

Teaching of the simple pendulum and its relation to accurate timekeeping

1. Title

Teaching of the simple pendulum and its relation to accurate timekeeping

Keywords: simple pendulum, timekeeping, Galileo, Richer, short historical text

2. Authors and institutions

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3. Abstract

The suggested teaching sequence is composed by a total of *four units* referring to the **simple pendulum** and its relation to accurate timekeeping. This sequence is addressed to high school students (14-15 years old) and differs radically from the traditional teaching approach.

In the traditional teaching of the pendulum, various conceptual frames are usually involved, such as Newtonian mechanics or the frame of energy conservation. On the contrary, in the suggested approach, there is a deep exploration of the frame of the pendulum's *isochronous movement*, as observed by **Galileo**, knowing at the same time that, in the particular stage, the basic conceptual problem for the students is that of the construction of isochronous movement of the pendulum and the construction of the concept of period. In parallel, a *hypothetico-deductive* approach of the relation within the simple pendulum period, the string length of the pendulum, its mass and gravitational acceleration is attempted. At the same time, the connection of the simple pendulum with the mechanisms of *measurement of time* up grade on one hand the cultural component of scientific knowledge and on the other hand it gives meaning in the study of the conceptual and methodological components of knowledge. The previous rationale is served by the introduction of *three short texts* into teaching that includes elements from the *history of science*.

4. Description of case study

In the suggested approach, there is a deep exploration of the frame of the pendulum's isochronous movement, as observed by Galileo. At the same time, there is the knowledge that, at this particular grade, the basic conceptual problem for the students is the understanding of isochronous movement as well as of the concept of the time period. The linkage between the simple pendulum and the mechanisms of timekeeping on the one hand enhances the cultural aspect of scientific knowledge while, on the other, it gives meaning to the study of the conceptual and methodological aspect of knowledge.

The previous rationale is served by the introduction of three short texts into teaching that includes elements from the history of science.

- In the *first text* a drawing of clock similar to which Galileo had drawn is represented. The students are asked for the role of each element of clock, are referred to the role of simple pendulum in the regulation of the clock and they formulate hypotheses with regard to the factors that influence the period of the pendulum so that they regulate the clock.
- The *second* refers to an extract from Galileo's book "Dialogue Concerning Two New Sciences" and concerns the isochronous movement of the pendulum. This text is introduced in teaching in relation to the "activity / problem solving" practice and aims mainly at making students discuss the paradox of the pendulum's isochronous motion, such as: a) "How do you think that Salviati (the person expressing Galileo's views) would respond to the views of Sagredo?" b) "Which particular technique would you suggest in order to examine whether Sagredo's claim is true or false?"
- In the *third text* the discovery of the astronomer J. Richer is described. According to him, the length of the pendulum for counting seconds, which was set up in Paris, should have been reduced in order for the pendulum to continue to count seconds in Cayenne. This text is related to the formulation by the students of hypotheses on the factors on which the pendulum's time periods depend.

5. Historical and philosophical background

Our historical and philosophical background depends on M. Matthews's book "Time for Science education".

- The obvious inability of sundials and water clocks (two types of clocks taken part in the Ancient Greek tradition) precisely measure spaces of time was compensated by the mechanical clocks which emerged in the 14th century and marked the passage from church time and unequal hours to secular time and equal hours. However, the great weakness of the escapement mechanism of the mechanical clock was that it had no natural frequency of oscillation. "It was the pendulum's natural frequency, ascertained by Galileo that was to make it the core of accurate timekeeping. In the ideal situation, all pendulums of the same length vibrated with the same frequency independently of mass or amplitude of swing" (Matthews, 2000, p.63). Finally, Galileo, while working on the longitude problem, constructed a mechanical clock in which the old escapement mechanism was replaced by the pendulum. According to Matthews (2000, p. 95) "the new technology of timekeeping resulted from a new scientific analysis of pendulum motion, which in turn was possible because of a new philosophical theory of knowledge." In other words, the pendulum clock emerged as the solution to a cultural/technological problem on the one hand, and, on the other, as the product of the scientific analysis of pendulum motion as it is found in the work of Galileo.

The main elements of this analysis are related as much to the conceptual dimension as to the methodological dimension of scientific knowledge.

