Module Booklet for

Inquiry-Based Investigation Tool

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Description of the Tool

Inquiry in science classrooms is linked to exploration of the phenomena. Literature on science education emphasize on discussing the phases/scaffolds during this exploration (Chiappetta, 1997) and later many studies asked educators to go beyond applications (Windschitl et al., 2008). Inquiry is not a one-way street and previous body of the literature provided various definitions of scientific inquiry (Minner et al., 2006; Pedaste et al., 2015). This should not be a surprise, since the emphasis on inquiry is defined as the "the main focus of science education reform" from 1996 to 2006 by Furtak and colleagues (2012 p.1). This module presents a new tool called the Inquiry Based Investigations Tool. This new tool presents inquiry as a cycle in which students define, explore and investigate phenomena to serve as a basis for new investigations. The idea of inquiry considering inquiry as a cycle relates to the design cycle (McElhaney, 2019).

The new inquiry tool designed in the DECOSTE project is in line with the common practices summarized in previous studies and it emphasizes the practices when exploring the phenomena in a cycle. Inquiry based investigations relate to the big ideas presented under driving questions and inquiry-based investigations continue to explore new problems/variables/parameters (see Figure 1). There are different models for creating inquiry-based investigations and there are different types of inquiry (e.g., open, structured). Inquiry-based investigations tool present a guideline (McNeill & Krajcik, 2009) for supporting the inquiry process and presents inquiry as a cycle. In this cycle, it is important that teachers support developing, testing, revising and explaining ideas (Windschitl et al., 2008). When starting inquiry-based investigations, a teacher presents an engaging problem situation through a simple demonstration, video-clip or through storytelling. The problem situation is often presented as a structured question (How does adding salt to water affect the boiling point of the liquid?) or as an open question (Can you have colored shadows?) question. The type of question depends on previous experiences with inquiry practices and the phenomena explored during inquiry.

The introduction of a problem situation helps students to develop their initial ideas and pose questions or state a hypothesis related to the phenomena under consideration. Next the teacher elaborates on students' initial ideas or research questions by them to share these ideas, hypothesis or questions. In this process, it is important to make sure students clearly present the links between variables (e.g., classify or look for patterns) in their hypothesis or the question (e.g., Colored light sources [same sized, placed in equal distance] can create colored shadows.) This step will serve as the baseline for the data collection.

The next step of the tool emphasizes the data collection to test the links between variables. In all inquiry investigations, it is vital to support data collection through observing and writing observations to a table. When collecting data, the teacher helps students understand the importance of scientific data and the constraints of data collection (e.g., when to start data collection and stop data collection, why different sources of data were collected). In the final step of inquiry investigations, teachers ask students to analyze their firsthand data to test their hypothesis. Then students are asked to explore the secondhand data collected by their friends to explore the patterns and discrepancies. The important idea here is to test students' hypothesis based on their own and others' data. Inquiry-based investigations are not a process and exploring a problem situation should lead to investigation of other potential problem situations by considering other related parameters and variables.

Figure 1. Inquiry Cycle

Link to Coherent Science Instruction

When we search for “science” and “inquiry” in the abstracts of the studies published in the Web of Science database, there were 10846 articles. When we limited these articles to Educational Research, the number decreased to 5129 articles. Under Educational Research, there were 10 countries that published more than 100 articles from 1971 to 2021. These countries published 84% of the articles (N=4321).

In our search, these countries published more than 100 articles in 2007. In the last 25 years, this steady growth in the number of publications continued (see Figure 2). United Stated took the lead with 2676 articles, accounting more than 50% of the articles published under Educational Research. United States is followed by Turkey [327 articles], Canada [246 articles], Spain [201 articles], England [196 articles], Israel [158 articles], Germany [149 articles], Netherlands [132 articles], Taiwan [219 articles], People’s Republic of China [185 articles].

