



# Students' Misunderstanding of Galileo's Experiment on the Leaning Tower of Pisa

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## Abstract

*The experiment at the Leaning Tower of Pisa is well-known to most people although no evidence proves whether Galileo ever performed it or not. When asked which objects Galileo dropped from the edge of the tower, to my surprise, most students thought the objects to be metal ball and cotton. Some students even misunderstood that the two objects would fall at the same time. This study is based on classroom observation, written tests and interviews. The subjects are high school students, college students majoring in engineering, and some science teachers.*

*It is a common misconception for most students that heavier objects fall more quickly than lighter ones. Students tend to emphasize that Galileo rebutted Aristotle and ignore the related physics. Textbooks usually illustrate that the different weights will fall together by using the examples of a coin and a feather in a vacuum and the experiment astronauts performed on the moon. As we know, the two experiments are real but not done by Galileo. The reason why students believe the two objects dropped were metal ball and cotton is perhaps they confuse these two real experiments with the legendary one Galileo performed. Students usually forget to consider air resistance when they drop cotton or feathers from the top of the Leaning Tower of Pisa. Based on these findings, several pedagogical implications can be drawn from this study.*

## 1. Introduction

Galileo's experiment at the Leaning Tower of Pisa is known to most people although it is said to be a thought experiment which did not really take place. I led my college students to picture Galileo's preparation for this experiment: he was busy running up and down the Leaning Tower of Pisa preparing for everything he needed in this demonstration. "What are the two objects Galileo dropped from the edge of the tower?" I asked my students. Surprisingly, most of them thought the two objects dropped by Galileo in this story were a metal ball and some cotton with the same weight. Some of the students thought that the metal ball and cotton fell from the top of the tower down to the ground at the same time. On the basis of these findings, several pedagogical implications can be drawn from this study.

## 2. The study

Data collection in this study is based on classroom observation, written tests and interviews. The subjects are high school students, engineering majors in college, adults who have graduated from college for several years and some science teachers. This study proceeded in 3 phases (Table 1).

Before answering the questions below, the subjects were given the height of the Leaning Tower of Pisa (54 meters, approximately 17 floors).

**Phase A:** open questions (written tests). The subjects were 101 college freshmen majoring in engineering.



- Question A1: What were the two objects that Galileo dropped from the top of the tower in the story?
- Question A2: What was the result of this demonstration?

**Phase B:** interview. This is a face-to-face one-on-one interview which offers this study a deeper understanding of teachers' and students' ideas about these questions.

The subjects were high school students, college students and science teachers. The interview questions were Questions A1~A2 and B1~B2.

- Question B1: Had Galileo made an educated guess about this experiment before climbing the tower? What was Galileo's educated guess?
- Question B2: What was audience's educated guess?

**Phase C:** multiple choice questions.

After collecting students' ideas in the above two phases, I designed a multiple choice question as below. The subjects were 209 high school students (grade 9 and 10) and 67 adults who have graduated from college for several years.

- Question C: If you drop a metal ball and some cotton both weighing one kilogram from the Leaning Tower of Pisa, which will arrive at the ground first? (1) metal ball (2) cotton (3) the two objects arrive at the same time.

Table 1. Study phases and groups of subjects

Study Phase	Group	Examinees & interviewees	#	Question Type
Phase A	Subjects A	college freshmen majoring in engineering	101	Open question of written test (Question A1, A2)
Phase B	Subjects B	high school students, college students and science teachers	20	Interview (Questions A1, A2, B1, B2)
Phase C	Subjects C1	high school students (grade 9 and 10)	209	multiple choice question (Question C)
	Subjects C2	adults who have graduated from college for several years	67	multiple choice question (Question C)

### 3. Findings

Some related observations and inferences in this study are stated as follows.

#### 3.1 Many students figured that the objects Galileo dropped were a metal ball and some cotton

The open question answers in Phase A were categorized into two patterns: pattern I is two balls with different weights; in pattern II, one of the two objects is something like cotton or feather. In Subject A (n=101), 68 students' answers belong to pattern II. 42 out of 68 students (61.8%) figured that the two objects struck the ground at the same time.

Table 2. Number of students in Question A1 and A2 (Subjects A, n=101)

Question A1	Question A2			No answer	Total
	Simultaneous impact	Asynchronous impact	Simultaneous impact (if vacuum)		
Pattern I	29	2	0	2	33
Pattern II*	42	16	3	7	68
Total	71	18	3	9	101

\* other open question answers including lead ball & feather, steel ball & cotton, apple & feather, and so on are also put into this category.



## NEW PERSPECTIVES IN SCIENCE EDUCATION

### 3.2 Some students didn't know why Galileo wanted to do this demonstration

In phase B, when answering Question B1 and B2, some students didn't deem Galileo had made an educated guess (under the hypothesis that Galileo's experiment did exist) about this experiment before climbing the tower. They didn't care whether or not the result would be the same with the opinion of the audience and were convinced the answer would be shown in the demonstration. They didn't even know what Galileo wanted to prove in this demonstration. Nor do they have any idea about Aristotle's experiment. This implies that students rarely consider the meaning of this demonstration and the result of this experiment. They do not follow the story by using the ability of logical reasoning.

### 3.3 Most students figured that a 1 kilogram metal ball and cotton of the same weight would strike the ground at the same time

In Taiwan, we have a very old brain-easer: "A bale of cotton weighing 1 kilogram and a 1kg metal ball. Which is heavier?" Almost every student heard of it when they were very young in their elementary schools. And this might be able to explain why most of the students believe one of the dropping objects was something like cotton or feather. It is very likely that students associate their vague impression of the old brain-easer with Galileo's experiment.