- On a conceptual level, the concept of isochronous pendulum motion is rendered fundamental. This concept derives as much from the law of length as from the law of amplitude. “To claim that pendulum motion is isochronous is to claim that every swing takes the same time. That is, that all subsequent oscillations take the same time as the first oscillation. This does not follow from the law of amplitude. It almost follows from the law of length: if period depends only upon length, then ideally, each swing will take the same time as any other swing. But friction at the fulcrum, the air’s resistance to the bob, and the dampening effects of the weight of the string or wire will all contribute to a slowing of the pendulum” (Matthews, 2000, p. 113).
- On the other hand, on a methodological level, Galileo’s work shows that the mathematical explanation precedes any experimental proof of isochronous pendulum motion. “If experiment does not confirm the proof, then there is always the ‘accidents’ and ‘imperfections’ of matter to consider (Matthews, 2000, p. 112). The concept of isochronous pendulum motion, therefore, appears at the same time as a new methodological approach to natural phenomena which is based on the transformation of natural objects into physical objects. As Matthews writes: “The history of the pendulum begins when real objects become theoretical objects. That is, when people begin to describe, conceptualize, explain, and ultimately theorize about pendulums” (Matthews, 2000, p. 79). At the same time, Richer's observation that the period at Paris and the period at Cayenne of Huygens' seconds-pendulum varied and the consequent arguments which led to examine new factors like the gravity and the Earth's shape, shows how the historical events affect methodology of science.

6. Target group, curricular relevance and didactical benefit

- The teaching sequence of simple pendulum is addressed mainly to students of 14-15 years old. Alternatively, the sequence can be used in the pre-service or in-service teachers’ training as example of a didactical transformation of science concepts and their historical construction.
- This approach can replace or complete, if there is enough educational time, the traditional approach of the 3rd grade of the gymnasium. In the table a sequence of didactical units is presented, based on didactical activities – problems while for each unit we propose the basic conceptual, methodological and cultural objectives of the concerned study. This approach differs to the traditional approach as to the following points:

Teaching unit	Activities / Problems	Didactical objectives		
		Conceptual	Methodological	Cultural
1st	How and why the medieval pendulum-clock can become more accurate?	<ul style="list-style-type: none"> • Periodicity 	<ul style="list-style-type: none"> • The identification of factors which influence the timekeeping of pendulum-clock 	<ul style="list-style-type: none"> • Time measurement as a techno-scientific problem
2nd	Which idea is behind the function of the pendulum clock?	<ul style="list-style-type: none"> • The pendulum's isochronal movement 	<ul style="list-style-type: none"> • Measurement of period in relation to amplitude 	<ul style="list-style-type: none"> • The historical approach of isochronal movement (Galileo)
3rd	How is a simple pendulum transformed into a pendulum clock (of 1 second)?	<ul style="list-style-type: none"> • Relation between period and <i>length</i> of string • Relation between period and mass of pendulum 	<ul style="list-style-type: none"> • Emergence of the factors which influence the period of the simple pendulum • Measurement of period in relation to length • Measurement of period in relation to mass 	
4th	Is the duration of the oscillation of a simple 1 meter pendulum the same everywhere?	<ul style="list-style-type: none"> • Relation between period and <i>gravity</i> 	<ul style="list-style-type: none"> • Measurement of period in relation to gravity 	<ul style="list-style-type: none"> • The relation between period – gravity as socio-scientific problem

