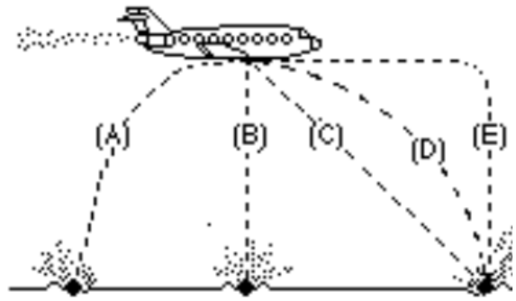


Table A4.1 Students' responses to item 4.1 on pre-post tests

The path observed by a person standing on the ground and viewing the plane.		
Paths	% of students' answer in Pre-Test (N=108)	% of students' answer in Post-Test (N=119)
A	33	34
B	37	45
C	9	5
*D	19	16
E	2	0

Again, this item was from the FCI, and we added more for item 4.2. Item 4.1 focuses on the path of the ball observed by a person standing on the ground and viewing the plane. On pre and post-tests, 33-34% of students chose path A, which presented that the ball will move backward and land behind the point of its falling off (ignore air resistance). It may reflect that students could not forget about the effecting of the air resistance in daily life. Students are quite difficult to get the Newton's idea of motion. On pre-test (post-test), 37% (45%) of students chose path B. The students imagined with regardless of air resistance that the ball will fall straight down to the point where it was fallen. Path A or B, students carried on the intuitive theory of mechanics that was widely held by philosophers in the three centuries before the Newton period. Somehow, less than 20% of students could correct answer (path D). In fact, the ball will continue to move forward at the same speed as the airplane and it moves downward at a steadily increasing speed (constant acceleration) that can be drawn as parabolic trajectory. Our results are similar to a research of McCloskey in 1983.

Table A4.2 Students' responses to item 4.2 on pre-post tests

The path observed by a pilot sitting on the airplane.		
Paths	% of students' answer in Pre-Test (N=104)	% of students' answer in Post-Test (N=111)
A	43	33
*B	31	37
C	13	14
D	13	15
E	0	0

Item 4.2 focuses on the path of the ball observed by a pilot sitting on the airplane. Although these two items have different observers, choice A still be the most popular incorrect idea. They may hold similar misconception presented in item 4.1. Interestingly, we found that the most frequent pair of responses was part B for item 4.1 and part A for item 4.2 (29% on pre-test and 28% on post-test). Semi-interview results with some students showed that their misconception are from everyday life experiences they encountered, such as when they drop a plastic bag during sitting on a moving car (motorcycle). They see that the plastic bag continuously moves similar to path A. And a

person standing on the ground would see the bag falls straight down in front of him/her. Moreover, of about 5% of the students chose the same response for both items.

5. A block slides along a frictionless ramp. Draw the arrow to represent the direction of the acceleration of the block at position A, B and C (after leaving the ramp).

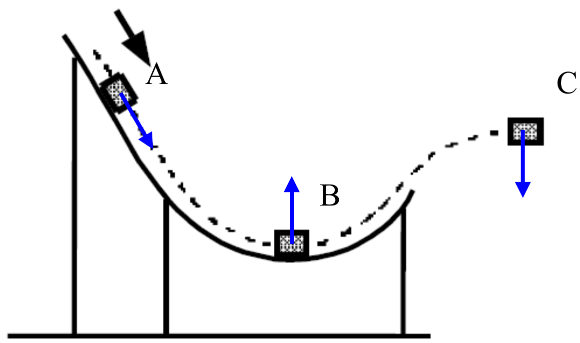
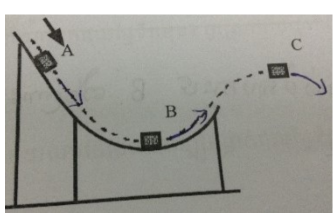
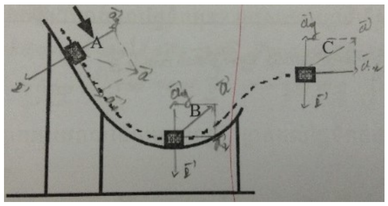
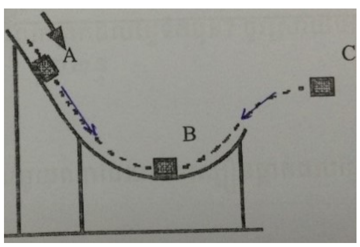
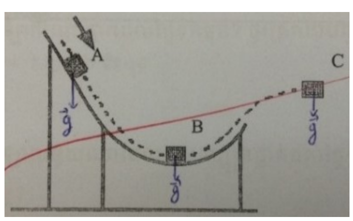
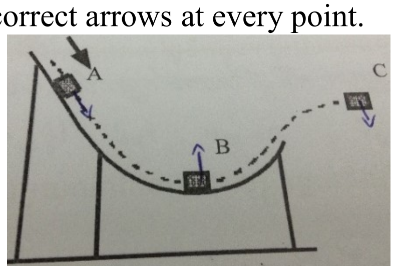


Table A5 Students' responses to item 5 on pre-post tests

Patterns of students' answers	% of responses on pre-test (N=50)	% of responses on post-test (N=55)
I. Draw one arrow following the trajectory at every position. 	86%	62%

II. Draw 2-4 arrows to indicate an acceleration and its components. 	6%	18%
III. Draw one forward arrow along the part at point A, and one backward arrow at point C. 	8%	9%
IV. Draw a downward arrow named **g** at every position. 	0	4%
*V. Draw correct arrows at every point. 	0	4%

This question aims to measure whether students are able to distinguish three kinds of motions: linear motion, circular motion, and projectile motion. We found that 86% (62%) of students on pre-test (post-test) drew an arrow following trajectory at every position to indicate the direction of accelerations. This implies the students' belief that the acceleration direction is in the direction of motion. Similar to pattern III, 8-9% of the students assumed that the acceleration direction is starting from the higher position to lower position. This also mentioned the confusion between position and acceleration, as reported in Trowbridge and McDermott (1996). Moreover, 18% of students on post-test tried to find components of the accelerations at every point (pattern II), students might forget about constant velocity along the ram (friction less). Many previous researchers documented that traditional instructions have a little effect of changing students' interpretation and prediction of motions in the World to Newton's idea (Tao, 1996). In fact, at position A, its acceleration direction is along trajectory because the block is moving on the incline followed by the Newton's second law. At position B, there is only the radial acceleration pointing to the center of the circle curve as the circular motion. At position C, the block is going to move as projectile motion and there is only the downward direction of the gravitational acceleration after it leaves from the ramp. This was shown in pattern V.

7. A girl throws a ball in the horizontal direction as shown in the figure below. Which of the paths would the ball most closely follow?

