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Motion Under Gravity: A Creative Lesson From The Paradigm of Constructivism

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ABSTRACT

This paper offers insight into the author's experience of teaching the topic of motion under gravity to students enrolled in a pre-service science teacher preparation program. The instructional method is based on the activity of the alternative to Galileo's experiment using the three stage teaching sequences proposed by Nussbaum and Novick from the paradigm of constructivism. The activity reveals the general misconception among pre-service physics teachers and non-physics majors regarding motion under gravity. The paper also highlights the research findings of two studies based on the same classroom activity - the alternative to Galileo's experiment. The studies involve two groups of Form Four secondary school students from urban and rural settings. The empirical data derived from the study of school students is consistent with the observation data gathered from the pre-service science classroom activity. It is concluded that the usual way of teaching the topic of motion under gravity with the goal of introducing the idea of gravitational acceleration is ineffective To rectify this shortcoming, the author suggests the 'teach less-learn more' philosophy that is in line with suggestions made in most recent science education reform documents. It is suggested that insights from this study can contribute to improvements in the training of future science teachers.

***Keywords**: constructivism, science teaching, methodology, education reform, classroom activities*

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Introduction: Galileo and Thought Experiment

The experiment carried out by Galileo Galilei at the leaning tower of Pisa is normally used as a set induction whenever the topic of motion under gravity is discussed. Did Galileo actually conduct this experiment? Abbas Raza (2005) thinks otherwise. He states:

> *"For all his work with inclined planes, even Galileo's reputation as an experimenter is probably exaggerated. For example, it is unlikely that Galileo bothered to drop objects of different weights from the Tower of Pisa to show that they fall at the same rate. He was too smart to have needed to do this, and had his own thought experiment to show that objects of different weights must fall at the same rate: imagine that you have two objects, say iron balls, one of which weighs 20 pounds and the other 5 pounds. Now, it was thought that the 20 pound ball falls faster (say at some rate F) than the 5 pound one (which falls at a slower rate S). Imagine connecting the two balls with a chain, then dropping them. What will happen? Well, presumably the 20 pound ball should pull the lighter object into a faster rate than S, while the lighter ball should slow down the 20 pound ball from its fast rate of F. In other words, joined together, the balls should drop at some intermediate rate between S and F. But now consider that the two balls joined by a chain can also be construed as one object with a weight of 25 pounds, which should fall even faster than the heavier ball alone, or faster than F! Here we have a contradiction, so they must fall at the same rate. Such is the beauty of the thought experiment!"*

My Paradigm

Being an advocator of constructivism in teaching science and seeing science from the constructivist perspective, it is my principle to walk the talk in designing curricula concerning various courses of science education such as Methods of Teaching Science, School Science, Creativity and Creative Teaching in Science, School Science and Science and Society. Science reform documents such as Science for All Americans (American Association, 1990) and the Six Domains in Science as spelled out in The Iowa Assessment Handbook (Enger and Yager, 1998) have been the sources of my references. As well as Concept and Process/

Skills, the Six Domains include Application, Attitude, Creativity and Nature of Science. The Application domain, among others, includes critical thinking, problem solving, decision making, and the integration of sciences and science with other disciplines. The Attitude domain encompasses the development of more positive student attitudes towards science and oneself, sensitivity to and respect for the feelings of others and decision making about personal values and social and environmental issues. The Creativity domain takes into consideration visualizing, combining objects and ideas in new ways, finding alternate or unusual uses for objects, solving problems and puzzles, designing devices and machines, producing unusual ideas and merging and diverging in thinking. The Nature of Science domain emphasizes understanding the way in which scientific knowledge is created, the nature of processes in science research, the meaning of the basic concept of scientific research, and the history of scientific ideas and theory.