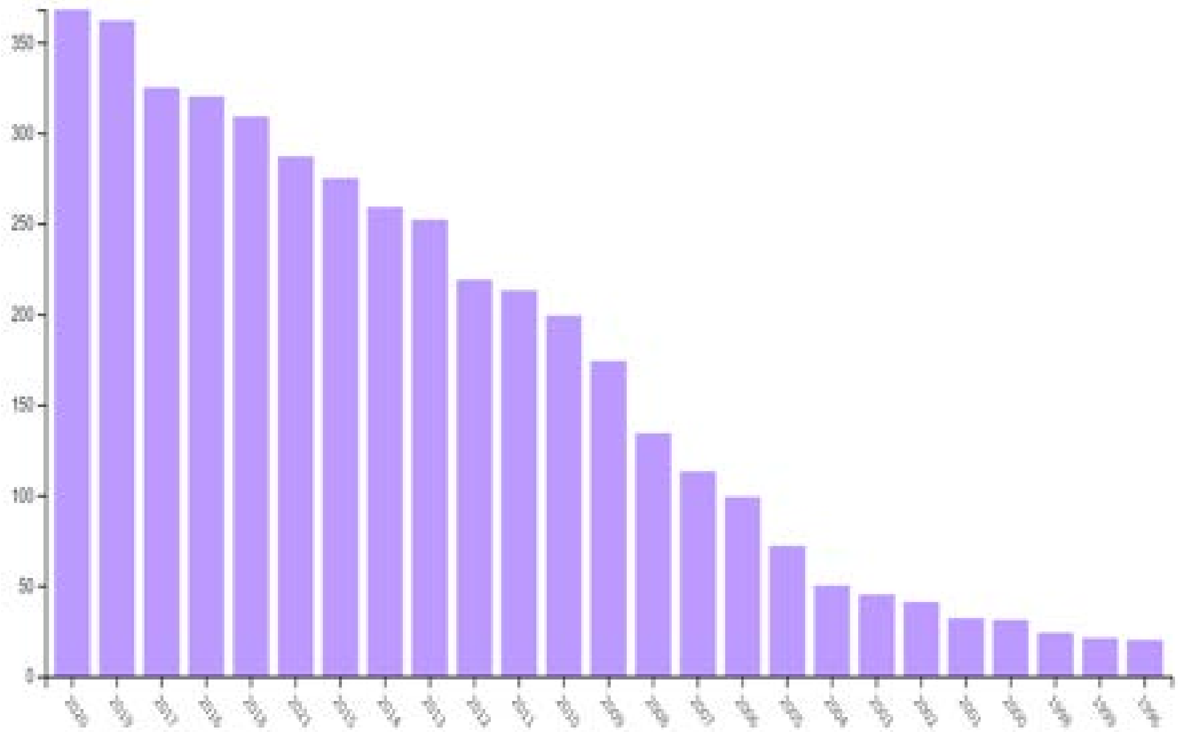


Figure 2. Publication Years

To understand trends, we examined the trends in the countries that published at least 100 articles from 1971 to 2021 under Educational Research. The threshold was 30, and 40 keywords met the criteria. We used VOSviewer software to analyze the keyword co-occurrence (Zupic & Cater, 2015). These keywords were presented in five clusters in Figure 3.

In the red cluster, argumentation and inquiry based teaching are at the center. This cluster also includes collaborative learning, high school, inquiry learning, middle school, primary education, problem-based learning, project-based learning, scaffolding, science inquiry, science learning, science teaching, scientific practices, secondary education and STEM (science, technology, engineering, mathematics).

In the yellow cluster, professional development and teacher education are at the center. This cluster also included elementary education, pedagogical content knowledge, science teacher education, self- efficacy, STEM education, teacher beliefs and teacher professional development.

In the blue cluster, inquiry is at the center. Assessment, biology, elementary, motivation, science and technology are also placed in blue cluster. Yellow cluster has nature of science, scientific inquiry and science literacy at the center. Yellow cluster also included elementary science. The final black cluster is consisted of curriculum, inquiry based teaching and discourse.

As stated in the previous section, inquiry has a diverse terminology. Our analysis also presents that inquiry is presented in five different keywords including: inquiry learning, inquiry based learning, science inquiry, inquiry and scientific inquiry.

In our analysis, top five keywords occurring with inquiry were professional development (occurred 211 times), nature of science (occurred 130 times), argumentation (occurred 85 times), teacher education (occurred 79 times) and assessment (occurred 69 times).