- A broad unit is formed whereas the time measuring constitutes the leading theme, which is the (cultural) framework within which the desired conceptual and methodological features of the pendulum study acquire meaning.
- There is an in-depth analysis of a conceptual framework that, in the specific occasion, relates to showing a qualitative / semi-quantitative relation between the period of the simple pendulum, the string length of the pendulum and gravitational acceleration. The mathematical approach of this relation is not necessary in this grade. At the same time, the paragraphs relating to other conceptual frameworks, like the Newtonian analysis, the energy analysis and measure of gravitational acceleration, are omitted.
- A hypothetico-deductive approach of the relation within the simple pendulum period, the string length of the pendulum and gravitational acceleration is attempted. Concerning the length of the string, a practical problem is raised concerning the explanation of how a clock “knocks the seconds”. This problem, by the educator’s guidance, can lead the students to plan on their own the same experimental activity imposed by the school textbooks in the traditional approach.
- The cultural dimension is nominated as an essential element of the educational procedure. The cultural dimension not only (a) acts as a means for approaching the everyday / technological reality and of getting familiarized with the scientific / technological tradition (e.g. familiarization with the medieval mechanical clock) and (b) constitutes a guiding principle of the broad unit but also (c) acquires an close relation with the conceptual and methodological dimension thus attributing meaning to the study of these two dimensions. Hence, the function of the clock is not viewed as a simple appliance of the pendulum study. In reverse, the study of the technological and natural phenomenon of the clock’s operation leads to the procedure of its conversion to a physical phenomenon (study of the modeled simple pendulum).

Another factor influencing the function of this approach can be the mental representations the students attain for the concepts of time measuring, pendulum period or / and for representing patterns / models in selected data. If this factor is also considered, then it is possible to have radical changes in the sequence and context of the approach proposed.

7. Activities, methods and media for learning

7.1 Schedule of activities

TEACHING UNIT 1

Actions of teacher – Activities/problems	Expected actions of students	Student products	Educational documents
<p>Introduces a historical approach of pendulum study (longitude problem, needs for accurate timekeeping)</p> <p>Discussion on the text. What is the role of four key elements of a pendulum clock? Assuming that the pendulum clock goes forward, what changes would you suggest to regulate it? Justify your opinion.</p> <p>Closing discussion</p>	<p>Recognize the necessity of accurate timekeeping</p> <p>To understand how the pendulum clock works.</p> <p>To relate the period of the pendulum with the time clock unit</p> <p>Suggest factors that change the period of the pendulum</p>	<p>Worksheet 1</p>	<p>Sort historical text 1: “Galileo's mechanical clock”</p>

TEACHING UNIT 2

Actions of teacher – Activities/problems	Expected actions of students	Student products	Educational documents
Discussion on the text. How do you think Salviati (i.e. the character that expresses Galileo’s ideas) would go about giving a convincing answer to Sagredo’s claims? What specific technique would you use in order to verify Sagredo’s claim?	Put forward ideas on how to confirm the isochronal movement of the pendulum. Propose a suitable technique to control through experimentation the independence of period of the pendulum from the amplitude of oscillation.	Worksheet 2	Short historical text 2: “From mechanical clock to pendulum study”
Adoption and implementation of a technique (Demonstration experiment or group work)	Measure the period of the pendulum Conclude the independence of period of the pendulum from the amplitude of oscillation		Laboratory apparatus concerning a simple pendulum
Closing discussion			

TEACHING UNIT 3

Actions of teacher – Activities/problems	Expected actions of students	Student products	Educational documents
<p>Discussion on how a simple pendulum is transformed into a pendulum clock (of 1 second).</p> <p>Could you propose a suitable technique to control through experimentation your assumptions?</p> <p>Adoption and implementation of a technique (Demonstration experiment or group work)</p> <p>Closing discussion</p>	<p>Suggest the length of the string or/and the mass as factors which influence the period of the pendulum</p> <p>Propose a suitable technique to control through experimentation the dependence of period of the pendulum on the length of the string or/and the independence from its mass</p> <p>Measure the period of the pendulum</p> <p>Conclude that the pendulum clock of 1 sec has a string length of 1 meter.</p>	<p>Worksheet 3</p>	<p>Laboratory apparatus concerning the simple pendulum</p>

TEACHING UNIT 4

Actions of teacher – Activities/problems	Expected actions of students	Student products	Educational documents
Discussion on the text. Which in your opinion is the factor which influenced the results of the measurements kept by Richer in Cayenne?	Recognize that the pendulum clock in Cayenne is slow (its oscillation is slower, ie, it lasts longer than 1 second). Assume the dependence of the period of the pendulum on gravity	Worksheet 4	Sort historical text 3: “An exciting discovery: the voyage of Jean Richer to Cayenne” Tracing of the trip on a desktop globe
In which ways could someone confirm or discredit the idea that period depends on gravity? (Specifically, the grater the gravity is the smaller the period becomes)	Propose a suitable technique to controlthrough experimentation the dependence of period of the pendulum on gravity	Homework (optional)	
How could this problem be resolved, in those times?	Propose the change of the length of the pendulum or the use of a clock whose timekeeping does not depend on gravity		