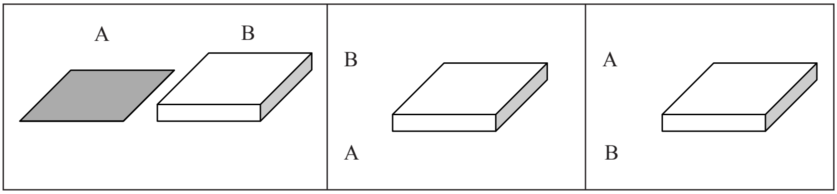
One of the many challenges I encounter is getting students actively engaged mentally and physically so that they feel productive and acquire a sense of joy and enlightenment after leaving the class. In the constructivist paradigm, the teaching and learning of science is more than the 'tabula rasa' assumption, i.e. that students come with a blank mind which can be filled by the teachers. Learning science is about investigating things, exploring how and why things do what they do and developing explanations that are sensible. Science is basically a human construct and can be fun.

The Constructivist Class Experience

Among the activities that I like to use in my class is an activity concerning motion under gravity as suggested by Gibbs (2007). However, I have modified the activity as shown in Figure 1. This activity is an alternative to Galileo's experiment.

Stage 1: I distribute the question as shown in Figure 1 to students. Students are required to put down their own ideas independently.

Stage 2: I present the situations stage by stage. To dramatise the situation I get students to participate. Students are happy with situation I and situation II when demonstrations are carried out. This is because the results of the



Situation I: side by side Situation II: B on top of A Situation III: A on top of B

A: a piece of paper; B: a thick book of same surface area as A

If A and B in situation (I), (II), and (III) are released at the same time by Ali, which one will fall and reach the floor first (A, B or both)? Provide reasons for your answer.

The pedagogy that I used is closely related to the three stage teaching sequences proposed by Nussbaum and Novick in Cosgrove and Osborne (1989), i.e.:

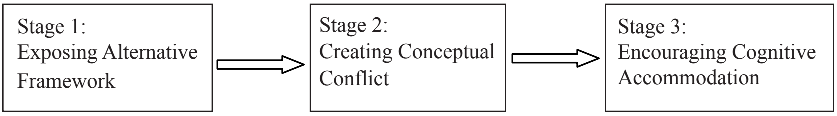


Figure 1: Motion Under Gravity

demonstrations comply with students' preconceived ideas. Students are advised to share the reasons for their answers for both situations with their fellow classmates. The notions of air resistance for situation I and the book pushing the paper for situation II are conceptualised. Situation III is the most interesting and challenging one among the three situations. This is because the result of the demonstration is at odds with students' common sense or intuitive ideas. Almost all students predict that the situation would be the same as situation I, that is, the book drops faster than the paper. Students watch in disbelief and are amazed when the book and the paper actually fall at the same rate before their eyes. Some students even request a replay to ascertain their 'observation'. Some students even demand to do it in other fashion, such as, to drop the book and paper from a higher level. Some cheeky students comment that I have tricked them by putting adhesive material between the paper and the book. In response to these students, I get the students to perform the act themselves. This activity has transformed the classroom atmosphere into one that is engaging in terms of students' critical thinking and emotion. The hands-on experience and the accommodation of students' ideas and suggestions in the learning process have proven to be a sure way in motivating students. Curiosity of the students has been aroused since what has happened before their very eyes is something against their common sense experience. Conceptual conflict has been established.

Stage 3: I post the "Why" question and the "What do you think?" question – a Socratic questioning technique to the students. This is where students are set in the thinking and guessing mode. Most students think air pressure is at work, that is atmospheric pressure is pressing the paper onto the book. Some students explain in terms of electrostatic force of attraction between the book and the paper. Strangely, none of the students, including the physics students, can associate this event with the idea of a vacuum although it has been explicitly stated in the topic of motion under gravity that all objects fall at the same rate in the absence of air resistance (i.e., vacuum). The rate is $g = 9.8\ m/s^2$ near the earth's surface. After deliberation by the students, I then make them recall Galileo's idea relating to motion under gravity which they have studied, i.e. that irrespective of shape and mass all objects fall at the same rate in a vacuum. I am hope that with this recall, students can associate the fall of paper with a vacuum. Although students agree with the notion of falling in vacuum, most of them have a hard time figuring out how is it that the paper is falling in the vacuum which in this case is created by the book. This is an abstraction that most students have trouble with. To make it concrete and meaningful, I have to come up with an analogy. The situation is likened to a book falling in a medium with jelly. In the passage, the book has apparently removed the jelly creating an empty space immediately behind it. Apparently with this analogy, students' conception of the situation has been rendered plausible, intelligible and fruitful.