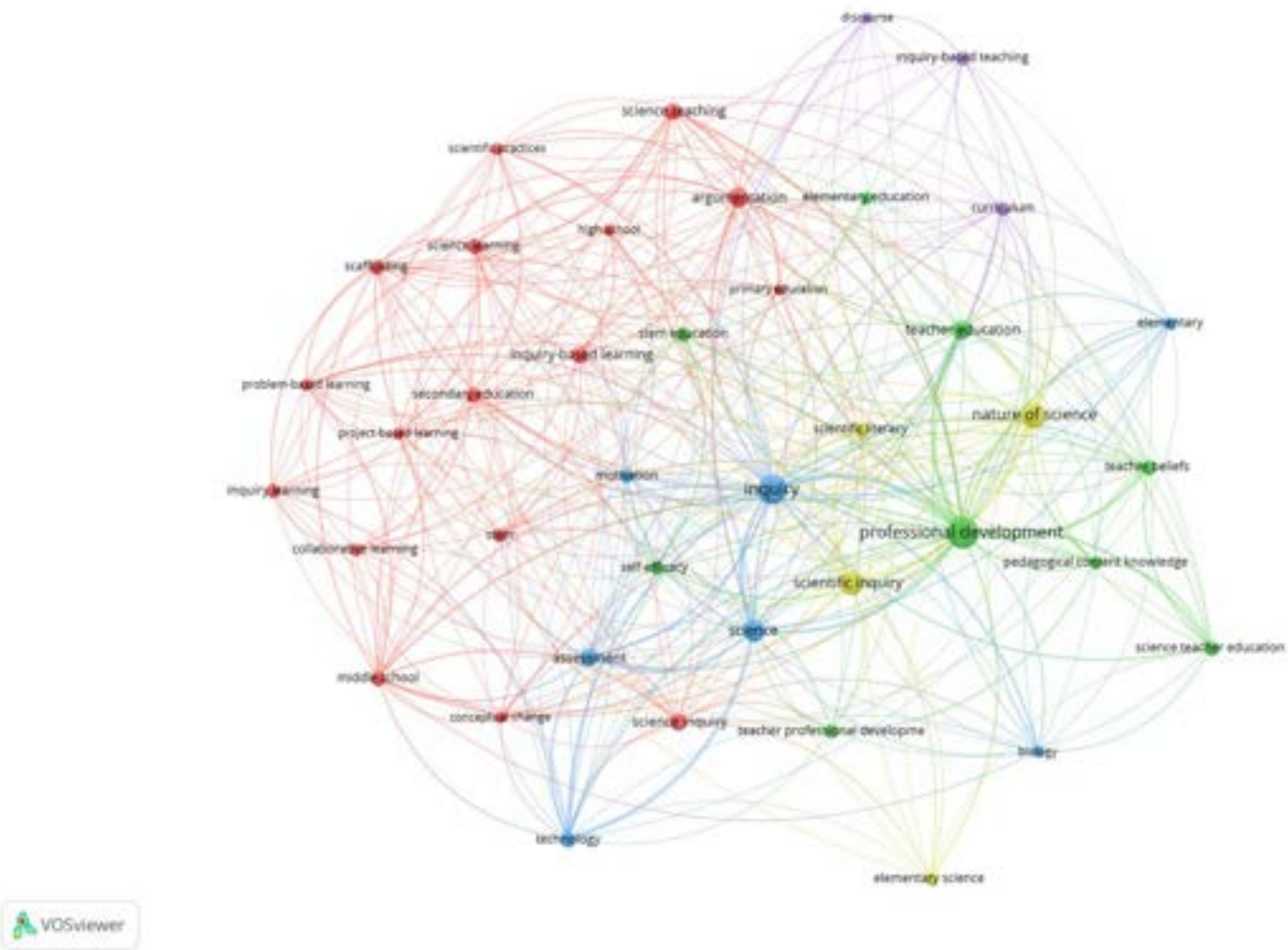


Figure 3. Keyword co-occurrence

Our analysis of inquiry studies presented several important themes, and the goal of the inquiry-based investigations tool is connected to these themes. Assessment, curriculum, teacher education and professional development emerged as important themes in our analysis. In addition, inquiry was connected to the nature of science, argumentation and scientific literacy. In a similar way, inquiry-based investigations tool is presented as an instrument supporting Coherent Core. We suggest that the inquiry-based investigations tool is used to support knowledge-in-use in Coherent Core. Inquiry-based investigations tool is designed as a cycle, it guides to explore phenomena and it opens the door to investigate new phenomena about the driving questions.

