Inquiry-based learning in science enhanced by digital technologies

Z.Ješková, M.Kireš, M.Ganajová, K. Kimáková
Institute of Physics, Faculty of Science, University of P.J.Šafárik, Košice, Slovakia
zuzana.jeskova@upjs.sk, marian.kires@upjs.sk

Abstract— **The science education in Slovakia currently faces the new curriculum reform that emphasizes the role of scientific inquiry in education that is in good correspondence with massive European movement oriented on implementation of Inquiry based science education. As many researches show, the implementation of digital technologies into science education can help a great deal in the process of scientific inquiry. The contribution presents the key ideas of inquiry-based science education with concrete examples in physics education as well as the projects currently running in Slovakia in this field. The Slovak national project Modernization of education at primary and secondary schools is aimed at the implementation of new ways of education enhanced by ICT. This project is in a good consonance with the European 7FP project Establish with Safarik University in Kosice as a partner institution that is aimed at the use of IBSE elements in classes across Europe.**

I. Introduction

The science education in Slovakia currently faces new challenges connected with the new curriculum reform running from 2009. The reform emphasizes the role of scientific inquiry in education that is in good correspondence with massive European movement oriented on implementation of Inquiry based science education (IBSE). As many researches show, the implementation of digital technologies into science education can help a great deal in the process of scientific inquiry. However, the digital technologies itself cannot help in better understanding of scientific concepts. Their effective use strongly depends on the teaching methods used in the class. As research shows, traditional methods such as lecture, problem solving, traditional labworks cannot survive in the classroom in the world of all the technologies that our students are able to handle easily in their everyday life. The school of the 21st century has to reflect these trends. And it is not only about trends. In addition, purposeful and appropriate application of digital technologies in science offers students to assist and progress their learning and to engage them in higher-order thinking skills.

However, to implement IBSE enhanced by digital technologies in classrooms is not an easy task. The success of the educational reform requires consonance of many elements to be taken into account, such like improvements in teacher training, change in curricula and student assessment as well as instructional materials available for easy use of teachers.

II. Inquiry-based Science Education

A. *What do we mean by scientific inquiry?*

There are many interpretations to the questions – What do we mean by scientific inquiry? A possible short answer is that it is the systematic and principled process of pursuing and refining explanations for phenomena in the natural or material world. According to Linn, Davis and Bell [1] "Inquiry is the intentional process of diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers and forming coherent arguments". The national Science Education Standards [2] describes inquiry as the way scientists do research and presents this as an inquiry cycle (fig.1), while Llewellyn [3] describes it as inquiry-oriented learning where the principles of constructivism are acting as the foundation for understanding inquiry (fig.2).

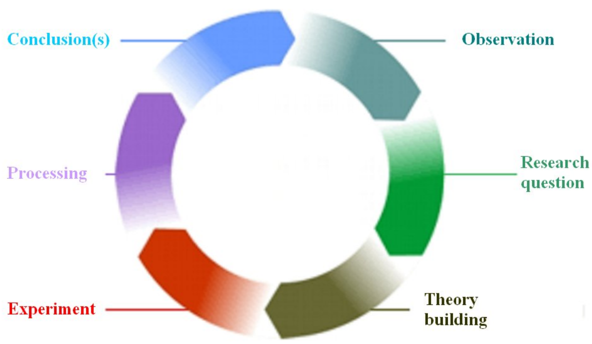


Figure 1. A 6-stage cycle for inquiry investigations and modeling [1].

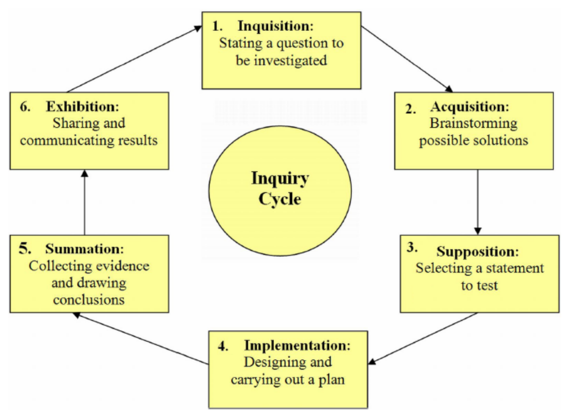


Figure 2. A 6-stage cycle for inquiry cycle [3].