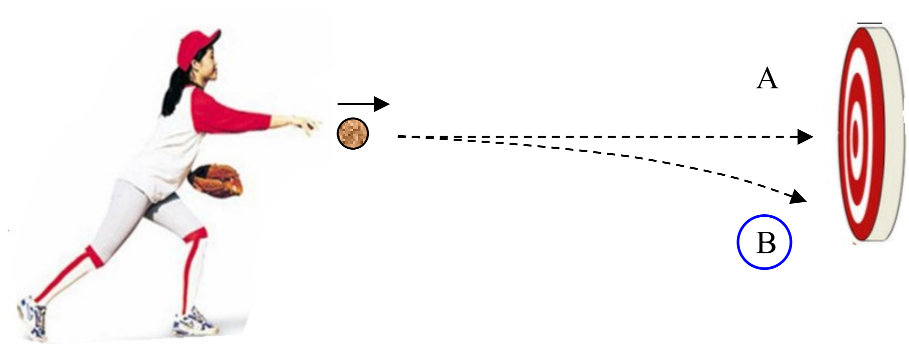


Table A7: Students' responses to item 7 on pre-post tests

Paths	% of students' answer in Pre-test (N=98)	% of students' answer in Post-test (N=116)
A	7	14
*B	93	86

Item 7 measures the students' ability to identify the parabolic trajectory of the projectile, similar to item 3 and 4, but different contexts. Results of item 7 much differed from the both items, in which of about 90% of the samples chose the correct choice B. Since item 7 has only two options, a straight line in choice A and a curve in choice B, it is possible that, for a simple situation, most students are able to identify that the path of the projectile motion is a curve. However, when there are more than one optional curve as shown in item 3, we found that around a half of the sample believed that a curve in choice C was a projectile' path. Moreover, the throwing ball situation presented in item 7 is similar to a shooting archery game, which many Cambodian students meet in everyday life. So it may be possible that an experience to win such game helps students to choose the correct choice B. Furthermore, some students explained that the situation in item 7 takes place close to the Earth surface so the gravitational acceleration does not change. In contrast, the situation in item 4 occurs far from the Earth surface, the gravitational acceleration changes and affects the path of motions. Some students believed that air resistance can be ignored for solving item 7 because of the short path of motion, so the hand force imparted with the ball leads the ball straight to hit the target. This misconceptions appear to be grounded in a systematic as intuitive theory of motion (McCloskey, 1983).

Appendix D

Lesson Plans

Lesson Plan

Here, we present another 2 lesson plans. The first one addresses the concept of item 1.1 and the second one strengthens students' background about velocity and acceleration of one dimension before starting projectile concept. We used the second one within one period follow the common class in Cambodia.

I. The objectives

Knowledge: Students give the definition of the projectile motion correctly following the instruction feedback and the textbook.

Skill: Students solve the problem of the vertical and horizontal of the velocity components correctly by practicing the equation of the path.

Attitude: Students practice the projectile motion in daily life by using the equation of the path to calculate altitude and horizontal range such as throwing a basketball, water spray, kicking the ball.

II. Content

Chapter 1: Mechanics, Lesson 1: Motion in space

1.1 Projectile motion

a) The equation of the path of the projectile motion

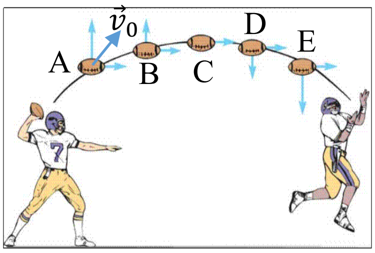
III. Instruments

-Student textbook at page 5-6 published in 2009

- Teacher book and quiz, ball, and picture

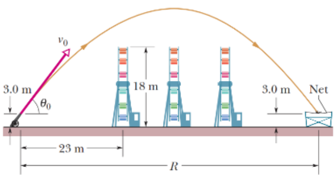
IV The instruction process (45 minutes)

IBL procedure	Teacher and students' activities
(1) Key questions **Quiz (5 min.)** A baseball player threw the ball with initial velocity $v_0 = 3m/s$ and angle $\alpha = 15°$ with horizontal direction. (neglect air resistant) Calculate the horizontal component v_x at point A, B, C, D, and E? And order the value of vertical velocity component at point A,	Students do the quiz

B, C, D, E from large to small?  	
(2) Hypothesis (5min.) Some students compute horizontal velocity at point A using equation $$v_x = v_0\ cos\alpha$$ $v_{xA} = 3 \times \cos 15 = 2.8m/s.$ The students have no idea about the constant horizontal velocity along the path. Most of the students could not calculate vertical velocity.	Students' responses are our hypothesis
Elicit questions (5 min.) -How do you shoot the ball into a basket? -How do you shoot the ball in the curve path? -Please describe the object move in projectile motion in daily life. **(3) Investigation (5min.)** Teacher throws a basketball moving in a curve path.	- We shoot the ball as a parabolic path or a curve path. - We shoot the ball at the angle θ above the horizontal. - Such as: water spray, kicking a ball, firing a ball, drooping a bomb from the airplane, shooting a basketball. - Students do the investigation on the movement of the basketball 

-Teacher separates students in 4 groups to define the equation of the projectile path.	Students sit in group 
(4) Analysis (15 min.) Teacher takes control if any groups have some questions or difficulty in analysing.	-Students analyze answering by discussing among the group. Students can also read from physics textbook. 
(5) Modelling (5min.) 	-The equation of the path: **-Object moves at a constant speed in a horizontal direction.** $$x = v_x t \Longrightarrow t = \frac{x}{v_x}$$ but $v_x = v_{0x} = v_0 cos\theta$ $$t = \frac{x}{v_0 cos\theta} \quad (1)$$ **The object moves vertically as a free fall motion**. $y = -\frac{1}{2}gt^2 + v_{0y}t$ or $y = -\frac{1}{2}gt^2 + v_0 sin\theta\ t$ Substitute (1) into the equation above $$y = -\frac{1}{2}g(\frac{x}{v_0 cos\theta})^2$$ $$+v_0 sin\theta\ (\frac{x}{v_0 cos\theta})$$

	$$y = -\frac{g}{(v_0 cos\theta)^2}x^2 + tan\theta.x$$
<u>(6) Evaluation (5min.)</u> -Students present their answer and provide the explanation on the whiteboard.  Teacher also gives feedback to the quiz at the first step related with the equation of the path.	Teacher gives feedback Some groups provide incorrect answer Techer provide feedback to follow their friends who have correct answers. Based on the equation of the path of a projectile. We compute the horizontal component v_x at position A, B, C, D, and E. $v_x = v_0\ cos\alpha$ $v_{xA} = 3 \times \cos 15 = 2.8m/s$ $v_{xA} = v_{xB} = v_{xC} = v_{xD}$ $= v_{xE} = 2.8m/s$ (constant along the trajectory) The baseball moves as a projectile motion. The vertical velocity is the change of the position respect to time. $v_{yA} > v_{xB};\ v_{yC} = 0;$ $v_{yD} < v_{yE}$ The horizontal and vertical velocities are vector components of an instantaneous velocity

Homework In 1939 or 1940, Emanuel Zacchini took his human-cannonball act to an extreme: After being shot from a canon, he soared over three Ferris wheels and into a net (Figure 3). Assume that he is launched with a speed of 26.5 m/s and at an angle of 53.0°. a) Treating him as a particle, calculate his clearance over the first wheel. b) If he reached maximum height over the middle wheel, by how much did he clear it? c) How far from the canon should the net's center be positioned (neglect air drag)? 	Students do homework at home.

