

TEACHING PROJECTILE MOTION TO ELIMINATE MISCONCEPTIONS

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Student misconceptions of projectile motion are well documented, but their effect on the teaching and learning of the mathematics of motion under gravity has not been investigated. An experimental unit was designed that was intended to confront and eliminate misconceptions in senior secondary school students. The approach was found to be effective, but limited by the teacher's own misconceptions.

In New South Wales, Australia, projectile motion is taught in Year 11 physics and Year 12 advanced mathematics courses. In the public mathematics examination at the end of Year 12, performance on projectile motion problems is poor. Students appear to learn standard techniques by rote and to resort to intuition when questions become more difficult—often revealing basic misconceptions about projectile motion.

This paper describes an investigation of the role of student misconceptions in the teaching and learning of projectile motion in Year 12 advanced mathematics.

STUDENT MISCONCEPTIONS ABOUT PROJECTILE MOTION

Students develop personal “theories of motion” by generalising the ideas they acquire from observation of objects in everyday situations (Keeports, 2000; McCloskey, 1983b). The research literature shows that many student misconceptions result from a pre-Newtonian *impetus theory* of motion. Put briefly, this theory attributes motion to an impetus that is given to an object initially and is then gradually used up over time. Consequences for student beliefs include the following:

A fired object initially moves in the direction of firing. Only after some impetus has to be used up can gravity act and the object fall towards the ground (McCloskey, 1983a).

An object that is dropped from a moving carrier does not receive any impetus, and therefore tends to drop straight down (Millar & Kragh, 1994). However, air resistance and the speed of the carrier might affect the actual direction of motion.

If an object is moving, then there must be a force in the direction of motion (Tao & Gunstone, 1999).

Falling objects possess more gravity than stationary objects, which may possess none at all (Thagard, 1992; Vosniadou, 1994).

For further misconceptions and detailed references, see Prescott (2004).

DEALING WITH MISCONCEPTIONS

Only a few studies have attempted to change student misconceptions about projectile motion, and we found only two embedded in classroom situations (Gunstone, Gray, & Searle, 1992; Thijs, 1992). A common method has been that of *cognitive conflict* (Behr & Harel, 1990), described by Liew & Treagust (1995) as a *predict-observe-explain* teaching sequence. In Piagetian terms, the conflict between what was predicted and what is observed may lead to disequilibrium and the construction of a new cognitive structure (Tao & Gunstone, 1999).

A review of the research literature on cognitive conflict suggested that it would be most successful when:

- students are made acutely aware of their misconceptions
- discussion is a major element of the teaching/learning process
- common misconceptions are discussed explicitly in the classroom
- students reflect on projectile motion in a variety of familiar contexts
- teachers are aware of their own misconceptions as well as those of their students.

Again, details may be found in Prescott (2004).

THE TEACHING PROJECT

A research project was designed to test whether a unit on projectile motion based on the above principles would lead to a reduction in Year 12 students' misconceptions. The effect of student misconceptions on teaching and learning was also investigated.

Participants

Two classes in each of two independent girls' schools in the Sydney metropolitan area participated. The relevant classes in School A were graded: Class A1 was the top class. The classes at School B were not graded: Class B1 and Class B2 were parallel. In all, 47 students participated.

One teacher in each school (the teachers of Classes A1 & B1, known hereafter as Teachers A1 & B1) agreed to teach an experimental projectile motion unit. One other teacher in each school agreed to teach the topic as they had taught it for a number of years (Teachers A2 & B2). All four teachers were female, and all had been teaching for between 10 and 20 years. They all had excellent reputations as mathematics teachers within their schools and in the mathematics community.

Assessing misconceptions

A structured 15-20 minutes interview was developed to assess student and teacher misconceptions about projectile motion. The final version (Prescott, 2004) consisted of 16 printed questions (some sourced from the research literature, some original) describing a variety of projectile motion situations and posing a number of questions. Students wrote or drew their answers. The interviewer encouraged students to explain their answers while being careful to avoid any evaluative comment.

The students were interviewed prior to the unit on projectile motion and again three weeks afterwards. The teachers were interviewed after teaching the unit.

In the present paper, we shall concentrate on two scales derived from this interview: one assessing understanding of the motion of fired objects (8 items) and one assessing understanding of the motion of dropped objects (5 items).

The experimental unit

The first author designed experimental materials intended to confront students' misconceptions. The emphasis was on the understanding of concepts—qualitative understanding was sought before the usual quantitative approach was introduced. The materials consisted of the following:

- Detailed information on common misconceptions about projectile motion
- A website that would help the teachers understand the topic (Henderson, 2001)
- Notes on the use of cognitive conflict in predicting the path of dropped and fired objects
- Some suggested activities:
 - Using a videotape of a ball rolling off a bench, students graph the x and y coordinates against time.
 - Students predict the path and time of flight of two coins, one dropped and other fired at the same time (van den Berg & van den Berg, 1990).
 - Students imagine observing a projectile from a long distance, either in the plane of the motion or above it.
 - Students walk across the room and predict where to drop an object so that it lands on a target on the floor.
- Websites where students could explore the effects of varying the velocity and angle of projection as well as air resistance (Fowler, 1998; Stanbrough, 1998)

The teachers were not given lesson plans, but were asked to design their own lesson plans based on the above materials. Teachers were expected to provoke discussion of projectile motion in a number of contexts in the first lessons, and to refer back to these discussions when deriving equations of motion analytically in the later lessons.

