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INQUIRY-BASED LEARNING - PEDAGOGICAL APPLICATION USING EDUCATIONAL DIGITAL TECHNOLOGY

Gerasimos Antypas[i]
M.Sc, M.ed,
Consultant for Chemical Engineering Education in Secondary Education,
Directorate of Secondary Education of Piraeus,
Greece

Abstract:
The inquiry-based teaching method is a method based on analytical thinking and requires a logical sequence with gradual steps that are implemented with full knowledge of the purpose. At the same time, it has an objective character and presupposes students' familiarity with the rules of logic. The research autonomy of students depends on the degree of familiarity and practice with scientific skills. Inquiry learning as a constructivist approach, on the one hand, has as its ultimate goal the creation of meanings by students who build knowledge with the practices of scientists. At the same time, it has an objective character and presupposes students' familiarity with the rules of logic. The selection - formulation of research questions is a very important process during the conceptualization phase of inquiry-based learning. Inquiry-based learning has gained a place in engineering curricula and in the classroom, and the availability of online learning environments has given it a new dimension as a pedagogical tool. The PhET Interactive Simulations project at the University of Colorado Boulder creates free interactive math and science simulations. PhET sims are based on extensive education research and engage students through an intuitive, game-like environment where students learn through exploration and discovery.

Keywords: inquiry-based learning, pedagogical digital application

1. Introduction

Inquiry learning is a pedagogical approach - strategy that was developed in the 1960s during the discovery learning movement, as an alternative to traditional forms of teaching, which mainly utilized memorization strategies. In inquiry learning, students construct knowledge with the practices of scientists. Its philosophy has its roots in discovery learning (Bruner, 1961) and obeys the principles of (constructivism). Since the beginning of the 20th century, Dewey had already proposed the active participation of

[i] Correspondence: email antygerse85@gmail.com

the student in learning with the guidance of the teacher who would assume the role of mediator. Specifically, according to the scientific method (Bruner, 1961), the student must: a) become aware of complex situations, b) clarify the problem that arises, c) formulate a provisional hypothesis, d) test this hypothesis or revise it after rigorous testing, and e) act to find the solution.

According to Barrow (2006), Dewey's original view from the early 20th century was that teaching students should increase their personal scientific knowledge, discussing topics that are interesting and capable of being studied by students. Later, in 1937, the element of correlating the problems under study with the experience and intellectual ability of the students was added, while in 1944, the stages of the scientific method that must be followed to achieve "reflective thinking" were re-formulated, consisting of: a) presenting a problem, b) forming a hypothesis, c) collecting data during the experiment, and d) formulating conclusions.

According to Schwab (1960), science is a series of ideas that are renewed with new knowledge, and students should treat science as a series of conceptual structures that are revised. At the same time, he considered the inquiry method as a basic method of motivating the use of the laboratory to search for knowledge and reference in science and encouraged science teachers to use the laboratory to study scientific concepts (Schwab, 1963).

Science teaching during the second half of the 20th century was the subject of study by various organizations and associations such as the American Association for the Advancement of Science - AAAS, (https://www.aaas.org/, National Research Council - NRC) (Rutherford & Ahlgren, 1989). The publication of the relevant "Project 2061", which concerned a long-term research and development initiative focused on improving the science education of Americans so that all of them can become literate in science, mathematics and technology, contained a reference to the investigation and implementation suggestions consisting of: a) starting with questions about nature, b) providing a historical perspective, c) focusing on the collection - use of data with the activation and collaboration of learners for expression rather than memorization of terms and d) connecting discovery with knowledge.

The National Science Education Standards (NSES) (1996), went beyond "Project 2061", addressed the teaching of Science and described the process of implementing inquiry. The National Research Council (2000), which contradicted the views of Dewey and Schwab, proposed not to teach all concepts of science through inquiry and further expanded the views of Dewey and Schwab to practice students in inquiry to develop critical thinking. It also identified five (5) basic characteristics of inquiry which include: a) activating students with scientifically oriented questions, b) collecting data from students to develop and evaluate their answers to the questions, c) explanations given by students, d) evaluation of students themselves for the answers they gave, e) justification and explanation of the choice of the answer method (National Research Council, 2000).

