

# Using discrepant events to teach the center of mass: A structured inquiry approach with the 5E model

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## Abstract

A discrepant event is a demonstration or phenomenon that produces an unexpected outcome, for example, an object that appears to be rolling uphill. The purpose of this research paper is to study the effect of such phenomena on the learning process, to determine whether they can improve students' understanding of a certain concept. In this study, the learning subject proposed is the center of mass in Secondary Education. Using the setup provided, students are called to complete two worksheets, designed according to the 5E educational model, with each activity corresponding to one of five phases: Engage, Explore, Explain, Elaborate, and Evaluate. They are also called to answer pre- and post-tests, which aim to evaluate their understanding of the concept before and after the learning process. The entire teaching module follows the guidelines of Structured Inquiry, where students experiment on the provided setup and collect data. In the end, they are asked to make appropriate conclusions based solely on the results of their investigation.

**Keywords:** 5E model, Discrepant events, Inquiry, Secondary Education

## 1 Introduction

A discrepant event is a phenomenon which produces a counter-intuitive outcome, a result that is not expected. A good example of such an event is an object that appears to go uphill when let on an inclined plane. Discrepant events, or counterintuitive concepts, are useful in the learning process for two reasons: Firstly, students often have a certain intuition that leads to misconceptions when learning about new scientific concepts [1, 2]. Secondly, the encounter of a counterintuitive outcome often grabs the attention of students, making the concept more memorable [1, 2].

This is important to teach that the outcome that a student expects is not always correct, so intuition cannot always be trusted when dealing with scientific phenomena. Furthermore, when an outcome is counterintuitive, it becomes more memorable for the student, making the subject more comprehensive [2]. There is general bibliographical support for Problem and Experiment-Based learning [3-6] that suggests this method to be more interesting and vivid and interactive for the students.

Combining problem-based learning with counter-intuitive concepts can have significant effects on the learning process. One application for this method in the classroom is to ask the students to predict the outcome of a counter intuitive phenomenon. After showcasing the actual outcome,

the students are asked to explain the divergence of their previous answer from the actual outcome [7].

In this study, the discrepant event chosen is a peculiar object that appears to be rolling uphill. This object is a double-cone and when placed on an inclined surface, it rolls uphill (Fig. 1). A side view shows that the center of mass is moving downwards when the object is rolling upwards.

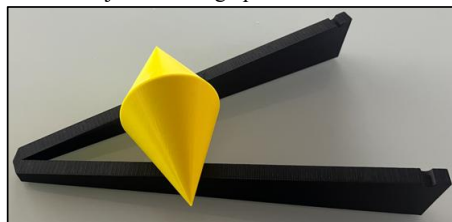


Fig. 1 The double cone object that rolls uphill

## 2 Theoretical Background

### 2.1 Structured inquiry

Inquiry is an educational technique that encourages the student to inquire and discover information on their own, instead of learning information directly from the teacher. Students can understand science concepts by actively engaging in the learning process [8, 9].

So far, there is plenty of research that supports inquiry-based learning [10-12], thus we chose to build a lesson plan around the structured inquiry approach. This means that students were given specific instructions for each step, accompanied by the according worksheets. The students' role is to

inquire the solutions to the questions given, with the proper guidance where needed [13].

Different from open inquiry, the structured inquiry approach supports students' exploration of the given topic, while providing given tasks to give more outcome control to the teacher and make the process easier for the students [14-19]. In the open inquiry approach, the educator presents a topic where the students must choose a procedure to address it. In the structured inquiry approach, the educator provides both the learning subject and procedure which the students will work on, with the results of the inquiry being unknown to the students [20].

Structured inquiry is a useful method when approaching inquiry-based learning for the first time, because it follows the basis of discovery while allowing the educator to hold control over the subjects discussed and the learning outcomes of the process.

## 2.2 The 5E model

The 5E model is a popular educational model created by the Biological Sciences Curriculum Study (1987), based on the Atkin and Karplus learning cycle, which is supported by cognitive psychology, and constructivist-learning theory, and consists of the following steps: Engage, Explore, Explain, Elaborate, and Evaluate. Each one of these five steps represents a cognitive learning stage.

The engagement part is the first phase, during which the teacher aims to introduce the students to the topic of study. During this stage, the teacher gets to evaluate the students' prior knowledge on the topic and motivate the students' curiosity before the next stages begin. The students now mentally focused on the subject, go through the exploration part where they can find out more information about the setup and phenomenon presented to them. This part is student-centered and provides a hands-on learning experience. This step promotes inquiry-based learning, since the students are not yet provided with typical explanation of the phenomenon by the teacher. [8, 14, 15]

After that, the explanation phase takes place, where the students are required to provide concise answers about their findings from the previous parts, as well as discuss their findings with the teacher and ask questions. In this stage, the teacher gets to introduce certain technical concepts as part of the discussion, after the students get the opportunity to share their own findings and opinions. This also aims to correct any misconceptions the students might have before going to the next phase, elaboration.