Although, many different types and levels of inquiry-based teaching and learning are available, it is widely agreed that inquiry-based teaching is an organized and intentional effort on behalf of the teacher to engage students in inquiry-based learning. The goal of inquiry teaching is not to transfer scientific knowledge, facts, definitions, and concepts, but rather to enhance students′ ability to reason and to become independent learners who are capable of identifying main questions and find relevant answers by a gradual acquisition and expansion of a body of scientific knowledge and abilities. It is a student-centered approach to science learning.

B. Types of inquiry-based activities

In all types of inquiry activities the most important principle is to decrease the teacher activity and participation and to increase the student activity. The levels of inquiry-based activity differ by the amount of teacher/material guidance, student independence and developed skills [4].

According to that there can be several types of inquiry activities, namely:

1. Interactive discussion /Interactive demonstration: the teacher is in charge of posing the question or conducting the demonstration and manipulating a scientific apparatus.
2. Guided discovery: same as the interactive demonstration, but in this case the students carry out the experiment introduced to them by the teacher. It is the traditional student laboratory work, mostly in the form of cookbook labs or work driven by step-by step instructions. Usually, this concerns a group activity simultaneously carried out by the whole class with a strong focus on verifying information previously communicated in class.
3. Guided inquiry: in this case, students work in teams on their own experiment. The teacher has identified the problem and has given a clear-cut objective: “Find...”, “Determine...” There is no predetermined answer and conclusions are solely based on student work. Students are given directions or extensive (pre-lab) instructions, and they are guided by multiple teacher-identified questions.
4. Bounded inquiry same as in the above, but in this case students are expected to design and conduct the experiment themselves with little or no guidance of the teacher and only partial pre-lab orientation. The research problem to be solved is given to them by the teacher, but they have the responsibility for designing and conducting an experiment. Bounded inquiry activities require a definite level of experience from the students, otherwise they could get lost.
5. Open inquiry: within a given context, the student is expected to propose and pursue their own research question(s) and experimental design. This will usually be a semi-final assignment of senior students. Example: “Setting up an experiment for speech analysis or recognition”. Students can either compare high or low tones, male or female, produced by musical instrument or vocally, loud or soft, etc.

III. INQUIRY-BASED SCIENCE EDUCATION AND DIGITAL TECHNOLOGIES

As many researches show, the implementation of digital technologies into science education, if used in an appropriate way, can help a great deal in the process of scientific inquiry. However, the digital technologies themselves cannot help in better understanding of scientific concepts. Their effective use strongly depends on the teaching methods used in the class. In science education the “inquiry” approach is connected mainly with all kinds of experimentation. Concerning the experiments in science, digital technologies play an important role in collecting, processing and analyzing data. Consequently, as used in science, it becomes a natural part of school experimentation. In science education, real-time experiments with datalogging (using interface and sensors), remotely-controlled experiments, experimentation on videoclips, and virtual experiments with the help of computer simulations have their strong educational benefits. Digital technologies in this sense can enhance inquiry approach to teaching and learning since:

- It supports active learning environment allowing students to work in a similar way as scientists do in their laboratories
- It encourages critical thinking skills. Students have more time for exploration and analyzing results since distractions and lower-level student chores during the laboratory are reduced.
- Frequent interaction and feedback is one of the most important features of experimentation supported by digital technologies. The immediacy of feedback allows students to “self-regulate their learning” towards more individual learning without fulltime supervision of the teacher
- It encourages students’ collaboration and peer instructions while discussing and analyzing results.

IV. EXAMPLES OF IBSE ACTIVITIES ENHANCED BY DIGITAL TECHNOLOGIES IN PHYSICS

A. Interactive discussion/ demonstration

This activity is carried out by the teacher with active student participation that can be supported by a prediction sheets where students make predictions and answer questions about the experiment presented by the teacher. Even if the experiment is carried out by the teacher, the experimental procedure involves student to participate, make predictions, think, compare and make conclusions.