Before the unit was taught, the first author held discussions with Teachers A1 and B1 individually to ensure that each teacher was comfortable with the lesson content and, more importantly, understood the ideas herself. During these discussions, both teachers admitted to having misconceptions about the trajectory of an object dropped from a moving carrier and about the time of flight of two objects simultaneously fired horizontally and dropped. These misconceptions were resolved by discussion.

No assistance was given to Teachers A2 and B2.

RESULTS

Firstly, we summarise what happened during the lessons (all of which were either video- or audiotaped). We then analyse changes in student understanding as shown by the fired and dropped objects scales. Finally, we look at teacher misconceptions.

The Experimental Lessons

Teacher A1 wrote a handout for her students based on the experimental materials. Because Teacher B1 was uncertain about her ability to work through the experimental material, these handouts were also offered to her. As a result, Classes A1 and B1 used the same handout and the lessons followed a similar course close to the intended sequence. After each activity, the teachers discussed the implications of the results in terms of the students' expectations and in terms of their knowledge about projectiles.

In introducing the idea of projectile motion, Teacher A1 included dropped objects as well as thrown or fired objects. A discussion followed about Wile E. Coyote and the Road Runner in the Warner Brothers cartoon and how they would in reality not run horizontally off a cliff and then suddenly fall vertically downwards. Teacher B1 only discussed fired objects.

Both teachers illustrated the horizontal and vertical components of motion by considering the vectors at several points along the trajectory of a projectile. They also discussed forces, emphasising that there is only one force (gravity) and that the vertical speed decreases by 9.8 m/s each second as the projectile rises and increases by 9.8 m/s each second on the way down. The vector diagrams also prompted a discussion of the vertical and horizontal velocity at the maximum height.

Discussion of the trajectories in the coins experiment raised many issues, including air resistance, friction, gravity, and the question (again) as to whether there was a horizontal force on the ball. These discussions were robust and gave students many opportunities to confront their misconceptions.

The students spent approximately 30 minutes playing with the suggested websites (Fowler, 1998; Stanbrough, 1998). This activity enabled them to "see" the impact of air resistance, and how different initial velocities and angles lead to different trajectories.

Finally the equations of motion were introduced via a simple problem, starting with the horizontal and vertical acceleration and integrating to find the x and y components of motion. The constants of integration were calculated from the initial conditions. During this part of the lessons and in subsequent work when the students asked about questions from their textbook, the teachers emphasised the link between this more abstract content and the earlier activities.

The lesson sequence of experimentation before formalisation allowed the students to become familiar with a number of different contexts before the introduction of the

algebraic techniques. The lesson transcripts show that the graphing, questioning, discussing, and web surfing provided a sound background for the algebraic approach.

The Traditional Lessons

Classes A2 and B2 both covered the topic in a similar manner. Teacher A2 included worked examples in class, while Teacher B2 spent the majority of the lesson time dealing with confusion over the algebra.

In the first lesson, both teachers talked very briefly about balls being thrown into the air. Several students showed that they had an impetus view of projectile motion:

S₁: Is it steeper to start with and then kind of drop a little bit?

S₂: It goes along and then drops

Without noting such misconceptions, both teachers then derived the equations of motion from the horizontal and vertical acceleration, presenting the analysis in general terms rather than using a specific question as a basis. The students were not very involved in the derivation of the equations of motion. The majority of students in both classes did not seem to understand the need for decomposing motion into horizontal and vertical components, and the teachers gave no reason in their “explanations”. Students had particular difficulty understanding the constants of integration, and in fact many of them did not seem to understand what was meant by the term “initial conditions”. Finally, in exasperation one student in Class B2 said

S₃: Just tell us in words without all the V’s and stuff. What’s the point of it?

After a long explanation about how the equations were parametric equations, Teacher B2 admitted that it was all “a little bit abstract”. To which the student replied:

S₃: I like things more concrete. I like to know what’s going on, especially if it’s a practical question. I need the practical explanation.

Changes in Students’ Understanding

Figures 1 and 2 show students’ mean scores on the fired and dropped objects scales in each class. In each case, the left hand column refers to the interview administered before the teaching and the right hand column refers to the interview administered afterwards. Recall that a higher score indicates fewer misconceptions.

Three of the four classes were initially very similar on the fired objects scale (Figure 1), with Class B1 unaccountably lower. Classes A2 and B2 showed no change after the teaching, but Classes A1 and B1 showed a substantial improvement. (Statistical tests could not be made because of the lack of random assignment and the small cell sizes.) However, in both experimental classes, there were still many students with misconceptions about the motion of fired objects.