The lesson plan addressing students' misconceptions of projectile trajectory

I. The objectives

Knowledge: Students recognize the projectile trajectory as the parabolic path correctly following the instruction feedback and the textbook.

Skill: Students draw correctly the parabolic path of a projectile in the worksheet following the demonstration.

Attitude: Students are interested in projectile trajectory instruments (spring-car) and compare with their beliefs in daily life.

II. Content

Chapter 1: Mechanics, Lesson 1: Motion in space

1. Projectile trajectory

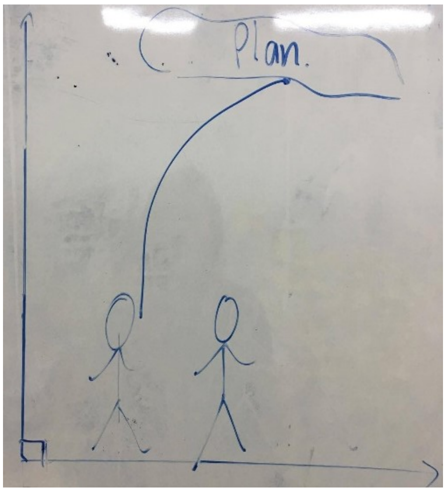
III. Instruments

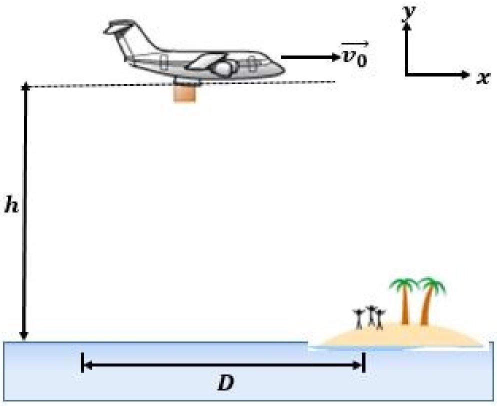
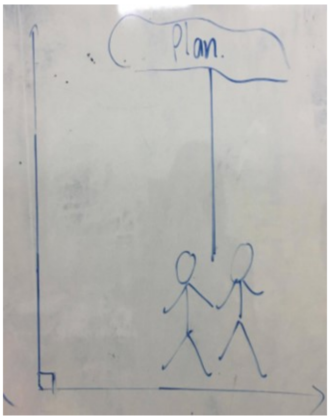
-Student textbook at page 3-4 published in 2009

- Teacher book

- Spring-car

IV The instruction process (45 min.)

IBL procedure	Teacher and students' activities
(1) Key questions **Quiz (5 min.)** A relief airplane is delivering a food package to a group of people standing on a very small island. The island is too small for the plane to land on, and the only way to deliver the package is by dropping it. The airplane flies horizontally with constant speed of $483 km/h$ at an altitude of $525\ m$. The positive x and y directions are defined in the figure. For all parts, assume that the "island" refers to the point at a distance D from the point at which the package is released, as shown in the figure. Ignore the height of this point above sea level. Assume that the acceleration due to gravity is $g = 9.8\ m/s^2$ (ignore air resistant)	Students do the quiz -Some students draw a curve path backward. 

	-Some students draw straight down. 
<u>(2) Hypothesis (5min.)</u> Students responses - The package lands behind its point of release to reach people standing on the island. - The plane drops the package straight down above people standing on island.	Students' responses are our hypothesis.
<u>(3) Investigation (15min.)</u> Teacher asks a few students to do the demonstration and the others to do the investigation. 	Students investigate the path of the ball dropping from a moving car. 

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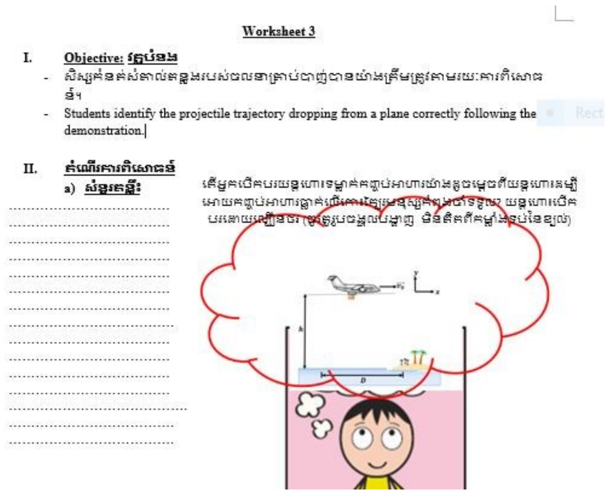
(4) Analysis (5 min.)

Students analyze the results and compare with their hypothesis.



</td>
<td>Students take notes on worksheet</td>
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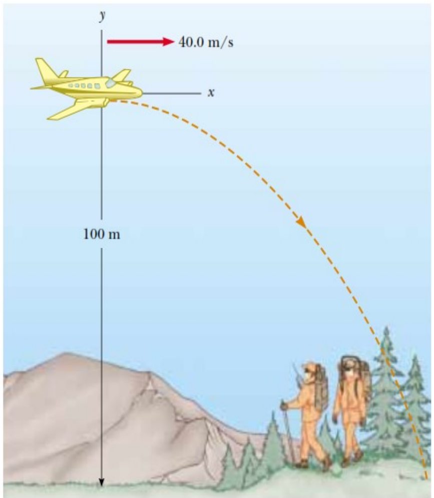
(5) Modelling (5min.)

Students draw their answers on the worksheet



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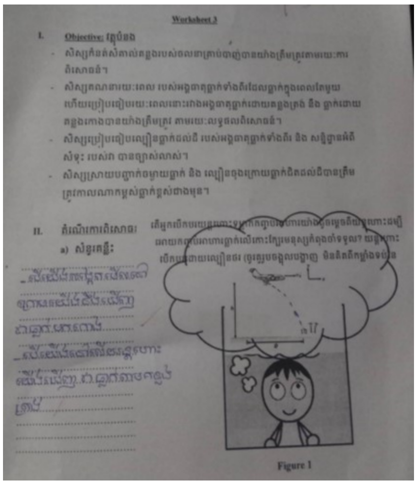
Students draw their answers on the worksheet.



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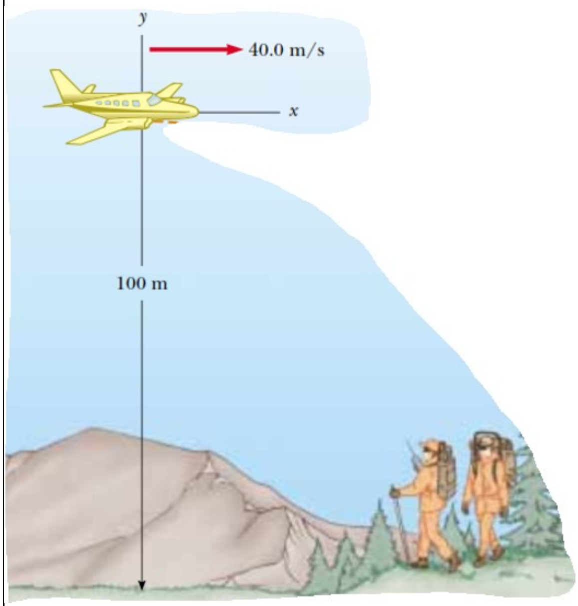
(6) Evaluation (5min.)