In fig. 3 there is an example of interactive experiment on the Archimedes principle using force sensor to measure the force on it while submerging a body into water.

A cylinder of density greater than the density of water ($\rho_{\text{cylinder}}>\rho_{\text{water}}$) is hung from a force probe with a rigid rod. It is lowered slowly into a container of water. Sketch your prediction for the force probe reading as a function of time. Be sure to include the initial reading before the cylinder touches the water, and also the reading when the cylinder is completely submerged.

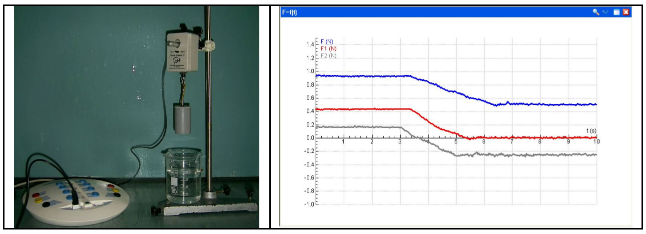


Figure 3 Example of a part of a demonstration worksheet, experimental setup and results gained by measurement.

B. *Guided discovery*

Students working in groups of 2-3 explore the uniform motion of a sailor or uniformly accelerated motion of a cyclist. Students verify previously introduced kinematic concepts and relationships following step to step instructions in their worksheets (fig.4).

Measuring procedure: Play the video. Describe the sailor´s motion. Measure the position of the sailor (choose as a video point location). The video is already scaled (4m horizontal ruler on the sailboat, frame rate of 5 frames per second). The horizontal position versus time graph of your measurements appears on the screen.
Assignment: Describe the motion of the sailor. What was the initial position of the sailor? What was the final position of the sailor? How long was the motion? What can you deduce about the sailor's speed?

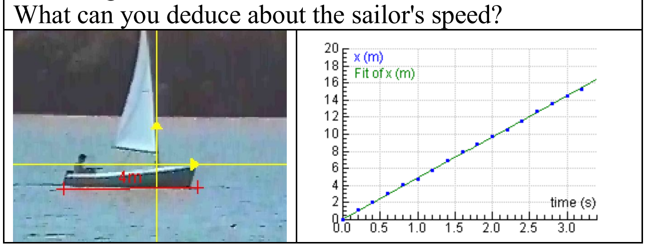


Figure 4. Example of a part of the uniform motion guided discovery worksheet, scaled video screenshot and experimental results.

C. *Guided inquiry*

Students are given a problem, e.g. what the bungee jumper fall looks like. Students working in groups of 2-3 can be given directions or extensive instructions in the worksheet. They can do the investigation on the prerecorded videclip or a real experiment with a weight attached to the rubber string (fig.5).

D. *Bounded inquiry*

Students are given a problem, but the way how to solve it has to be decided by the students. They can be given just a small help. In fig. 6 there is an example from electricity about the changing brightness of two different bulbs in a dc circuit when closing the circuit. Students are given materials and they decide an experiment to carry out to explain this phenomenon. In this case they should understand that for the bulb brightness the power dissipated is crucial. Then they decide what quantities to measure and what to compare in order to draw conclusions.

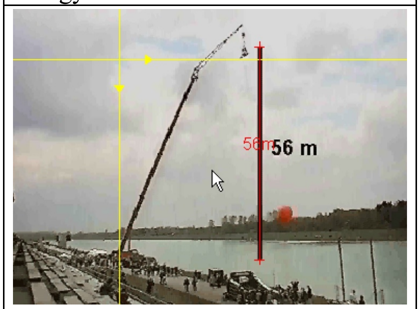
E. *Open inquiry*

In this case students learn to find and formulate their own research question without a strict guidance of their teacher. They learn to setup and successfully finish their own practical experiment and draw conclusions. In fig. 7 there is a part of the worksheet students get in order to do the open investigation.