The multiple choice questions in phase C were designed according to the results in Phase A. In Table 3, 82% of 209 subjects C1 and 72% of 67 subjects C2 figured that the metal ball and cotton falling from the top of the tower reached the ground at the same time. Most students never image how big the volume of the cotton of 1 kilogram is before and after they chose the answer to this question. They were surprised how big the volume of the cotton was when I showed 0.5 kilogram cotton to them after the test.

Table 3. Number of students in Question C

Subjects	answers				Total
	metal ball*	cotton	the two objects arrive at the same time	others	
Subjects C1	37	0	171(82%)	1	209
Subjects C2	19	0	48(72%)	0	67
Total	56	0	219(79%)	1	276

\* correct answer

## 4. Discussion and implications for instruction

### 4.1 The heavier object reaches the ground first is an ingrained misconception for students but most physics teachers have no idea about it.

It is a daily experience for people that the two falling objects with different weights will hit the ground at about the same time if one of the two objects is not something like a feather or cotton. However, when I conduct this experiment in my classroom, students usually do not believe the result they see but argue that the height from the ground is not enough. Hence, we should pay attention to the fact that most of the physics teachers seldom realize students' misconception of this part.

Because most physics teachers and textbook authors fail to understand students' misconceptions experiments under special situations are often stressed in particular in classroom teachings. For example, the two popular experiments of a coin and a feather falling in a vacuum tube and dropping a hammer and a feather conducted by the astronaut on the moon are often emphasized. As a result, students confuse these two real experiments with the legendary one Galileo performed on the Tower of Pisa.



#### **4.2 Most students just recalled the answer “hit the ground at the same time” but they forgot other aspects of this demonstration.**

Physically, the speeds of the free fall objects increase at the same rate, and they fall together. Although the forces of gravity applied to the two objects are different, the change of the velocity, namely acceleration, is the same. Therefore, the two dropping objects will fall down together. Owing to the fact that catching on the concept of acceleration is not easy for students, students have problems understanding why the two balls impact simultaneously.

As I have mentioned above, for most physics teachers, that two dropping objects reaching the ground simultaneously is a common sense. Therefore, teachers do not think it necessary to discuss this question with students. They usually emphasize Galileo’s rebuttal of Aristotle or the special situation such as the vacuum tube or the moon experiment. Consequently, the only thing students remembered from the free-fall motion unit is that these two objects “hit the ground at the same time”. On the other hand, most students were short of the logical reasoning ability when they heard the story. It is taken for granted that they had no idea about which two objects had been dropped off and whether the two objects have the same weight or not.

#### **4.3 It is difficult for students to differentiate whether the air resistance must be taken into consideration or not.**

Textbooks usually illustrate the conception of free fall in the ideal condition. That is to say, the air resistance is not taken into consideration. However, in the situation of Question A, it is impossible to remove the air resistance when two objects fall from the top of the Leaning Tower of Pisa. The key point in this question is what two objects were dropped. If the dropping objects are two balls weighing differently (pattern I) the influence of the air resistance can be ignored. On the other hand, the air resistance must be taken into consideration when one of the two objects is something like cotton or feather (pattern II). It is difficult for students to differentiate the two situations. This may account for why students usually forget to consider the air resistance even when one of the two objects is such a big bale of cotton.

#### **4.4 It is difficult for students to imagine the concrete processes of designing and performing an experiment.**

In the interviews in phase B, I found many students have no idea about what Galileo wanted to prove in this falling demonstration. They didn’t deem Galileo had made an educated guess about this experiment before climbing the tower. They can not image the process of conducting the demonstration if they were Galileo.

In Taiwan, middle school students seldom have a chance to carry out an experiment by themselves in a laboratory, let alone the opportunity to design their own experiments because the traditional experiment handouts are written like a cookbook and the only thing these Taiwanese students have to do is to follow the instructions step by step. As a result, it is difficult for these teenagers to imagine the concrete process of designing and conducting an experiment.

## **5. Conclusion**

That heavier object reaches the ground first is an ingrained misconception which will not be easily changed by some simple illustration or demonstration of experiments. Only when students have established a clear and correct concept of force and velocity will they truly understand why two objects weighing differently arrive at the ground at about the same time under the circumstance that air resistance can be ignored. Unfortunately, most teachers have no clue to students’ difficulties.





Therefore, we find that students tend to misread the content of their texts or misunderstand the knowledge taught by their teachers.

On the other hand, many students, when first learning the story of the Leaning Pisa Tower (usually before grade 9), do not have sufficient logical reasoning ability to think and explore the physical problem in the story. When they enter senior high school or even college, their teachers, more often than not, take this issue for granted and will not lead them to discuss related questions. As a result, students' misconception has never been cleared up.

Due to the pressure of entrance exam, students in Taiwan make a habit of memorizing answers instead of thinking independently. When I ask questions in classroom, students tend to answer, "I can't remember it" and cannot offer their own ideas or thinking.

The conflicts between the textbook answers and students' own ideas in their mind happen frequently. Unfortunately, students seldom doubt the knowledge from their texts. They find memorizing the answers a shortcut to get a good grade. Such a fast learning culture demanding quick answers to all questions kills students' ability to independent thinking.

Consequently, instead of questioning teacher's or textbook answers, students choose to memorize them. Nevertheless, they memorize answers but questions. Misconceptions thus appear. Hence, showing the answers too early or having students to memorize the answers may deprive students of their independent thinking. Teachers should be aware of this.

## References

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