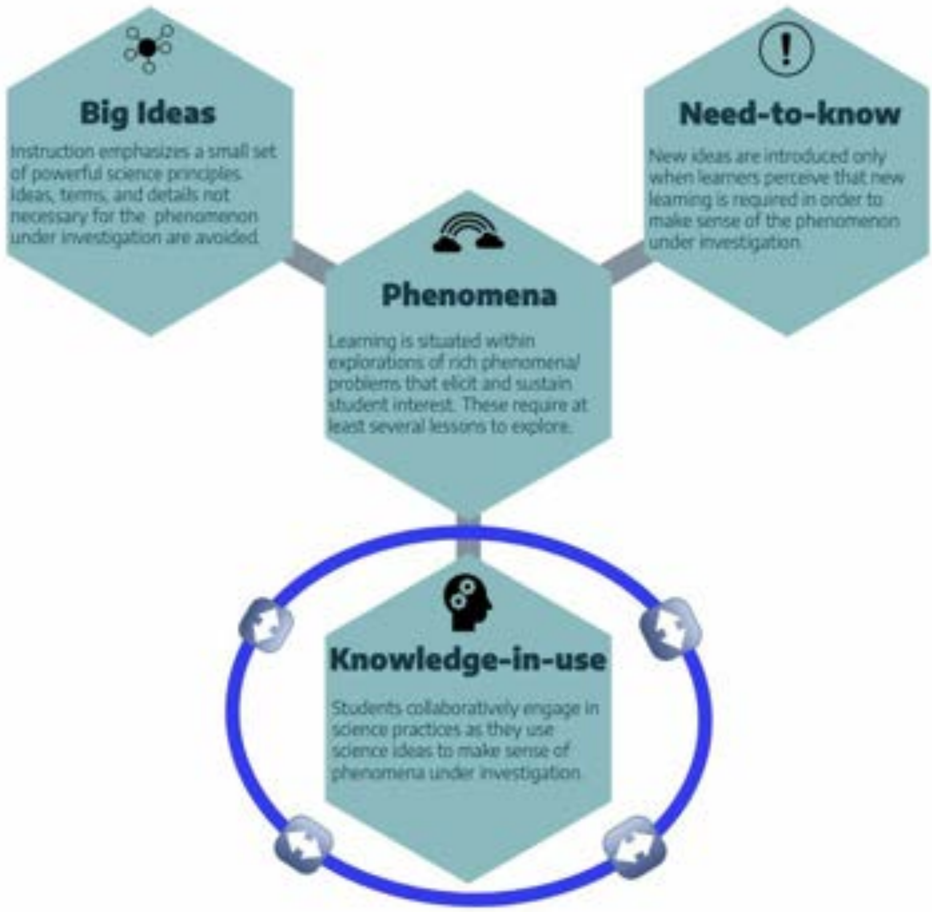


Figure 4. Placing Inquiry-Based Investigations Tool in Coherent Core

Possible Integration into the Teacher Education Curriculum

Inquiry based science learning is a prominent component of teacher education programs across Europe and it is introduced in different stages in teacher education programs. The inquiry-based investigations tool introduces a cycle which guides students to make sense of phenomena through exploring. Inquiry can be implemented in different forms (e.g., structured or open). In the case of shadow investigation, teachers can start by discussing pictures including a short and a long shadow. This could trigger the question: What affects the size of a shadow? This could present a more structured example. On the other hand, long cycle inquiry example includes an open inquiry example in which teachers challenge students to create their own claims before students start exploring these claims (open inquiry).

Difficulties of Pre-Service Teachers

Pre-service teachers may struggle to understand how and when to integrate the inquiry-based investigations tool since there is a big variety across different teacher education programs. In this document, we will elaborate on these differences by discussing several examples from each partner of the DECOSTE project. In several teacher education programs inquiry can be found in many different courses (see Table 1). There are different forms of inquiry and implementing inquiry may depend on the instructor (e.g., Denmark). Finally, there could be differences in the intended and enacted curriculum (Nordine et al., 2021). Türkiye presents an interesting case for this. Inquiry is first presented in the 3rd year in the intended curriculum; however, the enacted curriculum is designed as an inquiry-based curriculum (Science Education Curriculum, 2018).

Table 2. Inquiry Examples from DECOSTE partners

Country/ City	Inquiry in Teacher Education Programs	Sample Inquiry Activities (Name of the course, where/when/ how inquiry was implemented
Germany/ Essen	„forschend-entwickelndes Unterrichtsverfahren” (problem-based teaching and learning) Nature of science Extensive collection of experiments	Teaching and learning concept as part of a lecture (only summer term) Experiments that are meant for inquiry as part of two different lab courses and seminars (one during summer term and one during winter term) Small scale research project as part of the so called „Praxissemester” (every term)
Germany/ Kiel	All pre-service teachers are required to take multiple lab courses during their teacher education program. As part of the lab courses, PSTs mainly conduct and analyze multiple experiments. As part of the method courses, PSTs are familiarized with methods to support students in formulating explanations and designing models.	For example, using a smartphone to determine the acceleration during a pendulum experiment. Analyzing a bouncing ball using a video analysis software.