7.2 Worksheets

Worksheet 1

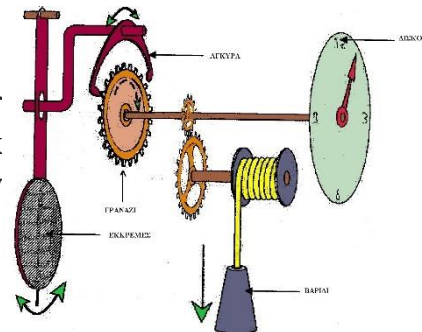
Galileo's mechanical clock The year 1636, Galileo proposes to the Dutch the construction of a clock mechanism (see photo) as which he claims «If you leave 4 or 6 of them to work simultaneously, you will not find differences in either of them not in 1 second, or even after several months.



A figure representation of this clock - pendulum is shown below. The mechanical pendulum consists of four main parts: (a) of the pendulum which is swung (b) of the anchor that is attached to the pendulum, so the swing of the pendulum be followed by a back and forth movement of the anchor (c) of a weight, which its fall causes the movement of the gears and the rod that is connected to the clock

Indicators and (d) of the disk on which are the indications of time and the indicators rotate. The anchor and gear (called escape mechanism) convert the continuous rotation of the gear in back and forth movement of the anchor. When the pendulum is at a extreme position, the "tooth" of the anchor locks the gear and does not let it spin. When the pendulum is hanging in the centre of the movement, the anchor releases the gear so it rotates, for a short time. When the pendulum reaches the opposite extreme position, the other "tooth" of the anchor "relocks" the gear and stops the rotation violently. The beat of conflict between the "tooth" of the anchor and the "tooth" of the gear is the familiar "tick-tack" of clocks. At the same time the gear, because of the weight, pushes back the anchor and the pendulum and the process repeats it self.

- Discuss the text with your teacher trying to understand how the clock works. What is the role of the four key elements of a pendulum clock?



- Pendulum
- Anchor -gear (escape mechanism)
- Weight that falls
- Disk with clock indicators
- Assuming that the pendulum clock goes forward, what changes would you suggest to regulate it? Justify your opinion.
 - We would suggest the following changes:
 - Justification of our point

Worksheet 2

From mechanical clock to pendulum study



The year 1638 was a historic one for science. Galileo published his work *Dialogues Concerning Two New Sciences*, one of the first written records of the birth of modern Physics. Galileo wrote *Dialogues* in the form of a play and discusses his ideas through its three main characters: *Salviati*, a brilliant scientist, who expresses Galileo's beliefs, *Sagredo*, a clever amateur disguised as a neutral participant and *Simplicio*, the well-meaning defender of the

ideas of the time. The following excerpt from Galileo's *Dialogues Concerning Two New Sciences* deals with pendulum motion, i.e. it is related to today's lesson. *Sagredo*: "... I have observed, thousands of times, the swinging of chandeliers, especially in churches, or lamps hanging from the ceiling and moving to and fro. But the only thing I have established from these observations is that it is most unlikely that the opinion of those people who claim that all these oscillations are maintained by the environment is correct. For, if that were the case, then the wind would have to act with great insight and have nothing else to do than to give this suspended weight a perfectly regular to-and-fro motion. It is impossible for me to imagine that the same body, suspended from a string of approximately 50 meters, and moved away by 90 degrees (90°) from its perpendicular position and then one degree (1°) from the perpendicular position could, in both cases, take the same time to cover a very large arc and then next a very small one. That seems to me very unlikely."

- How do you think Salviati (i.e. the character that expresses Galileo's ideas) would go about giving a convincing answer to Sagredo's claims?
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- What specific technique would you use in order to verify Sagredo's claim?