At this point, the students are asked to use their understanding of the phenomenon in a discussion with peers, a design of a new experiment, or an application of the phenomenon on a new idea, as a result of the knowledge they have acquired from the

previous process. The last phase is the evaluation, which serves as an assessment of their knowledge. This can be done by any traditional (written evaluation, verbal quiz) or non-traditional assessment form (peer-evaluation, etc.). The phases can be used in order during a lesson, but a rewind to a previous stage is always possible. In this research, the parts are followed in the lesson plan in serial order. [8, 14, 15]

The 5E model follows the necessary steps to make the learning process both interactive and understandable for the student. There are multiple sources that confirm the advantages of the usage of this model, with great results showing improvement in the educational process in STEM subjects [20]. Studies report a better understanding of scientific concepts, an effect on the decrease of formation of misconceptions, and an increase in scientific achievement [21-24].

## 3 Results

### 3.1 Overview of the lesson plan

The lesson plan is designed for the course of Physics, with the learning subject being the center of mass. The application should take 3 hours (study periods), consecutive or separated. The application space can either be in physics class, or in an after-school physics club. The lesson plan was designed to be applicable on students at the high school grades (10<sup>th</sup>, 11<sup>th</sup>, 12<sup>th</sup>).

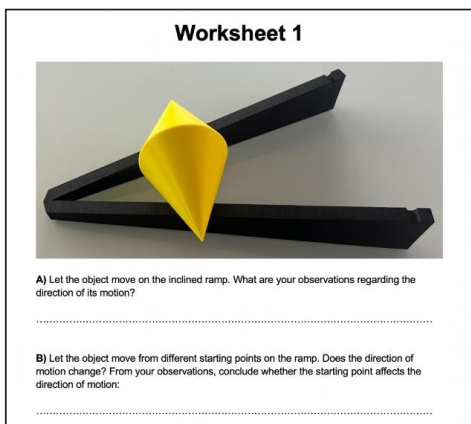
The center of mass appears in the Greek syllabus in paragraph 4.2 (kinematics of solid bodies). The definition of the center of mass according to the textbook is the following:

*"The center of mass of a solid body is the point that moves like a point mass with mass equal to the mass of the solid body, if all the forces that are applied to the solid body are applied to it."* [25]

In the textbook there is also information about the path of the center of mass during the movement of a solid body. The lesson plan aims to teach the students the concept of the center of mass, the ability to locate it on different shapes, and the ability to predict the motion of an object on an inclined surface.

### 3.2 Worksheets

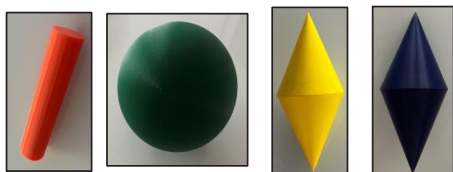
The students are given two worksheets, which accompany the lesson plan in detail. The worksheets contain precise diagrams and pictures of the setup that accompany each question, to make the learning experience more descriptive. All the questions are formed in a way that supports both the structured inquiry base, and the 5E model phases. The first worksheet contains the Engage and Explore parts, with the second worksheet containing the rest. Some expository questions from the worksheets are shown in Fig. 2, 4, 5, 6.



**Fig. 2** Example of Worksheet 1: Questions from the "Engage" phase of the 5E model

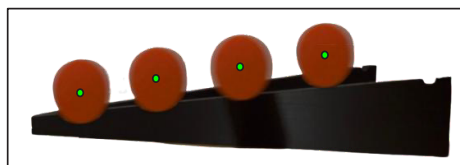
The first part of the lesson plan is based on the "Engage" part of the 5E model. At this stage, it will be important to familiarize the students with the experimental setup. They will be given the inclined ramp and double-coned object. They will be asked to let the object move on the ramp and place it on different starting points and then observe the direction of motion each time. The students should observe that the direction of motion is the opposite of that expected - the object moves uphill.

Continuing the application of the 5E model, the students will now move on to the "Explore" part. They will be given four different objects to experiment with. The objects are shown in Fig. 3. They will be asked to note the direction of the motion of each object. They are to observe that the direction of motion will vary. This will lead them to the conclusion that the center of mass is the parameter that explains the upwards (and downwards) motion.