USA/Iowa	Elementary science methods are responsible for conducting science inquiry into everyday phenomena. Secondary students evaluate instructional materials relative to the "EQuIP" rubric to evaluate how materials align with the vision of the NGSS.	Elementary science students explored why baking soda and vinegar react to form bubbles and considered how this phenomenon could serve as the basis for a learning activity in which pupils collect and represent evidence for the conservation of mass.
Finland/ Helsinki	Inquiry for class teachers: biology, geography, physics, chemistry and health education didactics courses (12,5 credits all together), and teacher training at normal schools Inquiry for subject teachers: subject didactics courses (10 credits), and teacher training at normal schools.	We introduce several different models like problem-based teaching and learning or discovery models. Some kind of inquiry is used all the time in science lessons. Course of health education didactics for class teachers - ongoing, last laboratory meeting was 2 weeks ago and students made hands on activities they can use as they teach health education. For example, they can investigate the amount of sugar and salt in food products.
Sweden/ Halmstad	The student teachers have to conduct science inquiry into everyday phenomena. Normally for lower secondary science and science education (PCK, methods) are integrated with the science content in the courses.	Students make an experiment where they put a glass on the candle and make a hypothesis and explain it. Then they did the experiment again and put a sensor next to the glass which measured the level of carbon dioxide and oxygen. Then we had a discussion about what digital tools can help us with and why they could be important in science teaching to visualize abstract phenomena such as gases.
Norway/ Bergen	Usually not in science subject courses (there only traditional lab experiments); can be a topic in all science education courses depending on lecturer examples: https://www.uib.no/emne/KJEMDID220 https://www.uib.no/emne/PHYSDID220 https://www.uib.no/emne/NATDID210	Chemistry education course, January 2022: modeling chromatography from a demonstration of paper chromatography with black ink Master project (august 2021): Students prepared what they need to make a campfire. They made one in fume hoods and discussed observations and potential explanations. They were challenged to describe what actually burns when they burn wood (chemistry

		perspective). The teacher showed a demonstration (dry destillation) to show that a “gas” is burning.
Denmark/ Copanhagen	Inquiry can be found in many courses at the Department of Science Education in the University of Copenhagen.	KOMODO dragon extinction avoidance through parthenogenesis. Students were given DNA genotypes for several dragons and their eggs and asked to devise a way that females can produce healthy offspring without sperm fertilization of their eggs. Furthermore, they were asked to hypothesize about the fact that all the baby dragons are males based on the DNA chart. Then a similar instance of a boa constrictor producing litters of baby snakes without male sperm, but in this case tge babies were all females. Basic science teacher education course. I taught the full 6F lesson to them as participants for 1.5 hours last week. They then constructed the 6F model on the basis of the Komodo activity. This lesson presented inquiry as a strategy of survival for Komodos as well as a pure inquiry about the pedagogical structure of an inquiry lesson through reflection on their just completed IBSE experiences.
Türkiye/ Uşak	The revised science teacher education program places strong emphasis on inquiry and inquiry experiments in the 3rd year (Council of Higher Education, 2018).	There are specific courses designed to support inquiry-based practices (e.g., laboratory courses). However, inquiry is a fundamental aspect of the Turkish science curriculum.

Suggested Activities for Introduction

The inquiry-based investigations tool presents a cycle that could be completed in several hours. Still, it is important to remember that completing the cycle depends on the time students spend doing research on the problem and collecting data when exploring phenomena. This module will present three examples: Learning the Tool, Short Cycle, and Long Cycle. Each cycle presents the steps to be followed during the cycle and offers potential ways to add new cycles. All materials needed for the investigations and the procedure for each investigation are presented under each experiment. In each investigation, sample results collected by pre-service teachers are included.

Learning the Tool

The main goal of this investigation is to help students become familiar with the inquiry-based investigations tool. The driving question that we investigated during this investigation is: "Why do we have shadows?"

Picture taken from pixabay.com.

The problem connected to the driving question is "How does the height of a shade change during the day when the position of light changes?" Students are given the following materials **(**light source [students can use their mobile phones], cardboard, 15-20 cm long object, ruler, screen), and they are asked to write their own questions, define variables to plan the investigation (students can also explore how does a projector create black color on screen and how the shape changes based on students' distance to the screen).

After defining the phenomena, the procedure is introduced to students. Students place the object on cardboard. As presented in Figure 4, students change the position of the light source and measure the height of the shadow on the screen and the distance between the screen and the light source.