According to Queensland Ministry of Education (2018), the key characteristics of inquiry are: a) implementation in stages, b) authenticity of student and teacher reflection,

c) utilization of prior knowledge to build - invest new knowledge, d) consolidation of knowledge - understanding in questions, e) active involvement of students in practical processes and communication with other students, f) the iterativeness of the approach as the resulting knowledge can be revised according to new research data/results, g) the possibility of reflection and metacognition and h) continuous evaluation based on criteria.

The skills that are cultivated in students during the implementation of inquiry-based learning consist of: a) Observation, as a mental/cognitive function that differs depending on age and situation (e.g. a student has a different observation than a university researcher scientist), b) Drawing a conclusion from observation data, automatic explanation - interpretation of an observed event, c) Classification, as a more complex activity than observation that can distinguish similarities - differences in processes, situations, etc., d) Measurement, where students find the values of various quantities, e) Calculation, where students perform mathematical operations to determine the value of various quantities, f) Prediction, where a future situation is determined regardless of whether it is confirmed, as the incorrect prediction has many learning elements, g) Communication, as students describe and record their observations, represent and present the data that arise, h) Controlling variables, as students identify and distinguish the variables of the process - experiment, i) Formulating a hypothesis, where students formulate the expected result of a process or experiment, j) Conducting an experiment, which includes the flow chart of an experiment until the presentation of the results, and k) Interpreting data, where the organization of data, the extraction of conclusions and the evaluation of results by other students or groups of students take place (Apostolopoulos, 2015).

Referring to international bibliography for the use of the inquiry approach, the greater understanding of scientific facts, the acquisition of skills required to understand these facts, the understanding of the nature of science and the development of a positive attitude towards science are indicatively highlighted (Chiappetta & Adams, 2004; Aktamış, Hiğde & Özden, 2016). In a related study in classrooms of different schools, a 92% improvement in understanding was observed among students who followed inquiry-based learning compared to students who followed the standard curriculum (Lambert & Whelan, 2008).

2. Phases and Types of Inquiry-based Learning

The effectiveness of the inquiry method as a teaching approach has been highlighted by many studies (Alfieri *et al.*, 2011), as it is considered appropriate for engaging students in scientific - discovery processes. At the same time, the division of research into parts highlights and signals key issues and stages of scientific thinking, while it is a method that can be supported in a digital environment (Pedaste *et al.*, 2015).

The bibliographic review on inquiry learning highlights several frameworks that move in the same direction for building knowledge with scientific processes. According to Pedaste *et al.* (2015), Figure 1 proposes a framework that incorporates all these characteristics in five (5) phases.

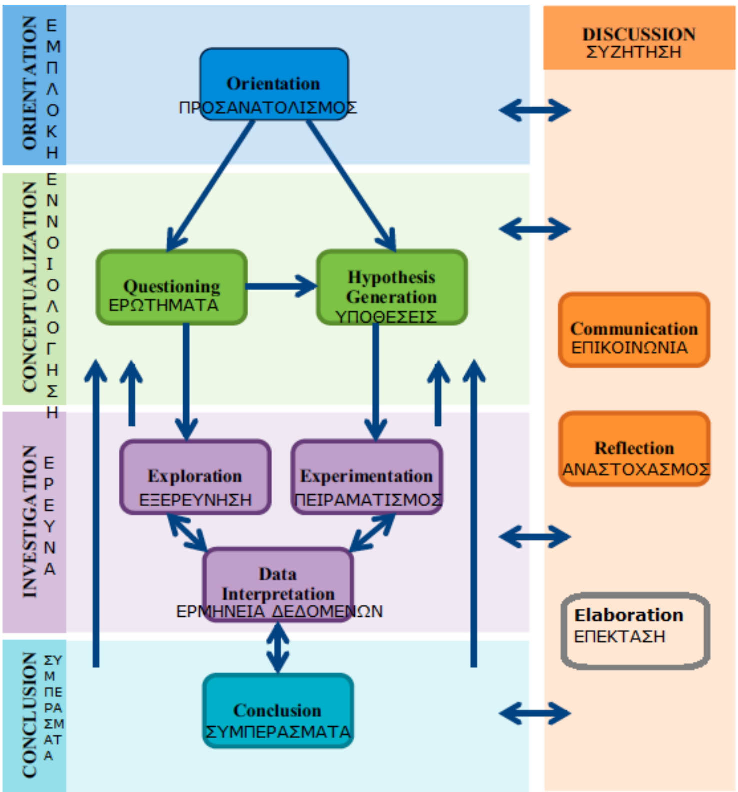

Figure 1: Analysis of the exploratory approach in 5 phases - Pedaste *et al.* (2015).