-Students present their answer and provide the explanation on the whiteboard.

</td>
<td>Teacher gives feedback
Some groups provide incorrect answers, teacher provides feedback to follow their friends who have correct answers and follow the model on the worksheet.</td>
</tr>
</table>

Homework An Alaskan rescue plane drops a package of emergency rations to a stranded party of explorers. If the plane is traveling with a constant horizontal speed at 40.0 m/s and is 100m above the ground, where does the package strike the ground relative to the point at which it was released? What are the horizontal and vertical components of the velocity of the package just before it hits the ground? Where is the plane when the package hits the ground? (neglect air drag)  	Students do homework at home.

Worksheet for projectile trajectory

Worksheet 3

I. Objective: វត្ថុបំនង

- សិស្សកំនត់សំគាល់គន្លងរបស់ចលនាគ្រាប់បាញ់បានយ៉ាងត្រឹមត្រូវតាមរយៈការពិសោធន៍។
- Students identify the projectile trajectory dropping from a plane correctly following the demonstration.

II. តំណើរការពិសោធន៍

a) សំនួរគន្លឹះ

How does the airplane drop the packed of the food to people standing on the ground?

The airplane flies at a horizontal constant speed. (ignore air resistant).

តើអ្នកបើកបរយន្តហោះទម្លាក់កញ្ចប់អាហារយ៉ាងដូចម្តេចពីយន្តហោះដម្បីអោយកញ្ចប់អាហារធ្លាក់លើកោះក្បែរមនុស្សកំពុងចាំទទួល? យន្តហោះបើកបរដោយល្បឿនថេរ (ចូរគូរូបចង្អុលបង្ហាញ មិនគិតពីកម្លាំងទប់នៃខ្យល់)

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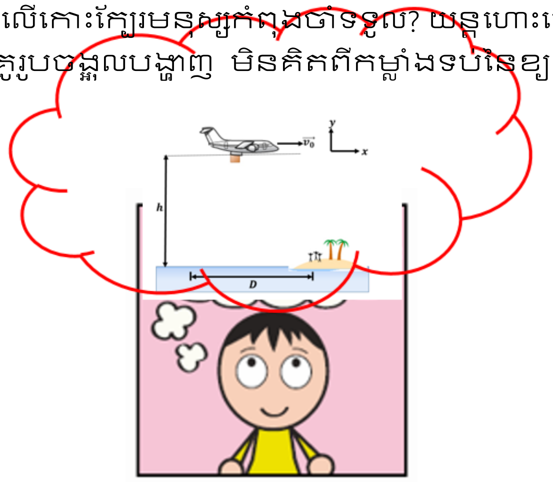

b) សម្មតិកម្ម

ចំពោះចលនាទន្លាក់សេរី (freely falling object)

$$H = \frac{1}{2} g t^2 + v_{0y} t$$ (កម្ពស់ធ្លាក់)

$$x = v_{0x} t$$ (ចម្ងាយធ្លាក់)

c) ឧបករណ៍ពិសោធន៍

(Demonstration set-up for projectile trajectory)

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d) តំណើរការពិសោធន៍ (Demonstration)

....

....

e) លទ្ធផល និង គំរូ (Results and models)

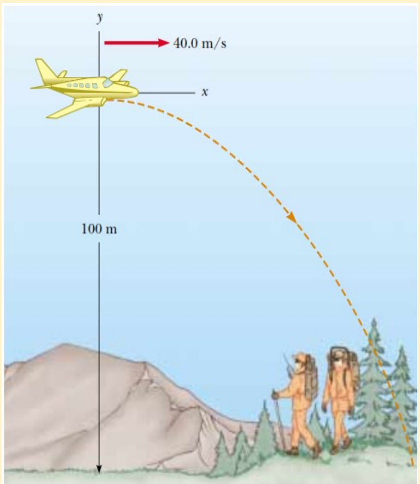
លទ្ធផល (Results)

ឡានរឺស័រផ្លាស់ទីដោយល្បឿនថេរគ្មានកកិត ទម្លាក់កូនឃ្លីទៅដី។ អ្នកសង្កេតម្នាក់ដាក់ក្រសែភ្នែកនៅនឹងដី សង្កេតឃើញគន្លងរបស់បាល់ជា Spring car is launched in a horizontal constant speed dropping a ball. An observer putting his eyes on the ball will see the ball move.……………………………

អ្នកសង្កេតម្នាក់ទៀតដាក់ក្រសែភ្នែកនៅនឹងឡានរឺស័រផ្លាស់ទី សង្កេតឃើញគន្លងរបស់បាល់ជា An observer putting his eyes on the car and see the path of the move.………………………………………………………………………………

Horizontal range $x =$……………………….

The height $H =$…………………………..



Model

$$H = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2H}{g}}, \quad x = v_{0x}t$$

Publications

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24-26 May 2017, Rayong, Thailand

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THAILAND

24 August 2017

Dear Authors,

I am pleased to inform you that, following the satisfactory completion of your revisions in response to the comments of the referees, your paper **"Cambodian students' prior knowledge of projectile motion"** **(ID:46)** has now been accepted for publication as a Research Paper in the Proceedings of Siam Physics congress 2017. This proceeding is a volume in the Journal of Physics: Conference Series (JPCS), which is part of IOP Conference Series and indexed in Conference Proceedings Citation Index – Science (CPCI-S) (Thomson Reuters, Web of Science), Scopus, etc.

The article will be published in the next available issue. Reprints of your paper will be available for download free of charge from JPCS website http://conferenceseries.iop.org/content/home.

Please note that the organizers are conforming to the IOP Publishing standard. For more information, please visit our website at http://spc2017.kasetsart.org.

On behalf of proceeding editors, I thank you very much indeed for publishing your work in the Proceedings of Siam Physics congress 2017, appeared in the Journal of Physics: Conference Series (JPCS).

Your sincerely,

(Asst. Prof. Apichart Pattnaporkratana, Ph.D.)

Editor

Cambodian students' prior knowledge of projectile motion

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Cambodian students' prior knowledge of projectile motion

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Abstract. Students always bring intuitive ideas about physics into classes, which can impact what they learn and how successful they are. To examine what Cambodian students think about projectile motion, we have developed seven open-ended questions and applied into grade 11 students before (N=124) and after (N=131) conventional classes. Results revealed several consistent misconceptions, for instance, many students believed that the direction of a velocity vector of a projectile follows the curved path at every position. They also thought the direction of an acceleration (or a force) follows the direction of motion. Observed by a pilot sitting on the plane, the falling object, dropped from a plane moving at a constant initial horizontal speed, would travel backward and land after the point of its release. The greater angle of the launched projectile creates the greater horizontal range. The hand force imparted with the ball leads the ball goes straight to hit the target. The acceleration direction points from the higher position to lower position. The misconceptions will be used as primary resources to develop instructional instruments to promote Cambodian students' understanding of projectile motion in the following work.