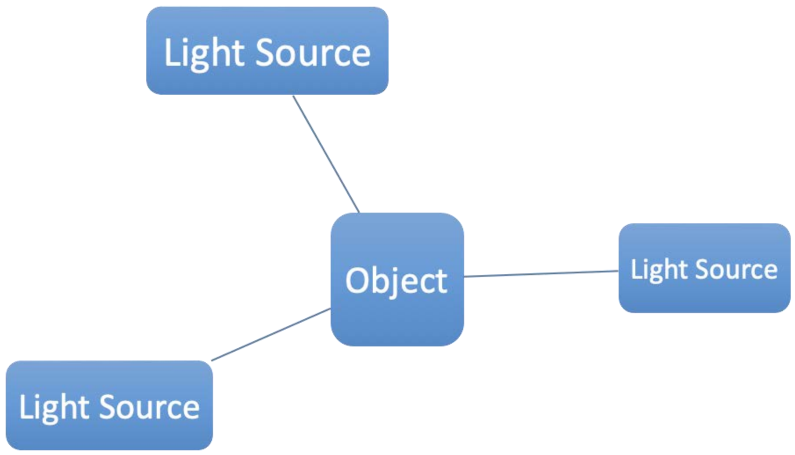


Figure 4: Experiment Setup for Learning the Tool

After completing the data collection, students respond to the following questions:

- When did you start collecting data? Explain why you collected the data.
- When did data collection end? Explain why you collected the data.
- Next, students start discussing their results and compare them with their friends' results to make explanations by responding to the following questions:
- What are your main findings?
- What are your friends' findings?
- What are some similarities/differences?
- Create a model/an explanation using your data and your friends' data.

In this process, students can also review sample data collected by pre-service teachers (see Table 3).

Table 3: Sample findings collected by pre-service teachers

	Height of the object	Distance between screen and the light source	Height of the shadow on the screeen
Trial 1	16.5cm	15cm	18.9cm
Trial 2	16.5cm	25cm	18cm
Trial 3	16.5cm	30cm	17.8cm
Trial 4	16.5cm	45cm	17.5cm
Trial 5	16.5cm	50cm	17.2cm
Trial 6	16.5cm	60cm	17cm

During the investigation, we suggest teachers create a group data table to help students review results from the other groups (see Table 4). Asking each group to explore the factors they would like to investigate and supporting groups to conduct multiple trials for each setup would help students to understand similarities and inconsistencies during the data collection.

Table 4. Creating a Data Table for Students

	Setup 1		Setup 2		Setup 3	
	Variable	Variable	Variable	Variable	Variable	Variable
Group 1- Trial 1						
Group 1- Trial 2						
Group 1- Trial 2						
Group 2- Trial 1						
Group 2- Trial 2						
Group 2- Trial 3						

When students complete their explanations, students are asked to discuss other potential problems/variables/parameters to explore. One potential question could be: “How does the color of the light change height of a shade?”

Instructor Materials

Blank Template

While using the inquiry-based investigations tool, the main steps will be:

1- Identify a Problem

2- Identify Phenomena

3- Explore Phenomena

4- Explain Phenomena

5- Plan new Investigations

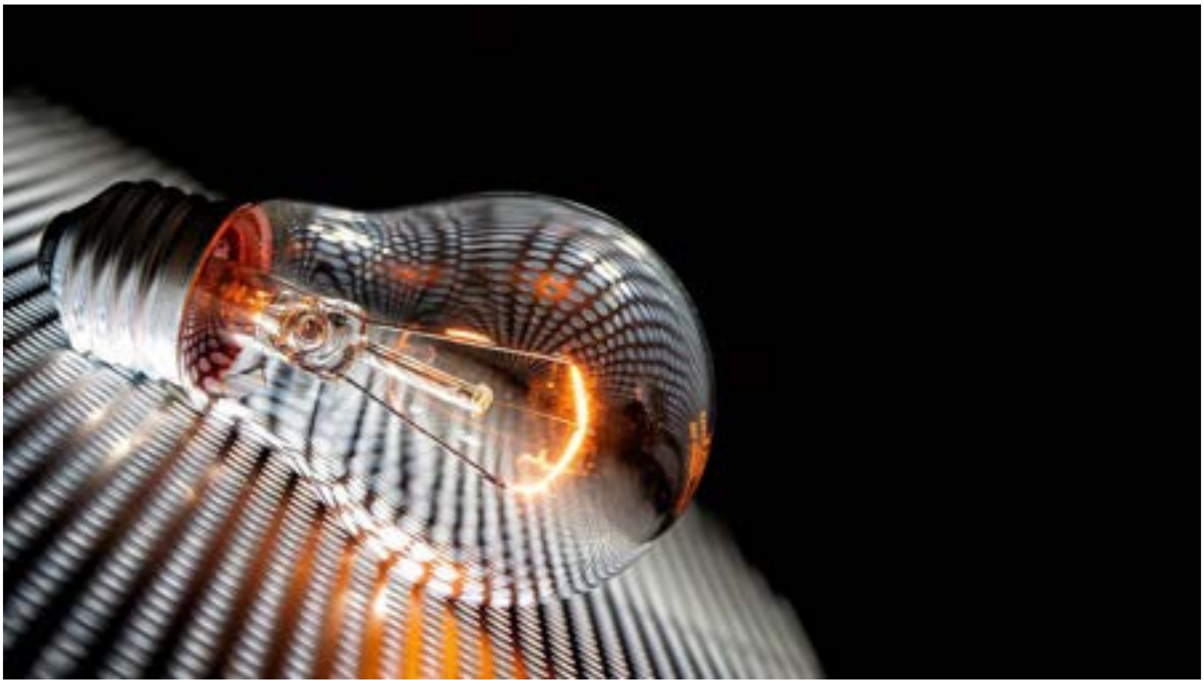
Several guideline questions for each step are presented in Table 1.