The proposed framework of five (5) phases contains the phases of engagement - orientation, conceptualization, research, conclusions and discussion. Specifically:

- **1st phase of Engagement - Orientation:** stimulating students' interest in a topic that constitutes the "problem" of the investigation,
- **2nd phase of Conceptualization:** interpretation of concepts related to the "problem". The questions/hypotheses are products of this phase,
- **3rd phase of Research:** research in sources, in case questions have been formulated in the previous phase, experimentation in case experimental hypotheses have been formulated. This is followed by organization, processing and interpretation in relation to questions/hypotheses of the previous conceptualization phase,
- **4th phase of Conclusions:** checking the ability to support questions/hypotheses from the results of the research process that was implemented. It is a process where meanings are created from the collected data, and new knowledge and generalizations are synthesized,
- **5th phase of Discussion:** discussion with the possibility of activation at any phase chosen by the teacher. Sub-phases of Discussion according to the proposed framework are a) Communication - presentation of results from some or all phases of the Investigation to others (classmates, other work groups, teachers) and

receiving feedback, b) Reflection - description, evaluation and discussion of one or all phases with the aim of cultivating metacognitive skills and Elaboration - possibility of applying knowledge to new areas to formulate new questions/hypotheses.

According to Banchi and Bell (2008), a model is proposed that categorizes inquiry into four (4) categories. The differentiation of the categories lies in the amount of information provided to students.

The four types of inquiry approach listed in Table 1, according to MacKenzie (2016), where T: Teacher, S: Student consist of:

a) Confirmatory Inquiry, where students are provided with the questions, the process and the results of the investigation in advance. It is a useful option for engaging students with little or no experience in an investigation process or for practicing a specific skill,
b) Structured Inquiry, where students are provided with the questions and the method in advance, but proceed to document their answers based on the data they have collected. It is a common choice of investigation, especially for young students, who thus have the opportunity to practice the scientific method of investigation, gaining valuable experience for engaging in more open-ended investigations,
c) Guided Inquiry, where students are provided with only the research question. After the discussion in which the research question has been raised, students design their own research method to follow in order to verify the hypothesis/question and subsequently interpret the results obtained. It is a successful option as students have greater participation in the overall process where they practice collecting - recording data, implementing experiments and drawing conclusions. The role of the teacher is guiding, supportive, encouraging, and generally facilitating the entire research process, and
d) Open Inquiry, where students are provided with complete freedom of scientific action in the fields of programming, design and implementation). It is an option where students generate questions/formulate hypotheses, design and carry out the research, derive results and formulate conclusions that they communicate. Obviously, it requires experience from students in research processes, a high level of knowledge, and scientific reasoning.

Table 1: Types of inquiry learning

Type of Inquiry-Based Learning	Confirmatory Inquiry	Structured Inquiry	Guided Inquiry	Open Inquiry
Inquiry elements				
Topic / Problem	T	T	T	S
Questions/Hypotheses	T	T	T	S
Research procedures (sources) or experimentation	T	T	S	S
Data	T	S	S	S
Conclusions	T	S	S	S

3. Application of the Method

Cultural subject: Technology
Research topic - Subject: Law of resistance
Educational Level: High school
Duration of teaching: 1 teaching hour

A. Objective:

Students, after the end of the teaching, will be able to:

a. Knowledge level

- distinguish the quantities that affect the resistance of a conductor,
- understand the relationship between the resistance of a conductor and a) the length of the conductor, b) the cross-sectional area of the conductor, and c) the resistivity of the conductor material.

b. Skill level

- develop the ability to collaborate with their classmates,
- record results and reach conclusions in a scientific manner after data processing,
- use digital interactive applications - simulations.

c. Attitude Level

- develop a collaborative culture and a positive attitude towards scientific critical thinking and working,
- cultivate respect for the personality and diversity of others within a team.

B. Classroom Organization:

Teaching can be implemented in a Computer Lab or in a classroom where an Interactive Whiteboard and laptops are available. For the implementation of the Worksheet, it is necessary to utilize computers with an internet connection and use the digital platform of Phet-Colorado - Simulations (https://phet.colorado.edu/sims/html/resistance-in-a-wire/latest/resistance-in-a-wire_all.html) as shown in Figure 2.

