# 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?

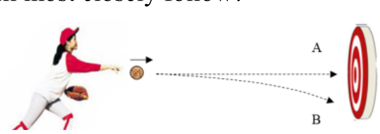


FIG 1. An example of conceptual questions on the parabolic trajectory of the projectile used in this study

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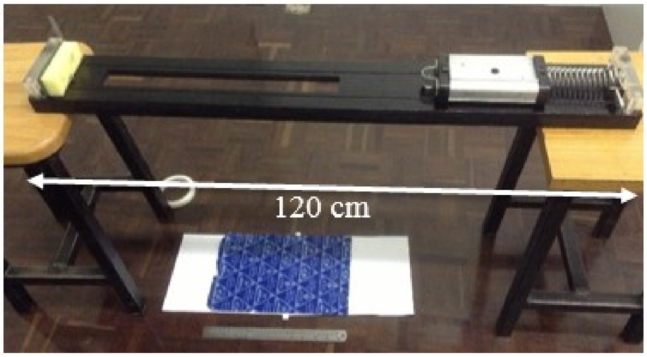


FIG 2. The set-up for demonstrating the projectile trajectory.

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 :

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

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:

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

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 ($\upsilon_\mu$). 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 ($\sigma_\mu^2$) 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 $31 \pm 3$, and an average post-test score of $52 \pm 2$ (full score =100). This revealed a middle level of normalized gain (<g> =0.31 ± 0.03sd) 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 ($\rho_{12}$ =78%) and after ($\rho_{12}$ =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) |

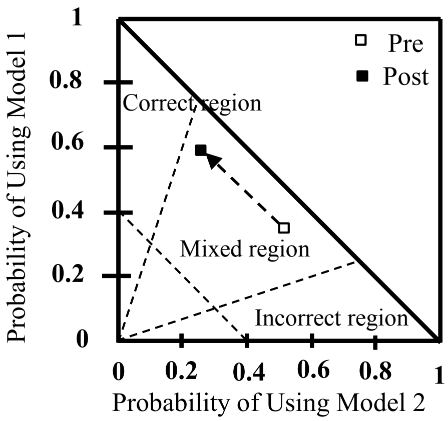


FIG 3. Model plot on the concept of the parabolic trajectory of the projectile taught by the IBL approach.

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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