Table 1. Guidelines for Supporting Inquiry

How to Identify, Explore and Explain the Phenomena?	
Identify the Phenomena	What is the big idea you are exploring? Which phenomena will you explore during the investigation? What is your dependent variable? What is your independent variable?
Explore the Phenomena	What type of data did you collect? Why did you collect data? When did you start collecting data? When did data collection end?
Explain the Phenomena	What are your main findings? What are your friends' findings? What are some similarities/differences? Create a model/an explanation using your data and your friends' data Discuss other related parameters/variables you can explore.

Short Cycle

The second investigation focuses on understanding energy transfers and the role of friction in a system. The driving question that we investigate is: “How is energy transformed from one form to another?” The teacher collects students' answers to understand their prior knowledge about different forms of energy, and energy transfers.



Picture taken from pixabay.com.

The problem connected to the driving question is “How does the height of a roller coaster affect the speed?” Students are asked to consider their experiences in amusement parks and they are given the following materials: 5m polyethylene pipe, double-sided tape, skewer, cardboard, marble, scissors, and ruler. After presenting the list of materials, the whole group discussion starts to write their own questions and define variables to plan the investigation. After defining the phenomena, the procedure is introduced to students.

Picture taken from pixabay.com.

Cut the polyethylene pipe into half and create a setup as presented in Figure 5. In this investigation, you need to measure three distances and time (t) marble spent in your roller coaster, and then calculate the speed.

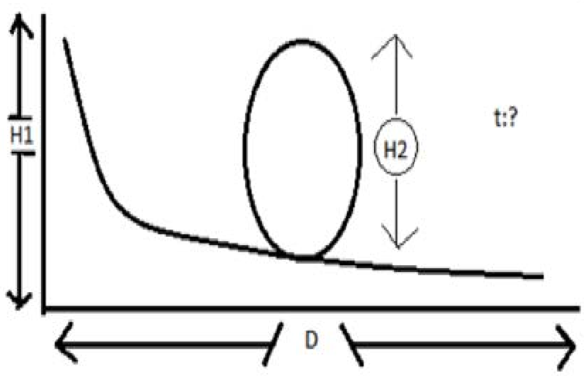


Figure 5: Experiment Setup for Short Cycle (D: Length of the system, H_1: The highest point of your roller coaster, H_2: Lower point of your roller coaster

After completing the data collection, students respond to the following questions:

- When did you start collecting data? Explain why you collected the data.
- When did data collection end? Explain why you collected the data.

Next, students start discussing their results and compare them with their friends' results to make explanations by responding to the following questions:

- What are your main findings?
- What are your friends' findings?
- What are some similarities/differences?
- Create a model/an explanation using your data and your friends' data

In this process, students can also review the data collected by pre-service teachers (see Table 5).

Table 5: Sample findings collected by pre-service teachers

	H1	H2	D	T
Group 1	50 cm	20 cm	140 cm	1,2 second
Group 2	70 cm	25 cm	73 cm	0,99 second
Group 3	51 cm	18 cm	47 cm	1,18 second
Group 4	82 cm	24 cm	55 cm	0,96 second
Group 5	46,5 cm	17 cm	58 m	1,16 second
Group 6	70 cm	26 cm	50 cm	1,05 second

During the investigation, we suggest teachers create a group data table to help students review results from the other groups (see Table 6). Asking each group to explore the factors they would like to investigate and supporting groups to conduct multiple trials for each setup would help students to understand similarities and inconsistencies during the data collection.