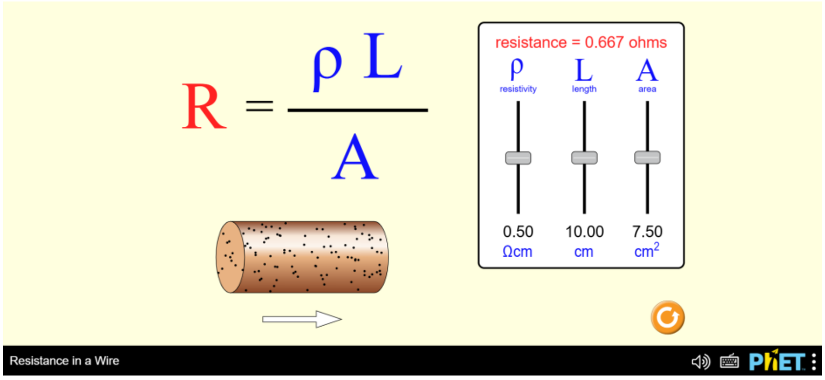

Figure 2: Phet-Colorado simulation

Students are divided into groups of 3-4 people and complete - process data. They also complete an individual evaluation sheet at the end of the lesson. The implementation time of the activity is 45 minutes.

C. Pedagogical Approach:

The purpose of implementing the Inquiry Based Learning method is for students to learn how to learn on their own, by investigating problems and issues that concern them and are related to their daily lives. The main goal of the teacher must be to teach students how to learn by acting like scientists.

Teaching is based on the guided inquiry method and follows the relevant implementation phases. The role of the teacher is coordinating, supportive and encouraging. Students use the materials and teaching tools to approach new knowledge and are gradually led to draw conclusions that are communicated to the class as a whole. The digital application functions as an investigative tool that activates students in exploratory and collaborative learning, promoting their critical thinking.

- **1st phase of Engagement - Orientation**: The teacher stimulates the interest of the students with an authentic everyday topic that constitutes the "problem" of the investigation. The students are asked for their opinion on a topic that is presented with an image, video, object or simple oral report.

- **2nd phase of Conceptualization:** The teacher presents the concept related to the teaching unit with a presentation and questions and answers. The question or hypothesis to be investigated is given by the teacher (e.g. If the length, or the resistivity or the cross-sectional area of a conductor is changed, the resistance of the conductor changes).

- **3rd phase of Research:** The digital experimental process is implemented by the students in steps that are recorded on a worksheet, data is collected that is processed in relation to the initial question or hypothesis.

Specifically, the following steps are implemented:

Step 1:
Access the digital application of Phet Colorado - (Phet Interactive Simulations) at the link: https://phet.colorado.edu/sims/html/resistance-in-a-wire/latest/resistance-in-a-wire_all.html

Step 2:
Set the conductor resistivity (ϱ) to 0.01Ω*cm.
Set the conductor length (L) to 20cm and the conductor cross-section (A) to 7.5cm^2.
Complete a measurement table with the results for resistance (R) for conductor resistivity values (ϱ): 0.01Ω*cm, 0.20Ω*cm, 0.50Ω*cm, 0.70Ω*cm, 1.00Ω*cm.

Step 3:
Set the conductor length (L) to 5.0cm.
Set the conductor resistivity (ϱ) to 0.50Ω*cm and the conductor cross-section (A) to 7.5cm^2.
Complete the measurement table with the results for resistance (R) for conductor length values (L): 5.0cm, 7.0cm, 10cm, 15cm, 20cm.

Step 4:
Set the conductor cross-section (A) to 1.0cm^2.
Set the conductor resistivity (ϱ) to 0.50Ω*cm and the conductor length (L) to 20cm.
Complete the measurement table with the results for resistance (R) for conductor cross-section values (A): 1.0cm^2, 5.0cm^2, 10cm^2, 12cm^2, 15cm^2,

- **4th phase of Conclusions:** The data collected by the students are used to extract the results of the research process that was implemented and lead to conclusions on the basis of which new knowledge is synthesized and generalizations are formed.