Worksheet 3

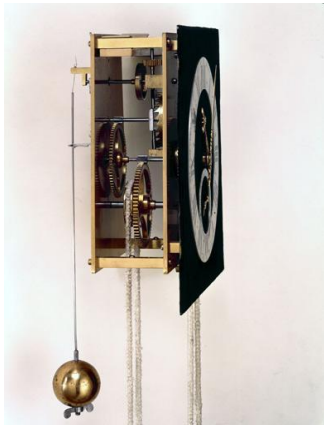
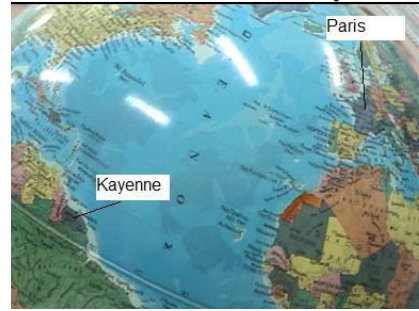
The 'second' pendulum

- How do you think you could transform a pendulum to a 'second'-pendulum?
- Could you propose a suitable technique to control through experimentation your assumption?

Worksheet 4

An exciting discovery: the voyage of Jean Richer to Cayenne

In 1672, the astronomer *Jean Richer*, was sent on a scientific mission by the French Academy of Sciences to the city of *Cayenne*, which is in French Guyana near the equator. Richer had a pendulum clock with him (like the one you see in the photograph) which had been set in *Paris* to oscillate in periods of 1 second. On observing the pendulum in *Cayenne*, Richer made an unexpected discovery: The pendulum clock was slow by 2.5 min each day. Richer's claim



that the pendulum clock of 1 sec slows down near the equator triggered a very interesting discussion concerning why this occurs. Some scientists doubted his measurements. In fact, there were several arguments like the one between Richer and *Huygens*, the man who had constructed the clock Richer had with him. Others tried to interpret the results of these measurements. They claimed that the assumption that the period of the pendulum depends only on the length of the string is not valid. In this way, they tried to identify other factors which could influence the period. This was in fact proven to be correct!

- Which in your opinion is the factor which influenced the results of the measurements kept by Richer in Cayenne?
- In which ways could someone confirm or discredit the idea that period depends on gravity? (Specifically, the greater the gravity is the smaller the period becomes)?
- How could this problem be resolved, in those times?

Homework (optional)

Make a small project on what you learned regarding the movement of the pendulum and the measurement of time. This project can contain text, drawings, photographs or other material that you judge that has relation with this. Then, with the help of your teachers in physics and engineering, "you hang" your work in the web page of your school.

8.Obstacles to teaching and learning

Existing student conceptions and alternative scientific ideas

A research study that we have made concerning the students' conceptions about the conceptual, methodological and cultural dimensions of knowledge

implicated in the study of timekeeping and the simple pendulum revealed various cognitive obstacles the students face before teaching. Two complementary methods were used in order to trace the students' conceptions: the *review*, with the help of a pertinent questionnaire, and the *case study*.

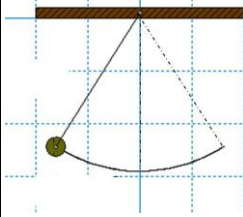
- The questionnaire is made up of three parts, one for each component of scientific knowledge of the pendulum (cultural, conceptual, and methodological). Each part includes three to five, mainly closed, questions. There are a total of twelve questions.
- The case study consists of the observation of two nine-member groups of students who are to participate in a discussion initiated by the researcher through certain "activities/problems" posed to the students. During the discussion, the students must produce a written text for each activity/problem. Ten such activities/problems (similar with those of teaching sequence), divided into four sections, were posed. Each section lasted 45-50 minutes. The students discussed among themselves, either split up into subgroups of three, or as a single group with the researchers monitoring the discussion.

Some results of this study are described here:

- With regard to the cultural dimension of scientific knowledge of the pendulum, we conclude that, even though a large part of the student sample recognizes that the pendulum is a precise timekeeping mechanism in relation to older mechanisms, nevertheless it does not seem to be able to express a clear perception of why this is so. That means that timekeeping can constitute an interesting context in which the simple pendulum can be studied by the students because it may be linked to interesting cultural elements for them (e.g. references to ancient Greek timekeeping mechanisms or a more "technological" context, as the mechanism in the mechanical clock).
- In relation to the conceptual context, it seems that the majority of the students do not recognize isochronous pendulum motion, as was to be expected. At the same time, however, it emerges as an interesting topic which can provoke constructive discussions, as was shown by the dialogue with and among the students. The students seem to be determined to find proof of the phenomenological paradox of isochrony which is "theoretical" rather than "experimental." Not emphasizing the problem of isochronous pendulum motion in traditional teaching means that an opportunity is lost for the creation of areas of conceptual interest for students (compared to other, more "mathematized" and, therefore, less interesting conceptual frameworks such as the dynamic and energetic analysis of pendulum motion). What's more, it appears that isochrony constitutes a serious conceptual problem for the students which must be taken into account when formulating suitable teaching goals.

- Finally, the data indicates that underscoring isochrony as a basic conceptual problem can facilitate the understanding of experimental procedure through which it is possible to highlight the laws of the pendulum. In the same time, underscoring the hypothetico-productive method as a basic methodological choice seems to take on, besides epistemological validity (in relation to the empiricist approach of traditional education), educational validity as well. However, a full analysis of our data as a whole is required in order for us to adequately substantiate this view.

QUESTIONNAIRE First read this text.



The simple pendulum (as you can see in the side figure) is a small object (usually round) that has the ability to hover hanging from the edge of a thread. We say that the simple pendulum is making a **simple swing** when moving once from one end to the other end of the movement.



1) **Circle the answer you believe to be correct.** In the 17th century, first Galileo studied the properties of motion of simple pendulum. Why do you think he did it? a) Because the problem of measurement of time bothered him. b) Because he was studying the motion of the oscillation c) I do not know

2) **Select one of the options in each sentence.**

1. The discovery of the clock-pendulum has greatly influenced the navigation.

correct wrong I do not know

2. The discovery of the clock-pendulum influenced our knowledge of the exact shape of the earth (if it is global or nearly global compressed at the poles).

correct wrong I do not know

3) **Circle the answer you believe to be correct**

The pendulum clock is a very complex mechanism that includes gears, springs and other sub-mechanisms. Do you think that:

a) To study the properties of the simple pendulum we necessarily need the knowledge of how it has built

b) construct a clock - pendulum it is necessary to have studied the properties of simple pendulum

c) I do not know

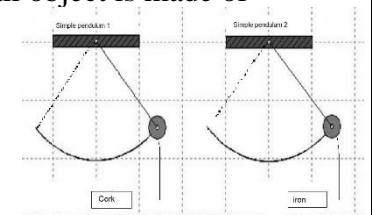
Justify your answer

4) **Circle the answer you believe to be correct** The two simple pendulums in the figure differ only in the material that each small object is made of (meaning as of the weight of the object). If allowed to swing freely, what will happen?

a) The simple pendulum 1 performs a simple swing longer in time than that of the pendulum 2

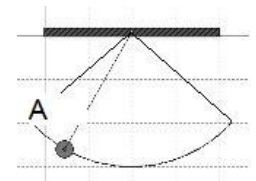
b) The simple pendulum 1 performs a simple swing longer in time than that of the pendulum 2

c) Both perform a simple swing in the same period of time d) I do not know



5) Circle the answer you believe to be correct Let the simple pendulum in the figure to swing freely from position A. As time passes, the pendulum swings more and more the less. The time it takes to make a simple swing:

- a) As time passes, increases
- b) As time passes, reduces
- c) As time passes, does not change
- d) I do not know

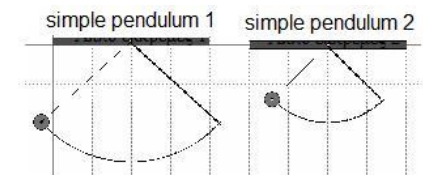


Justify your answer

6) Circle the answer you believe to be correct

The two simple pendulum in the figure differ only in the length of the rope from which they are hung. If we allow them to swing freely, what of the three will happen?