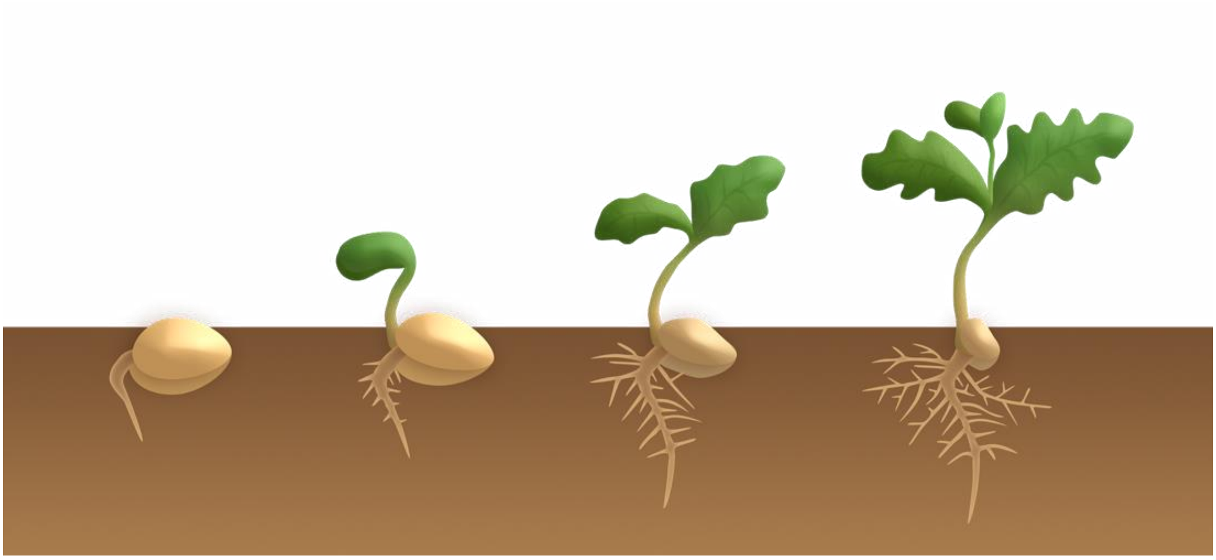
Table 6. Creating a Data Table for Students

	Setup 1		Setup 2		Setup 3	
	Variable	Variable	Variable	Variable	Variable	Variable
Group 1- Trial 1						
Group 1- Trial 2						
Group 1- Trial 2						
Group 2- Trial 1						
Group 2- Trial 2						
Group 2- Trial 3						

When students complete their explanations, students are asked to discuss other potential problems/variables/parameters to explore. One potential question could be: “How does friction change the speed of the marble in a roller coaster?” Students can tape or glue the path of the marble. Another potential question could be: “How does the weight change the speed of a roller coaster?” Students can use different marbles to explore this question.

Long Cycle

In the long cycle, students first germinate seeds. In this sample investigation, students germinated bean seeds.



Picture taken from pixabay.com.

Before starting the investigation, the teacher presents pictures of beans and cotton to students. Then the teacher asks: “What can we do with these materials?” After having a group discussion, the teacher asks each student to place beans in two different cups. The teacher tracks the student progress and asks the students to keep the system warm and moist.

Pictures taken from pixabay.com.

For two weeks, students track and report their progress as seen in Figure 5. The teacher asks students to find out when germination ends and when they will be ready to plant their bean seeds.

Figure 5. Keeping track of germination

When germination is completed, each student plants their seeds and starts discussing the factors affecting the plant growth. For eight weeks, students continue to observe different factors and report their growth.

During the investigation, we suggest teachers to create a group data table to help students review results from the other groups (see Table 7). Asking each group to explore the factors they would like to investigate and supporting groups to conduct multiple trials for each setup would help students to understand similarities and inconsistencies during the data collection.

Table 7. Creating a Data Table for Students

	Setup 1		Setup 2		Setup 3	
	Variable	Plant Growth	Variable	Plant Growth	Variable	Plant Growth
Group 1- Trial 1						
Group 1- Trial 2						
Group 1- Trial 2						
Group 2- Trial 1						
Group 2- Trial 2						
Group 2- Trial 3						

When students complete their explanations, students are asked to discuss other potential problems/variables/parameters to explore for future investigations.

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