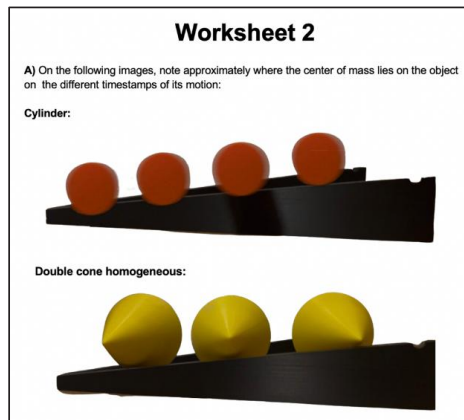
**Fig. 3** Cylinder, Sphere, Double-cone homogeneous, Double-cone hollow

The third phase of the lesson plan is the "Explain" part. At this stage, students will be called to pinpoint (approximate) the position of the center of mass in the four objects for various timestamps of the motion of each object. They will do this for all the four objects. During this time, there will also be a discussion for the center of mass of the hollow double cone. Students are called to find that the center of masses of the two double cones is in the same spot, even though the one is hollow. An example of the pinpointing the center of mass is given below:



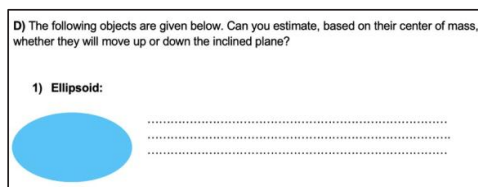
**Fig. 4** Example of approximate placement of the center of mass on the cylinder motion stamps

Because the images of the timestamps in the worksheets are given in 2D view (from the side), it is important to also hold a discussion about the location of the center of mass with the students on the actual experimental setup. It is advised to ask them to also pinpoint where they think the center of mass is on the real object. This discussion is well fitted as part of the explanation part of the 5E model.



**Fig. 5** Example of Worksheet 2: Questions from the "Explain" phase of the 5E model

The next part is the "Elaborate" part, a continuation of the previous part, where the students are asked to connect the points, they have drawn and show the path of center of mass on each object. By finding the path, and noting the direction of motion, they will come to an important realization: The center of mass is always moving downwards. They now come to explain, that the objects that move uphill are simply an illusion, since their center of mass is rolling downwards.



**Fig. 6** Example of Worksheet 2: Questions from the "Evaluate" phase of the 5E model

For the last phase of the 5E model, the "Evaluate" part, students are asked to evaluate their understanding of the center of mass by predicting the direction of motion in two objects shown to

them. The objects given are an ellipsoid and a cube. By now, the students should be able to predict the direction of motion of a given object. This shows that they have understood the setup in depth.

### 3.3 Pre-Post tests

A pre-post test is designed to test the students' performance and the efficiency of the lesson plan introduced in teaching the concept of the center of mass. The test covers a basic level of understanding of the concept of the center of mass. Specifically, it tests the students' knowledge on the definition of the center of mass, the ability to point the center of mass in 2D and 3D objects, and to predict the path of an object on an inclined ram. It is hypothesized that before the lesson, the students will predict that all objects will move downhill on the inclined ramp. After the lesson, the students should have learned that this is not always the case.

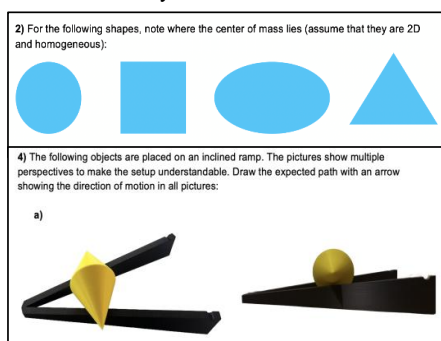


Fig. 7 Example of some questions from the pre-post test

## 4 Discussion

Students often have many misconceptions about scientific phenomena, based on their intuition. These misconceptions can be used to the educator's benefit, with the application of discrepant events in the classroom. This is why discrepant events could be a great tool to teach students certain concepts that are otherwise challenging. The concept of the center of mass is often difficult to absorb, because it is a theoretical concept (not something the students can directly see and sense).

The lesson plan designed opts to challenge the students to discover the center of mass on their own while conducting experiments with unexpected outcomes. Both experimenting and seeing unexpected results, helps the students get a memorable and hands-on learning experience, guaranteeing that the concept taught will be easily absorbed. Finally, the material given to the students (worksheets and pre-post test) aims to help the educator apply the structured inquiry approach while using the 5E model.

The teaching materials presented in this work are set to be used for an application at an after-school club for high school students that have a high

interest in physics, which will ensure the highest possible interest for the given subject. Although the initial group size will be small, consisting of 15 students, the application will be later done in a larger-scale audience in order to acquire more accurate results for the efficacy of the method presented.

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