Indicative conclusions - circle your choices:

  - The value of resistance (R) changes / does not change when the specific resistance of a conductor (ϱ) that expresses the material of the conductor changes.
  - The value of resistance (R) changes / does not change when the length (L) of the conductor changes.
  - The value of resistance (R) changes / does not change when the cross-sectional area (A) of the conductor changes.

- **5th phase Discussion:** The results of the groups are presented to the class plenary and the relevant conclusions are drawn. This is followed by Reflection - description, evaluation and discussion of one or all phases with the aim of cultivating metacognitive skills and Elaboration - the ability to apply knowledge to new areas to formulate new questions/hypotheses.

4. Discussion

The inquiry-based teaching method is a method based on analytical thinking and requires a logical sequence with gradual steps that are implemented with full knowledge of the purpose. At the same time, it has an objective character and presupposes familiarity of students with the rules of logic. The research autonomy of students depends on the degree of familiarity and practice with scientific skills.

The framework of teamwork allows for the free negotiation of ideas between group members, which will lead to creative proposals for management and problem-solving. The positive results consist indicatively in the development of critical skills, understanding of concepts, motivation to find - upgrade knowledge through research processes and the creation of an open learning climate (Wallace & Kang 2004).

The selection - formulation of research questions is a very important process during the conceptualization phase in an inquiry-based approach. Essential elements of formulation are the expressions "how", "what" and "why" at its beginning, the identification of independent and dependent variables and the correlation, description or comparison of variables. Characteristics that include, among others, the feasibility of implementing an investigative approach, as well as the necessary technical skills, logistical infrastructure, financial requirements and the allocation of a reasonable time for the implementation of the educational action, constitute the parameters of the success of the teaching method. According to Hulley *et al.* (2007), the satisfaction of "FINER" criteria for the development of good questions is proposed. The "FINER" criteria consist of: a) F (Feasible): which includes sufficient technical experience - know-how, reasonable time - cost allocation and ability to manage the question framework, b) I (Interesting): as it will answer a real researcher/student problem, c) N (Novel): confirmation, rejection or extension of research findings, d) E (Ethical): based on existing ethics, e) R (Relevant): with scientific knowledge and future research.

Given the possibility of utilizing electronic learning environments with new digital cognitive tools (hardware/software), inquiry-based learning has gained its place in the curricula of educational engineers, but also in the overall learning process of a school class (Komis, 2004).

Typical examples are simulations (e.g. Photodentro: photodentro.edu.gr/, Phet Colorado https://phet.colorado.edu/el/, etc.), virtual laboratories (e.g. Tinkercad https://www.tinkercad.com/), educational programming environments (e.g. Scratch https://scratch.mit.edu/), educational games, virtual reality applications, which can be utilized in the educational process.

The PhET Interactive Simulations program at the University of Colorado at Boulder creates free interactive math and science simulations. PhET simulations are based on extensive educational research and engage students in an intuitive, playful environment where students learn through exploration and discovery.

Inquiry-based learning is not a set of instructions that teaches students to follow the scientific method, but an educational methodological approach that focuses on developing problem-solving skills through the scientific method. The view of Open Inquiry as the only authentic Inquiry-based learning is a misconception documented by Banchi & Bell (2008), accompanied by the notion that for students to successfully implement it, prior experience using structured inquiry that adequately develops scientific inquiry skills is required.

As Inquiry Learning aims at high cognitive levels, it is up to teachers to encourage divergent thinking in students, which leads to critical thinking. In addition, laboratory courses that provide students with kinesthetic skills are a key area that can provide valuable know-how for implementing inquiry learning.

Conflict of Interest Statement

The author declares no conflicts of interest.

About the Author

Gerasimos Antypas holds a diploma in Chemical Engineering and Bachelor's Degree in Environment Technology. He also has a Master's degree in Educational Studies, a Master's degree in Education Management and a specialization in Counseling and Vocational Guidance. He serves as a Consultant for Chemical Engineering Education in Secondary Education. He has also served in the position of principal at the Second Chance School of Patras and at the 2nd Second Chance School of Prison St. Stefan in the region of West Greece. He is interested in teacher training and especially in adult education, as he holds a certification for adult training in technology, quality management, safety, hygiene and environmental issues. His research work refers to environment research, in school administration, and mainly to teacher training in innovation practices in education. He has participated in Summer Schools in the area of the environment. He has also published articles in conference proceedings (32), and international & Greek journals (19) on the above topics.

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