Methods

The class activity as described above embraces the elements of the Six Domains in Science and is in line with the philosophy of the Malaysian Science Education as reflected in the Thinking Skills section in the Science Curriculum Specifications for secondary school (Curriculum Development Centre Malaysia, 2009). Thinking skills encompass intellectual processes that include Relating, Making Inferences, Predicting, Making Generalisations, Visualising, Synthesising, Making Hypotheses, Making Analogies and Inventing. From the constructivist perspective, I am curious to know the nature of conception of physics students in schools. Four students were persuaded to carry out research using the question shown in Figure 1 for their Academic Exercise requirement (a project conducted in the final year of a four year BEd. TESL program). The data was collected between June to September 2009 at various schools. I would like to share the data collected by two students, Farizatul Shima Bt Hashim (Farizatul, 2010), and Norazila Bt Anuar (Norazila, 2010).

Table 1 shows the sample size of the two groups of Form Four physics students involved in the research in terms of gender and academic ability. Academic ability is determined by the physics grade as shown in Table 2.

Table 1: Sample Size

Group	Gender			Academic Ability			
	Male	Female	Total	High	Average	Low	Total
A	32	33	65	15	23	27	65
B	44	36	80	8	36	36	80

A: Urban School B: Rural School (Selangor)

Table 2: Classification of Academic ability

	Academic Ability		
	High	Average	Low
Physics Grade	A1/A2	B3/B4/C5/C6	7D/8E/9G

Situation I

Table 3 shows the classification of students' responses to Situation 1 (If a thick book (B) and a piece of paper (A) are dropped side by side at the same time, which one will fall first to the floor?) in terms of the level of sophistication (Scientific/Partial/ Non-scientific) of their explanations from the perspective of gender and academic ability.

Table 3 shows that the percentage of students offering scientific reasoning is low for both group A and group B (A: 10.8%; B: 15.0%) and for both male and female students. In terms of high academic ability, only 20% of students from group A and a substantial 75% of students from group B were able to reason scientifically. Only 17.4% and 16.7% of

Table 3: Students' Responses to Situation I

Classification	Gender (%)						Academic Ability (%)							
of Student	Male		Female		Total		High		Average		Low		Total	
Response	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Scientific	12.5	13.6	9.1	16.6	10.8	15.0	20.0	75.0	17.4	16.7	00	00	10.8	15.0
Partial Scientific	75.0	86.4	57.6	83.3	66.1	85.0	66.7	25.0	60.9	83.3	70.4	100	66.1	85.0
Non-Scientific	12.5	00	33.3	00	23.1	00	13.3	00	21.7	00	29	00	23.1	00

average academic ability students from group A and group B respectively were able to do so. None of the reasoning offered by the low academic students from both A and B could be considered as scientific. These students were able to include the factor of weight and the effect of air resistance in their explanations that the book would fall faster than the paper. The following are examples of students' explanations:

> "*Since both have the same surface area, the difference in weight determines which one falls first. B which has a large weight is able to overcome the air resistance more effectively than A and therefore, falls first*." (Male student from A)
>
> "*B will fall and reach the floor first. It is because B is heavier than A. It overcomes air resistance easily compared to A*." (Female student from A)
>
> "*B falls first. There is more* ***air resistance*** *for the piece of paper but the air resistance against the book is cancelled out as the book has* ***heavier mass*** *than the paper*." (Male student from B)
>
> "***Mass*** *of B has overcome the* ***air resistance*** *therefore it falls faster than A*." (Female student from B)

A majority of students, irrespective of gender and academic ability were able to offer partial scientific explantion for their answer that the book would fall faster and reach the floor first. Almost all students offered the factor of the book being heavier than the paper in their answer. The following are examples of students' explanations.