1. Introduction

Students' misconceptions are usually used as guidelines in developing instructional approaches to facilitate students' learning in a given topic. Survey the students' misconception is generally the first phase of the research. It can study from both correlated previous researches and the direct target group. In this study, the target group of learners is Cambodian high school students, who are less published on their teaching and learning. Moreover, the adversity from the damage in the Khmer Rouge regime (1975-1979) still impacts on the education system in Cambodia nowadays [1-2].

To help Cambodian students in grade 11 effectively learn physics on the projectile motion as a crucial concept of mechanics, their misconceptions are firstly investigated and presented in this article. The instrument is seven open-ended conceptual questions developed from previous researches, well-known physics textbooks and personal experiences of the researchers. Students' responses are categorized based on main ideas and compared with other references.

2. Design the open-ended questions

Seven open-ended questions (English version), designed in this study, cover main ideas of the projectile motion for a high school level namely velocity, acceleration, and force (Q1, Q2, Q5), travelling times (Q2), the trajectory (Q3, Q4, Q7), the highest point, the maximum range, and complementary angles (Q6). Q1 is shown in figure 1 as an example. The questions have been evaluated the agreement between an item and its behavioral objectives by eight physics experts (more than five-year experiences in teaching at a university level) via the item-objective congruence (IOC) form. The questions were modified technical terms and contexts following the experts' suggestions. After that, the questions were translated into Cambodian version, checked the matching translation, and revised by a group of experts to reach an acceptable Cambodian version.

3. Data collection

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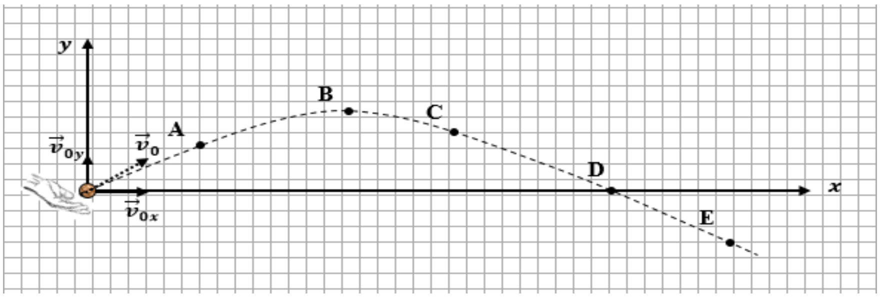
We applied the questions into 6 common classes of grade 11 students from a middle school located in Kampong Cham province, Cambodia. Data were collected from both before (N=124) and after (N=131) instruction. Normally, the instruction approaches in those classes are such as reading aloud the formal books by one student and others listen, lecturing, passive problem-solving by teachers and students take note, and question and answer method. These are general teaching methods found in common high schools in Cambodia. Approximately, teachers spend 6 periods in teaching the projectile motion. After the end of a class around 3 weeks, we asked the students to fill out the post-test. Questions on pre-test and post-test are the same. The students' responses to pre-test and post-test were analyzed and classified as shown in the following.

4. Results and discussion

This article presented results in details for only a part of Q1. Q1 consists of 3 sub-questions, as shown in figure 1.

Q1: A ball is thrown upward, at an angle, with the initial velocity $\vec{v}_0$. The horizontal component $\vec{v}_{0x}$ and vertical component $\vec{v}_{0y}$ of $\vec{v}_0$ are depicted in the figure below.



1.1 Draw arrows to indicate the horizontal and vertical components of the ball's velocity at position A, B, C, D and E. (Draw arrows into the figure.)

1.2 Mark √ in the table that agrees with the magnitude and direction of the ball's acceleration ($\vec{a}_{ball}$) at position A, B, C, D and E, and give your reasons. (Define: *g* is the magnitude of the acceleration due to gravity.) *(A table is provided for students to mark √.)*

1.3 Identify and draw arrows to indicate the direction and magnitude of the force(s) acting on the ball at position A, B, C, D and E. *(A blank and a figure are provided for students.)*

Figure 1. An example of Q1 about projectile motion used in this study.

Of about 90 students gave responses to Q1.1 in pre-and post-tests. But there were only 39 students on the pre-test, and 57 students on the post-test, who completely drew arrows at point A, B, C, D, and E of the ball. The others drew arrows only some points and left some. 49% (30%) of the students in pre-test (post-test) drew only one arrow at each point following the curved path, as shown in figure 2(a). The others drew 1, 2 or 3 arrows at each point, such as an arrow following the trajectory, rightward, downward, and upward arrows. An example was shown in figure 2(b). This indicates that most students had low background knowledge not only the projectile motion but also the vector concept, even though they were taught at a lower level. They had the misconception that a velocity vector laid over the curved path. Correctly, a velocity vector just contacts the parabolic path at a given point. Moreover, many students had the difficulty in representation the horizontal and vertical velocities with vectors, as shown in figure 2(b). They just drew upward or downward arrow, or a vector with non-corresponding components. Overall, after the passive instruction, many students still strongly held their misconceptions. It reflects ineffective of the traditional physics instruction as

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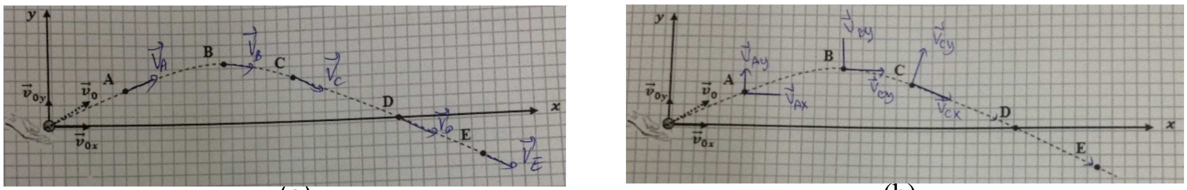
mentioned by several works in physics education research [3-4]. This also implies that the students have to be improved the understanding of the vector concept before the projectile motion class.



(a) (b)

Figure 2. Examples of students' drawings in Q1.1

In Q1.1 when we considered at each point, we found that at point A, most students (63% before instruction and 75% after instruction) knew that the ball was going up by drawing the upward arrow (connecting with the rightward arrow). However, they disregarded the vector's length. Most students drew a vertical arrow at point A longer than that of the starting vector presented in the question. Many students drew a vector laid over the trajectory with non-corresponding xy-components. In fact, they have to draw the shorter upward arrow and the identical rightward arrow with the starting arrows. At the highest point of the projectile path (B), we found that less than 20% of the students correctly understood that the vertical velocity at this point is zero. However, they drew one longer rightward arrow than the starting vector. It displayed misconception about the horizontal velocity of the projectile motion. Responses to point C, D and E were quite similar. Before (after) the instruction, less than 20% (35%) of the students drew the downward arrow (connecting with the rightward arrow). Most drew the upward arrow (connecting with the rightward arrow), and the arrow following the path.