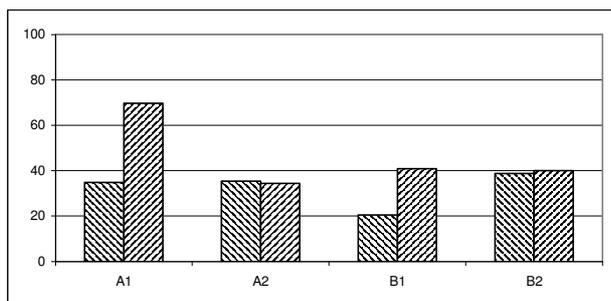


Figure 1: Mean percentage correct in each class for fired objects

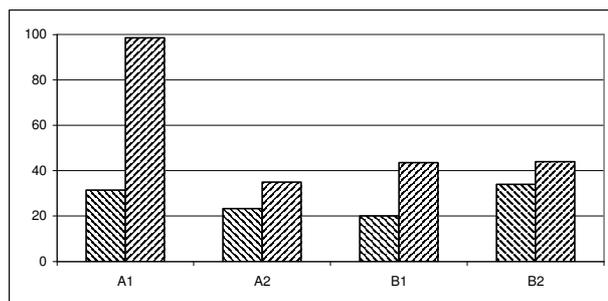


Figure 2: Mean percentage correct in each class for dropped objects

The four classes were also initially similar on the dropped objects scale (Figure 2). Although all classes showed an increase after the teaching, Classes A1 and B1 showed greater increases in mean scores (77% and 24% respectively) than Classes A2 and B2 (12% and 10% respectively). More importantly, all but one student in Class A1 showed they had no misconceptions.

These results indicate that the experimental teaching unit had the desired effect in reducing student misconceptions. But the effect was not uniform across the two scales and, with one exception, it was not very great.

Teacher Misconceptions

There were several times when the teachers revealed their own misconceptions about projectile motion, thus reducing the effectiveness of their teaching.

Although Teacher A1 generally showed an excellent understanding of projectile motion, she did once slip inadvertently into impetus theory: In a discussion about what happens at the maximum height of the trajectory, she incorrectly stated that the projectile “starts to be affected by gravity”.

Teacher B1 was not consistent in her understanding of projectiles launched from a moving carrier. She correctly used an example of throwing car keys in the air while walking as an example of projectile motion. However, she became confused when a student mentioned a newspaper article in which a number of stowaways were reported to have fallen from an aeroplane wheel bay into an airport car park. Teacher B1 concluded incorrectly that the wheel bays were opened right above the car park, and no student protested. Through this one example, she negated much of the conflict created by the earlier examples.

Teacher B2 did not seem to understand gravity:

- T: Because gravity is the deceleration of an object. Gravity is 9.8 m/s^2 . That means I throw something up in the air then this gravity affects it by 9.8 m/s^2 .
- S: Does that mean that you have to throw something greater than 9.8 m/s for it to go up?

The subsequent discussion did not help the students to differentiate between velocity and acceleration, and appeared to increase their misconceptions about gravity.

The teachers' misconceptions were quite obvious during the interviews. For example, Teacher A2 indicated an impetus approach to projectile motion:

T: If you've given it a push, you must have given it a force.

When asked about objects dropped from a plane, she was torn between the bomb dropping depicted in the film "The Dam Busters" and her misconceptions:

T: I'm thinking of "The Dam Busters" now. In theory, ignore wind, I say it should go straight down but I know in fact it wouldn't. The bomb didn't.

DISCUSSION

The experimental teaching unit set out to show the students by cognitive conflict and "playing" with projectiles that they had misconceptions; then, through discussion and reflection, it was intended that students should deal with those misconceptions. The unit was also designed to help students gain a qualitative understanding before the standard algebraic techniques were introduced.

The results suggest that the unit was partially successful in helping students deal with their misconceptions. Almost all the students in one class eliminated their misconceptions about objects dropped from a moving carrier, but they still had misconceptions about fired or thrown objects. In the other experimental class, there were still many misconceptions about both types of projectiles. On the other hand, the teaching in the comparison classes, which did not confront student misconceptions, had virtually no effect on student misconceptions.

It seems to us that the main reason why teaching was more effective in some cases than others lies in the teachers' own understanding of projectile motion.

Figures 1 and 2 show that Teacher A1 was the most effective teacher, but she was more so for dropped than fired objects. She became aware of her misconceptions during the preliminary discussions, she worked to overcome them, and she was clearly successful in helping her students with their misconceptions. But she seemed less comfortable with fired objects, and an analysis of the lesson transcripts shows that she paid more attention to dropped than fired objects in her teaching.

By contrast, Teacher B1 was only moderately effective on both scales. While she was aware of her misconceptions, this was not sufficient to change her ideas (Viennot & Rozier, 1994). Although she made no errors when she discussed the ideas from the notes, she made several errors when the discussions extended to other examples.

It was clear from the interviews and observations that Teachers A2 and B2 were not aware of their own misconceptions or those of their students. Accordingly, their class activities and discussion did not challenge student misconceptions—indeed, there was some evidence that they actually reinforced student misconceptions. In their classes, the majority of students continued to believe that a projectile had a horizontal force acting on it—but they learned to use equations of motion that assumed there

was no such force. It is little wonder that such students should have difficulties solving problems that go beyond routine applications of the equations of motion.

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