> "*B will fall first. Mass of B is heavier than mass of A*." (Male student from A)

> "*B will reach the floor first. B is heavier than A. Therefore, B reaches first*." (Female student from A)

> "*The mass of* ***B is heavier*** *than A. So B falls first*." (Male student from B)

> "***B is heavier*** *than A. Therefore B falls faster than A*." (Female student from A)

A significant proportion of students from group A (23%) offered explanations that were naive and non-scientific. The following are examples:

> "*Both B and A will reach the floor first. It is because A and B have the same surface area*." (Male student from A)

> "*B will reach the floor first. Because the force of gravity surrounding A is more than force surrounding B. And this is because of the weight of A and B*." (Female student from A)

> "*B falls first. This is because B has* **higher pressure** *acting on it than A*." (Student from B)

Situation II

Table 4 shows the classification of students' responses to Situation II (If a thick book (B) with the piece of paper (A) under it has been dropped, which one will fall first to the floor?) in terms of the level of sophistication (Scientific/Partial/ Non-scientific) of their explanations from the perspective of gender and academic ability.

Table 4 shows that percentage of student offering **scientific reasoning** is low for both group A and group B (A: 24.6%; B: 12.5%). and for both male and female students. In terms of academic ability, only 26.7% of high academic ability students from group A and a substantial 50.0% of high academic ability students from group B were able to offer reasoning that was scientific. Only 30.4% and 16.7% of average academic ability students from group A and group B were able to do so. As for responses from the low academic group, none from group B and only 18.5% from group A can be considered scientific. These students were able to include the notion that "Both A and B fall together as B pushes A since B is moving faster than B". The following are examples of students' explanations:

Table 4: Students' Responses to Situation II

Classification of Student Response	Gender (%)						Academic Ability (%)							
	Male		Female		Total		High		Average		Low		Total	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Scientific	15.6	13.6	33.3	11.1	24.6	12.5	26.7	50.0	30.4	16.7	18.5	00	24.6	12.5
Partial Scientific	25.0	45.5	21.2	27.8	23.1	37.5	33.3	00	13.1	38.9	25.9	47.2	23.1	37.5
Non-Scientific	59.4	40.9	45.5	61.1	52.3	50.0	40.0	50	56.5	44.4	55.6	52.8	52.3	50.0

> "*Both will reach the floor at the same time. Because A will be pushed downwards by B due to B weight, make A fall faster and both of them will stick together, thus both will reach the floor at the same time*." (Male student from A)

> "*A and B will fall and reach simultaneously. B will force A to fall down simultaneously. Its weight pushes A down and therefore fall together*." (Female student from A)

> " *Both A and B fall together. This is because B is pushing A downward as B is moving faster than A*." (Male student from B)

> "*Both A and B will reach the floor simultaneously. The weight of B will push A down and both will fall at the same speed. The weight of A and B is greater than the air resistance acting on A*."(High achiever from A)

> "*A will reach the floor first. Because the weight of B is acting on the top surface area of A, therefore constantly pushing A to the ground. The combined weight of A and B overcomes the air resistance that would normally stagnant the falling speed of A since A is underneath B, A would reach first*." (Average achiever from B)

Table 4 also indicates that a high proportion of students (A: 23.1%; B: 37.5%) irrespective of gender and academic ability were able to offer **partial scientific** explanation for their choice of answer that the book falls faster and reaches the floor first. Almost all students offered the factor of "the book being heavier than the paper would push down the paper" in their answers. The following are examples of students' explanations:

> "*Both fall together. B is heavier than A, so B pushes A together downwards*." (Male student from B)

> "*Both A and B will fall together. It is because the mass of B is higher that's why it will push the paper downwards*." (Female student from B)
>
> "*A will fall first and touch the floor. It is because B is pushing A*." (Female student from A)
>
> "*A will reach the floor first. B being on top of A, pushes A down along with it towards the ground and hence A, being below touches the floor first*." (Male student from A)
>
> "*Both will reach the floor at the same time. Because the B acting on A and because B is heavier than A*." (Average achiever from A)

Table 4 reveals that a very high proportion of students (A: 52.3%; B: 50.0%) irrespective of gender or academic ability offered **non-scientific** explanations. Among the factors offered are the notion of B being heavier, momentum, and pressure. The following are examples of students' explanations:

> "*B will reach first. Because B is underneath A and B heavier than A*." (Female student from A)
>
> "*B will reach the floor first. B has a larger resultant force because of its larger weight. A's weight is lower, the air resistance below A prevent A to falls faster*." (Male student from A)
>
> "*A reach the floor first. This is because the pressure from B pushed A downward*." (Female student from B)
>
> "*A will fall and reach the floor first. It is because the momentum between B and A. A is pushed first*." (Male student from B)
>
> "*A and B will fall and reach the floor first. The force acting on B is the same as A so both A and B will reach the floor first*." (High achiever from A)
>
> "*A and B will fall and reach the floor first. The force of gravity acted on A and B is same to overcome the air resistance*." (Low achiever from A)

> “*They will both reach the floor at the same time. It is because both will fall at the same velocity*.” (High achiever from B)

Situation III

Table 5 shows the classification of students’ responses to Situation III (If a thick book (B) with the piece of paper (A) resting on top of it has been dropped , which one will fall first to the floor?) in terms of the level of sophistication (Scientific/Partial/ Non-scientific) of their explanations according to gender and academic ability.

Table 5: Students’ Responses to Situation III

Classification	Gender (%)						Academic Ability (%)							
of Student	Male		Female		Total		High		Average		Low		Total	
Response	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Scientific	3.1	27.7	00	22.2	1.5	25.0	6.7	50.0	00	30.6	00	13.9	1.5	25.0
Partial Scientific	00	00	12.1	00	6.2	00	20.0	00	4.3	00	00	00	6.2	00
Non-Scientific	96.6	72.3	87.9	77.8	92.3	75.0	73.3	50.0	95.7	69.4	100	86.1	92.3	75.0

Table 5 shows that the percentage of students offering **scientific reasoning** is low for both group A and group B students (A: 1.5%; B: 25%) and for both male and female students. In terms of academic ability, only 6.7% of high academic ability students from group A and a substantial 50.0% high academic ability students from group B were able to offer scientific reasoning. The achievement decreases according to ability. None of the low achievers from A and only 13.9% of the low achievers from B could offer scientific reasoning. The following are examples of students’ explanations:

> “*Both A and B will fall together and reach the floor at the same time. B in this case overcomes the air resistance thus preventing A from experiencing any resistance, created vacuum area between A and B, and remains on top of B and therefore, both fall at the same time. Since B is at the bottom it touches the ground first*.” (Male student from A)
>
> “*Both A and B will fall together at the same time. This is because B has created a vacuum for A to fall together*.” (Male student from B)

> "*Both fall together. It is because as B falls it creates a vacuum on top and atmospheric pressure will push against the top filling the vacuum*." (Female student from B)

> " *Both A and B fall together. It is because when A and B fall, B creates vacuum on top of B then the atmospheric pressure will fill the vacuum and push A to fall together*." (Average achiever from B)

Table 5 shows only a few students' responses can be classified as **partial scientific** (A: 6.2%; B: 00). The following are examples of student explanation;

> "*Both will fall together. When B descends, A also follows as there is a low pressure area displaced by B*." (High achiever from A)

> "*A and B will fall and reach the floor simultaneously. There is no air resistance in A because it is on top of B. So it falls with B*." (Average achiever from A)

Table 5 shows a very high proportion of students' responses which can be classified as **non-scientific** (A: 92.3%; B: 75). The students have the similar ideas as in situation I, that is, the book will fall first and the paper being lighter in mass/weight will fall at a slower rate. The following are examples of students' explanations:

> "*B reaches the floor first. This is because the mass of A is less than B, so it will fall slowly*." (Female student from B)

> "*B will fall and reach the floor first because the position of B in under A and its mass is heavier. So it will and reach the floor first*." (Male student from B)

> "*B will reach the floor first because B is underneath A and B is heavier than A*." (Female student from A)

> "*B will reach the floor first. A greater force acts on B causes B to reach the floor first*." (Male student from A)

> "*B reaches the floor first. B has a larger resultant because of its larger weight. As weight is lower, the air resistance below prevents A to fall faster*." (High achiever from A)

> "*B will fall and reach the floor first. A is lighter than B, so the air pressure on A decrease*." (Average achiever from B)

> "*B will fall first. B has a larger weight and its under A*." (Low achiever from A)

A detailed analysis of students' responses in Situation I and Situation 3 reveals that 40 of the 65 students in A (61.5%) and 54 of the 80 students in B (67.5%) offered identical answers (i.e. the book will fall faster than the paper for both situations) and similar explanations (e.g. the book is heavier than the paper) for these two situations.