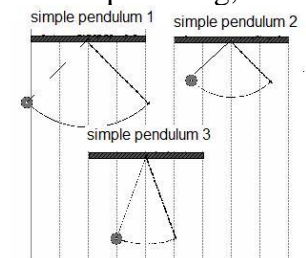
- a) The simple pendulum 1 performs a simple swing longer in time than that of the pendulum 2
- b) The simple pendulum 2 performs a simple swing longer in time than that of the pendulum 1
- c) Both perform a simple swing in the same period of time
- d) I do not know



7) Circle the answer you believe to be correct

In the figure below three simple pendulums are shown, which differ by two, according to the position from which we release them (from higher or lower), or according in length of the string. If you wish to control the effect of the position where we let the pendulum on the time it takes to make a simple swing, which of the pendulums would you use?

- a) The pendulum 1 and 2
- b) The pendulum 1 and 3
- c) The pendulum 2 and 3
- d) All 3e) I do not know



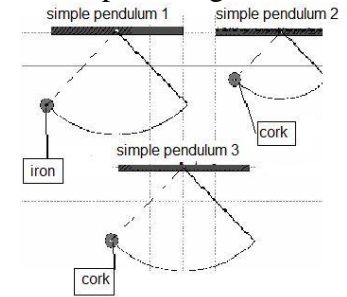
Justify your answer

8) Circle the answer you believe to be correct

In the figure below three simple pendulums are shown, which differ by two, either in the material the small object is made of (meaning the weight of the

object), either in length of the string. If you wish to control the influence that the length of the string has on the time it takes to make a simple swing, which of the pendulums would you use?

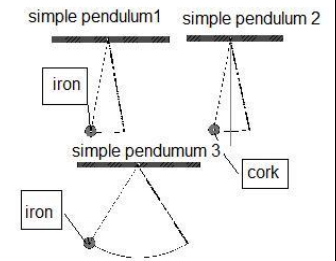
- a) The pendulum 1 and 2
- b) The pendulum 1 and 3
- c) The pendulum 2 and 3
- d) All 3
- e) I do not know



9) Circle the answer you believe to be correct

In the figure below three simple pendulums are shown, which differ by two, either in the position from which we release them (from higher or lower), either in the material the small object is made of (meaning the weight of the object). If you wish to control the influence that the weight of the item has on the time it takes to make a simple swing, which of the pendulums would you use?

- a) The pendulum 1 and 2
- b) The pendulum 1 and 3
- c) The pendulum 2 and 3
- d) All 3
- e) I do not know



10. Research concerning the implementation of the case study

10.1 Description of teachers' and researchers' experiences regarding problems of teaching and learning specific for this Case Study (see Ref. 10)

The present case study was applied in three schools from three different teachers[1] within a framework of dissemination of the teaching program in everyday educational conditions (teacher with short-term training in the subject, regular school environment). The teachers were attended an 8-hour workshop about the content of the study. The finale evaluation of the disseminated teaching sequences is currently in progress.

10.2 The attitudes of students toward the introduction of case histories inspired from the history of science in the teaching of science (see Ref. 7)

A small research concerning the attitudes of students toward the introduction of the three case histories that have been introduced to the teaching is currently in progress. The data, which was collected from a questionnaire of four questions, was given to the students in the end of teaching program. A first analysis of data shows that the big majority of students consider that the introduction of small case histories inspired from the history of science in the teaching of the particular subject is an interesting idea and make science meaningful, connect this interest with the narrative approach in learning and understanding the world and differentiate the importance and the objectives that serve the different case histories in the teaching.

QUESTIONS ABOUT THE SHORT HISTORICAL STORIES

We would like your opinion on the three short texts that you used (quoted at the end of the questionnaire) during the teaching. So answer the following questions as honestly as possible. It will help us improve the next course for the simple pendulum.

1. Would you be interested in short story lessons such as those used during instruction?

Yes No

Justify your answers

2. Which of the three short stories seemed more interesting;

a) *Galileo's mechanical clock*

b) *From the mechanical clock in the study of simple pendulum*

c) *An exciting discovery: The voyage of Jean Richer in Cayenne*

Justify your answer

3. Which of the three short stories seemed to you more suited to the course?

a) *Galileo's mechanical clock*

b) *From the mechanical clock in the study of simple pendulum*

c) *An exciting discovery: The voyage of Jean Richer in Cayenne*

4. The three short stories used in class refer to earlier times in history and historical figures who played an important role in the development of physics. Did it bother you that such stories did not speak about modern times?

Yes No

Justify your answer

9. Bibliography

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