Misconceptions found in this study	Other references
The acceleration and the instantaneous velocity are always the same parameters.	[7]
An acceleration is a displacement.	[7]
A moving object has positive velocity if it is located above xy position graph, and negative velocity if it is located below the graph.	[8]
A force is in the direction of motion.	[6], [9], [10]
Released at the same level, the object falling straight will hit the ground before the object moving as a curve because the former uses shorter distance.	[10]
Released at the same level, the object having a constant initial horizontal speed will hit the ground before the object moving without the initial speed because the former is faster.	[11]
Two projectiles with different initial horizontal speeds have different vertical accelerations.	[11]
The fired ball moves as a curve because in the first phase the impetus acting on it greater than its weight causes the ball moves as a straight line, then the initial impetus slowly reduces, and the downward gravitational force gradually acts on it at the middle phase. At the final phase, there is only the downward gravitational force acting on the ball causes the ball goes straight down.	[9],[11],[12],[13]
Observed by a person on the ground, the falling object, dropped from a plane moving at a constant initial horizontal speed, will travel backward and land after the point of its release.	[9, 11]
Observed by a pilot sitting on the plane, the falling object, dropped from a plane moving at a constant initial horizontal speed, will travel backward and land after the point of its release.	-
The greater angle of the launched projectile creates the greater horizontal range.	-
Theoretically, complementary angles of the launched projectile create different	-

horizontal distances.	
The hand force imparted with the ball leads the ball goes straight to hit the target.	[9], [12]

For responses to Q1.2, we found that most students believed the ball's acceleration at point B was zero. Many students though at point A and C the ball's acceleration is greater than *g* (or zero) because it is located above the x-axis, as well at point D and E the acceleration is less than *g* (or zero). The misconception about the direction of acceleration follows the direction of motion were also found in these students, similar to ref. [5-6]. The most popular misconception in Q1.3 was that a hand force (or thrown force) and a reaction force are forces acting on the ball.

In addition, we summarized misconceptions on projectile motion and other related concepts found in this study shown in the table.

5. Conclusions

Our study disclosed some misconceptions on the projectile motion from a group of Cambodian students in grade 11, which agreed with several references. Moreover, it indicated that the students still strongly held their prior knowledge after the conventional instruction. Students have to be revised their prior knowledge about vectors and motions in one dimension before the projectile motion class. This result will be used as a key resource to design the teaching tools to improve Cambodian students'understanding of projectile motion in a next step.

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References

[1] Sideth S D 2003 Basic Education in Cambodia: The Impact of UNESCO on Polices in the 1990s. *Education Policy Analysis Archives.* **11** 1-20
[2] Sam R et al 2012 Cambodia's Higher Education Development in Historical Perspectives (1863-2012). *International Journal of Learning and Development.* **2** 224-241
[3] Hestenes D 1987 Toward a modeling theory of physics instruction. *American Journal of Physics*. **55** 440-454.
[4] Thornton R K and Sokoloff D R 1998 Assessing student learning of newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active learning Laboratory and lecture curricula. *American Journal of Physics.* **66** 338-352
[5] Ping K T 1997 Confronting Students' Alternative Conceptions in Mechanics with the Force and Motion Microworld. *Computer in Physics*. **11** 1-25
[6] Ping K T and Richard F G 1999 The Process of Conceptual Change in Force and Motion during Computer-Supported Physics Instruction. *Journal of Research in Science Teaching*. **36** 859-882
[7] Mark L R and Lillian C M 1987 A Conceptual Approach to Teaching Kinematics. *American Journal of Physics*. **55** 503-513
[8] Awelani V M 2014 Pragmatic Review of Literature Associated with Projectile Motion Perceived as Difficult to Teach by Some South African Teachers. *Mediterranean Journal of Social Sciences.* **5** 441-445
[9] Michael M 1983 Intuitive Physics. *Scientific American.* **248** 122-130
[10] Anne P and Michael M 2004 *Student Misconceptions about Projectile Motion* (Reported part of a Ph.D. study). Macquarie University, Sydney, Australia.
[11] Robert J W 1983 Aristotle is not dead: Student Understanding of Trajectory Motion. *American Journal of Physics.* **51** 352-357
[12] Ibrahim A H and David H 1985 Common Sense Concepts about Motion. *American Journal of Physics*. **53** 1056-1065

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[13] David H, Malcolm W and Gregg S 1992 Force Concept Inventory. *The Physics Teacher*. **30** 141-158

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Evaluation of high school Cambodian students' comprehension of the projectile trajectory using the model analysis technique

written by So Piten and Suttida Rakkapao

This study aimed to investigate Cambodian high school students' understanding of the parabolic trajectory of a projectile, learned by the inquiry-based learning (IBL) approach, using the model analysis technique. An artificial car was set up to be applied in the investigation step of the IBL approach. The car was driven by spring force on a low friction wooden track and released a marble with a parabolic trajectory observed by the students. The study was conducted in three medium-sized high schools located in cities in Cambodia, with 204 students participating. The results revealed an average normalized gain at a medium level (= 0.31±0.03sd). The model estimation of the model analysis technique displayed a small shift of model points before and after the instruction and remained in the mixed model region.

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Evaluation of Cambodian high school students' comprehension of the projectile trajectory using the model analysis technique

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This study aimed to investigate Cambodian high school students' understanding of the parabolic trajectory of a projectile, learned by the inquiry-based learning (IBL) approach, using the model analysis technique. An artificial car was set up to be applied in the investigation step of the IBL approach. The car was driven by spring force on a low friction wooden track and released a marble with a parabolic trajectory observed by the students. The study was conducted in three medium-sized high schools located in cities in Cambodia, with 204 students participating. The results revealed an average normalized gain at a medium level (<g> = 0.31±0.03sd). The model estimation of the model analysis technique displayed a small shift of model points before and after the instruction and remained in the mixed model region.

I. INTRODUCTION

The low scientific knowledge of Cambodian students is concerned due to pedagogical barriers such as curriculum content, teaching and learning methods, and lack of equipment [1]. The education system was badly affected by the Pol Pot Regime (1975-1979) and in 1994, the Asian Development Bank (ADB) attempted both quantitative and qualitative improvements in the school system and curriculum in Cambodia but this resulted in only limited success [2].

Helping high school students in Cambodia to improve their understanding of science and technology is a fundamental key to developing the country. This work focused on understanding the parabolic trajectory of a projectile among grade 11 students. Based on the results of a preliminary study in 2016 (N=250), an inquiry-based learning (IBL) procedure was designed and administered to grade 11 students (N=204) in 2017. The normalized gain and model analysis techniques were employed to evaluate the students' conceptual understanding before and after the IBL instruction in this study.

II. INSTRUCTIONAL INSTRUMENTS

A. Conceptual questions on projectile motion

Seven conceptual questions relating to projectiles were developed, based on the Force Concept Inventory (FCI), well-known physics textbooks and personal experiences. In 2016, the seven questions were administered to 250 grade 11 students, before and after conventional instruction by the methods currently practiced in Cambodia, that is by one student reading aloud from a textbook and the others listening, lecturing by a teacher, and passive problem-solving by the teacher with the students taking notes. The results and the students' misconceptions revealed were used as the key resource in designing the IBL approach applied in 2017. The seven questions were used in pre-and post-tests in 2017. This article presents only the results relating to the parabolic trajectory of a projectile, therefore only three identical concept questions with different contexts are mentioned. Of these, two are Q12 and Q14 from the revised FCI [3] and the other, Q7 is based on personal experiences of the researchers as illustrated in Fig. 1.