Conclusion

The class experience and the above study lead us to conclude that cognitive change about motion under gravity is minimal among students. The Aristotelian idea of a heavy object falling at a faster rate than a light object that students have acquired through their daily experience is very tenacious and difficult to change although the topic of motion under gravity has been explicitly introduced at several stages of the Malaysian Science Education system. They are such as the Malaysian School Science Curriculum for SPM, the Pre-university Science Curriculum (Matriculation/STPM/Diploma), and in the first physics course at university level as what my students of teacher preparation program of Physics major have to undergo. This is no surprise, as it has been widely acknowledged that rote learning is apparently the norm in science classroom although thinking skills are the targets of learning outcomes that have been stated in the Curriculum Specifications for Science. The WHY behind the discourse between the objectives of the curriculum and the actual student learning outcomes is of great concern that needs to be addressed urgently. But how? A visit to school by a practicum supervisor would provide much needed insights into the problems. These problems are multi-faceted and a systemic change is necessary if the National Science Education Philosophy is to be translated into reality. However, this is easier said than done. To begin with, we might consider adopting the philosophy of "teach less learn more" as the guiding principle as suggested by reformers in science education documents rather than continuing with the "touch and go" with "drilling in exercise" instructional methodology that is the norm in the current examination orientated system of schooling. With the extra hour gained from "teach less", science teachers will have the opportunity to encourage students to continue to investigate and explore how and why things behave as they do and to develop explanations that are sensible and useful, reflecting an inquiry approach to teaching. This instructional mode is in association with the paradigm of constructivism where learning with understanding is achieved via students actively constructing or generating meaning from sensory inputs such as sights, sounds, smell and so on. No one, not even teachers can do it for them. This perspective of constructivism that knowledge is acquired by students not by way of transferring from teachers to students but through students' self construction from within has been shared by Kelly, Piaget, Driver, and Wittrock among others (in Freyberg and Osborne, 1989).

References

Abbas Raza. (2005). *Monday musing: Stevinus, Galileo, and thought experiments*. 3 Quarks Daily, http://3quarksdaily.blogs.com/3quarksdaily/2005/05/monday_musing_s.html.

American Association for the Advancement of Science. (1990). Science for All Americans. Washington, DC: American Association for the Advancement of Science.

Cosgrove, M. & Osborne, R. (1989). Lesson frameworks for changing children's idea. In R. Osborne and P. Freyberg (Eds.), *Learning in Science: The implications of children's science*. (pp.101-111). London: Heinemann.

Curriculum Development Centre Malaysia. (2009). *Integrated curriculum for secondary school: Curriculum specifications*. Malaysia: Ministry of Education.

Enger, S. & Yager, R. (1998). *The Iowa assessment handbook*. Iowa: Science Education Centre, The University of Iowa.

Farizatul Shima bt. Hashim. (2010). *A study on rural students' conception of motion under gravity from the perspectives of academic ability* *and gender differences, academic exercise*. Shah Alam: Faculty of Education, UiTM.

Freyberg, P. & Osborne, R. (1989). Assumption about teaching and learning. In P. Freyberg and R. Osborne (Eds.), *Learning in science: The implications of children's science*. (pp. 82-90). London: Heinemann.

Gibbs, K. (2007). http://www.schoolphysics.co.uk /teachers/Creative%20 teaching%20ideas/Gravity_/index.html.

Norazila bt. Anuar. (2010). *A study on urban students' conception of motion under gravity from the perspectives of academic ability and gender differences, academic exercise*. Shah Alam: Faculty of Education, UiTM.

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