B. A demonstration set for the projectile trajectory

A demonstration instrument was set up, which consisted of an artificial car (a modified PASCO car), a spring, a glass marble, a wooden track and carbon paper, as shown in Fig. 2. In the demonstration, the car carrying the marble is pushed against a spring which is compressed to varying degrees by which the speed of the projectile can be controlled. The value can be easily read from a ruler glued onto the track.

Q7. A girl throws a ball in the horizontal direction as shown in the figure below. Which of the paths would the ball most closely follow?

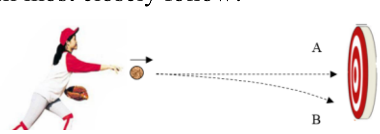

FIG 1. An example of conceptual questions on the parabolic trajectory of the projectile used in this study

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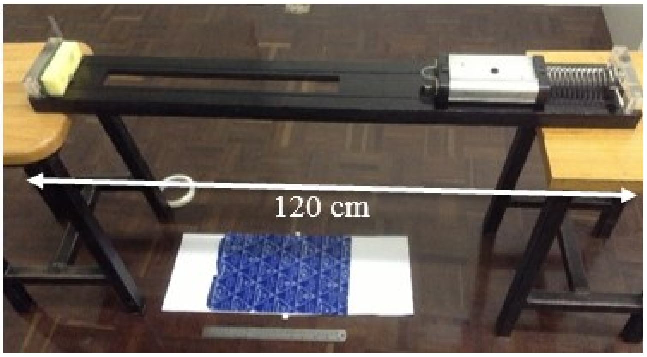

FIG 2. The set-up for demonstrating the projectile trajectory.

When the car is released, it moves on the low friction wooden track and drops the marble through a gap in the track. The marble has a constant horizontal speed before falling freely from the car.

In the classroom, students compared the traces on the white paper placed under the carbon paper between 2 situations: 1) the marble is directly dropped, and 2) the marble is released from the moving car. Moreover, this instrument motivated students to find the approximate horizontal speed of the marble, or study the times that a projectile takes to hit a target when released at different heights.

C. Inquiry-based learning (IBL) approach

To promote students' learning, this study employed the IBL approach comprising six main steps: 1) key question, 2) hypothesis, 3) investigation, 4) analysis, 5) model, and 6) evaluation [4]. In respect of the parabolic trajectory of a projectile, the teacher asks a *key question* such as "A rescue plane flies at a constant height and speed to drop a package of food to a victim on the ground. How does the plane drop the package to reach the victim? (Ignore air resistance)". Here are examples of *hypotheses* from the students "The plane flies directly above the victim and drops the package straight down on the victim" or "The plane flies beyond the victim and drops the package of food which lands behind its point of release to reach the victim". The teacher then explains the instrument and asks volunteer students to demonstrate the output as well as recording a video in order to *investigate* the trajectory of the projectile. The students *analyze* and discuss the demonstration results, the prediction and the physics principle. Next, the students conclude by drawing a *model* of the concept on their worksheet. At the end of the class, the teacher asks an *evaluation* question and gives feedback to the students.

III. DATA ANALYSIS TECHNIQUES

A. Normalized gain

The average normalized gain (<g>) was used to assess the students' improvement through learning, which is defined as the ratio of the difference between the average post-score and the average pre-score (or actual gain) to the difference between the full score and the average pre-score (or maximum possible gain). There are three levels of <g>: 1) high-gain for <g> ≥ 0.7; 2) medium-gain for 0.7 > <g> ≥ 0.3; and 3) low-gain for <g> < 0.3. The gain value indicates by how many times the learners improve from their maximum possible increase. Previous research results suggest that traditional instruction is only able to improve students' knowledge at a low level of gain (<g> < 0.3) [5] and this is widely used as the standard criterion for traditional methods for comparison with other instruction methods [6-7].

B. Model analysis

To study the movement of each student's mental model after the IBL intervention, model estimation of the model analysis technique was applied. The three questions focusing on the parabolic trajectory of the projectile in different contexts were used to activate the students' mental models. The students will apply different mental models to answer different questions and a single student's responses to a group of identical concept questions is displayed by a vector. All the vectors from the individual students in a class can then be summed to find the average. The average vector will thus reflect the probability of common model characteristics in the class.

For example, for three common mental models, the models can be represented by 3 orthonormal vectors in a linear vector space :

$$\mathbf{e_1} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}, \quad \mathbf{e_2} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \quad \mathbf{e_3} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \qquad (1)$$

where $\mathbf{e}_1$ is the correct model (model 1), $\mathbf{e}_2$ is an incorrect model (model 2), and $\mathbf{e}_3$ is a null model. The responses from a single student to the questions are used to construct a student model state with a vector of unit length $\mathbf{u}$ in the model space. The model state for the k^{th} student in a class can be shown as:

$$\mathbf{u}_k = \frac{1}{\sqrt{m}} \begin{bmatrix} \sqrt{n_1^k} \\ \sqrt{n_2^k} \\ \sqrt{n_3^k} \end{bmatrix} \qquad (2)$$

where n_1^k, n_2^k and n_3^k represent the numbers of the k^{th} student's answers corresponding to model 1, model 2, and model 3, respectively. m represents the total number of questions. The individual student vector is then used to construct a single student density matrix $\mathbf{D}_k$ where $\mathbf{D}_k = \mathbf{u}_k \otimes \mathbf{u}_k^T$. The class density matrix $\mathbf{D}$ is the average of the individual student density matrices in the class,

$$\mathbf{D} = \frac{1}{N}\sum_{k=1}^{N}\mathbf{D}_k = \frac{1}{N.m}\begin{bmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_2^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{bmatrix} = \begin{bmatrix} \rho_{11} & \rho_{12} & \rho_{13} \\ \rho_{21} & \rho_{22} & \rho_{23} \\ \rho_{31} & \rho_{32} & \rho_{33} \end{bmatrix} \quad (3).$$

The diagonal elements of the class density matrix reflect the percentage of the responses generated from the corresponding models used by the class. The off-diagonal elements reflect the consistency of the individual students' use of their models. Large off-diagonal elements signify low consistency (large mixing) for individual students in their model use. An off-diagonal element is significant if its value > 50% of its components [8]. Eigenvalues and their eigenvectors can also be calculated. The largest eigenvalue (>0.65) indicates that many single student model vectors are similar to each other, and they can be adequately represented by the corresponding primary eigenvector (υ_μ). The class model vector is the weighted average of all individual student model vectors. These can be presented in a model plot with a model point expressing the class model state as shown in Fig. 3. The model plot is a two-dimensional graph representing the class use of two models. It is divided into 3 regions accounting for the class model state in each concept, where model 1 is the correct model, model 2 is an incorrect model, and the middle is a mixed-model state. The two axes represent the probabilities that students in the class will use the corresponding models. The largest eigenvalue (σ_μ^2) and its primary eigenvector, denoted by $\upsilon_\mu = \begin{pmatrix}\upsilon_{1\mu} & \upsilon_{2\mu} & \upsilon_{3\mu}\end{pmatrix}^T$, are pointed on the model plot with the coordinates (P_2, P_1), where $P_1 = \sigma_\mu^2 \upsilon_{1\mu}^2$ and $P_2 = \sigma_\mu^2 \upsilon_{2\mu}^2$.

In this study, three models of the parabolic trajectory of the projectile were estimated for the three conceptual questions. Model 1 was the correct idea that the projectile trajectory is a parabolic path. Model 2 was the most popular misconception, that the impetus will make the projectile move in a curved or straight line [9-10]. Model 3 was a null model.

IV. DATA COLLECTION

In 2017, 204 grade 11 students from three medium-sized high schools located in cities in Cambodia (average age 17) participated in this research. Each class contained around 45-50 students. Before studying the projectile lesson, the students had studied the vector concept and one-dimensional motion in grade 10. The researcher spent six periods (45 minutes per period) teaching all topics of the projectile motion using the IBL approach, which replaced the in-service teachers' activities in the class. Pre-and post-tests were conducted respectively, before the instruction and around 3-4 weeks after it.

V. RESULTS AND DISCUSSION

The results relating to the three questions concerning the trajectory of a projectile, showed an average pre-test score of 31 ± 3, and an average post-test score of 52 ± 2 (full score =100). This revealed a middle level of normalized gain (<g> $=0.31 \pm 0.03$sd) and indicates an average improvement of 0.31 times of the maximum possible gain after the IBL instruction. This suggests that the IBL approach used in this study was able to promote the students learning of the projectile trajectory concept better than traditional teaching methods (<g> < 0.3 for traditional methods [5]).

Table 1 shows the results of the model analysis, and as can be seen from the diagonal elements of the pre- and post-tests class matrices, the percentage of students, who selected the correct model (model 1), was 41% before instruction, which increased to 62% after the IBL instruction. In contrast, the percentage of students, who selected the incorrect model (model 2), decreased from 55% to 34% after the instruction. Similarly, the off-diagonal elements of the class density matrices revealed significant mixing in model 1 and model 2 before (ρ_{12} =78%) and after (ρ_{12} =70%) instruction.

The IBL approach designed in this study was based on the preliminary results of Cambodian students' misconceptions in the year 2016. Most misconceptions agree

TABLE I. Class density matrices, eigenvalue, eigenvectors and model point in this study.

	Pre	Post
Class density matrix	$\begin{bmatrix} 0.41 & 0.37 & 0.02 \\ 0.37 & 0.55 & 0.03 \\ 0.02 & 0.03 & 0.04 \end{bmatrix}$	$\begin{bmatrix} 0.62 & 0.32 & 0.05 \\ 0.32 & 0.34 & 0.02 \\ 0.05 & 0.02 & 0.04 \end{bmatrix}$
Dominant eigenvalue	0.86	0.84
Primary eigenvector	$\begin{bmatrix} 0.64 \\ 0.77 \\ 0.04 \end{bmatrix}$	$\begin{bmatrix} 0.84 \\ 0.55 \\ -0.07 \end{bmatrix}$
(P_2, P_1)	(0.51, 0.35)	(0.25, 0.59)

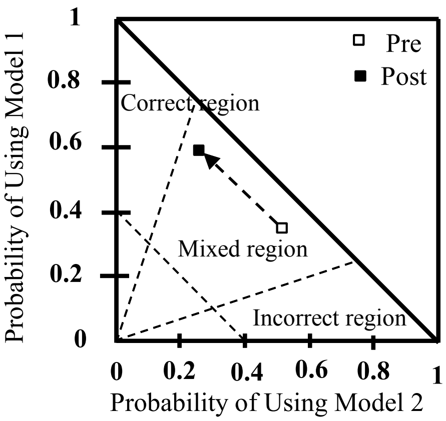

FIG 3. Model plot on the concept of the parabolic trajectory of the projectile taught by the IBL approach.

with those previously reported of ref. [9-10]. The most popular misconception about the parabolic trajectory of a projectile is that the impetus makes the projectile move in a curve or a straight line that the projectile travels and lands behind the point of its release. In this study, the demonstration set was developed to help the students to easily visualize the trajectory of the projectile. The students were engaged by using the *hypothesis* step, and they were asked to await the demonstration results in order to check their hypotheses. Overall, the classroom environment was interactive and the students enjoyed discussing with their friends and the teacher before and after the *investigation* step. The steps of the IBL approach help students to learn and transfer what they have learned to new contexts [11]. Moreover, in this study we found that most students were excited by and interested in our instrument since they had never seen it before. Many students paid a lot of attention to the instrument and the *key question*. They came to discuss with the teacher after the class, which is quite unusual in the atmosphere of a classroom in a high school in Cambodia. Based on the researcher's more than ten-years' experience in teaching high schools, normally after the class most children simply return home to help their parents work, with a few of them going to a tutoring school.

Moreover, as revealed by the model plot in Fig 3, there was a slight improvement in the mixed model states of the students' understanding after the IBL instruction. This reflected some difficulties in this work since, the projectile topic is strongly associated with the vector, and the force and motion concepts, and the students' understanding of those concepts impacted what and how the students learned. Further studies together with active learning activities and proper instructional instruments for Cambodian contexts are necessary to improve the science abilities and skills of learners.

VI. CONCLUSIONS

This study applied the IBL approach to help Cambodian high school students learn the concept of the parabolic trajectory of a projectile. Overall, the research found that this approach was able to improve the learning of the target students into the middle level of gain and there was a small movement of the model states in the mixed region. Although the approach may not have enabled the students to progress to learning a completely correct model, it was able to change some of the confused states, which is a sign of learning [12]. Physics education research is significantly required to enhance teaching and learning for Cambodian high school students.

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[1] K. Sothy et al., *Cambodia Education 2015 Employment and Empowerment* (Cambodia Development Resource Institute, Phnom Penh,2015), p. 132.
[2] S.S. Dy and A. Ninomiya, Educ. Policy. Anal. Arch **11**, 48 (2003).
[3] I. Halloun et al., (1995) Revised From 081695R .D. Hestenes et al., Phys. Teac, **30,** 141 (1992).
[4] CSMEE, *Inquiry and the National Science Education* Standards (The Center for Science, Mathematics, and Engineering Education, Washington, D.C. 1995), p. 143-152.
[5] R.R. Hake, Am. J. Phys, **66**, 1 (1998).
[6] B. Thacker et al., Phys. Rev. ST Phys. Educ. Res, **10**, 2 (2014).
[7] J. J. B. Harlow et al., Phys. Rev. ST Phys. Educ. Res, **10**, 1 (2014).
[8] L. Bao and E. F. Redish, Phys. Rev. ST Phys. Educ. Res, **2**, 1 (2006).
[9] M. McCloskey Sci, Am. **248,** 4 (1983).
[10] R.J. Whitaker, Am. J. Phys. **51,** 4 (1983).
[11] A. Cahill and S. Bloch-Schulman, Teach Philos **35**, 1 (2012).
[12] S.D. Melloa et al., Learn. Instr. **29**, 1 (2014).

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