Examples of research questions student could formulate concerning the human speech analysis:

- What, I any, is the difference in amplitude and frequency between vowels a, e, o and u? Which property can be used best to distinguish them?
- How to approach orally the sound of a tuning fork?
- Analysis and recognition of the sound pattern of the world Earth.
- How do we recognize gender in the same vowels a, e and u? Man versus woman.
- Comparison of the spectrum of a flute and a singing voice, producing the same note.

Find out:
How the position, speed and acceleration changes with time during the fall.
How the force acting on a jumper changes with time.
Check the validity of the law of energy conservation.



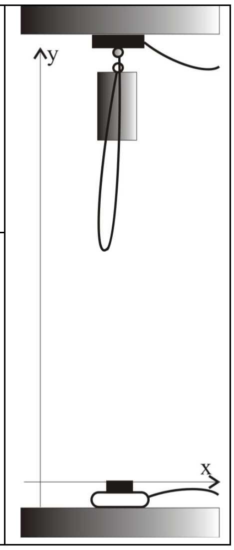


Figure 5. Example of a guided inquiry activity on the bungee jumper fall.

If we put two different bulbs in the holders one of them will light up later then the other. There is a noticeable delay between the two bulbs. Explain.

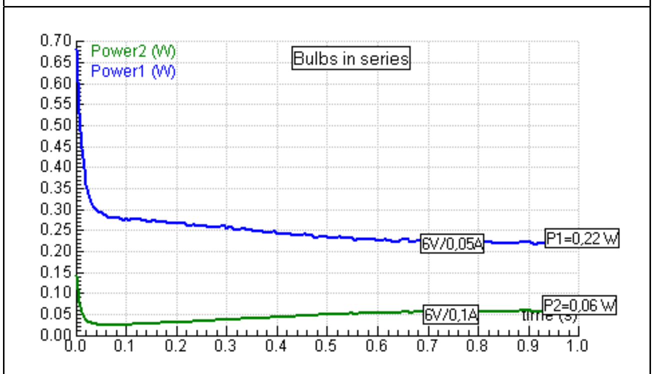


Figure 6 Example of a bounded inquiry on the bulbs behaviour and experimental results.

Human speech analysis dates back to the mid twentieth century and has been an active field of research ever since. Governments eagerly made and make use of it. Recently, commercial applications come into play as well, with the development of passive and active speech computers, robotics, automation and security.

This is an open investigation. Formulate a research question connected to sound signal analysis, which you would like to investigate. Perform your investigation to answer your research questions. Prepare a presentation about the results of your investigation for your classmates.

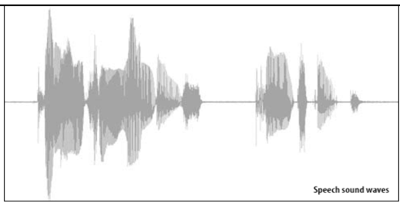


Figure 7 Example of a part of the worksheet aimed at human speech open inquiry activity.

V. Implementation of IBSE in Physics Classes

To implement IBSE enhanced by digital technologies in classrooms is not an easy task. The success of the educational reform requires consonance of many elements to be taken into account, such like improvements in teacher training, change in curricula and student assessment as well as instructional materials available for easy use of teachers. The currently running educational reform strongly emphasizes the necessity of scientific inquiry in physics education. On the other hand, very little has been done in order to wide successful implementation. There is still a lack of appropriate instructional materials and well-educated teachers. Teachers should understand what inquiry means, what activities they can carry out with their students, what levels are appropriate for their students, etc. in order to move from teacher-centered education to student-centered inquiry lessons and labs.

There are several national and international projects currently running in Slovakia trying to help in this field. The huge Slovak national project Modernization of education at primary and secondary schools [5] has already prepared instructional materials for the use of physics teachers [6, 7]. Within the project 543 physics teachers participate at 5 days course on how to develop competencies on the use of IBSE methods enhanced by digital competencies. The project activities are supported by e-learning platform offering a wide selection of instructional materials for an easy-use of teachers. The Slovak national project is in a good consonance with an international 7FP project ESTABLISH [8]. Within this project of a consortium of partners from 11 European countries there are instructional materials for teachers and students currently being prepared. This is followed by in-service and pre-service teacher training in this field.

VI. Conclusion

The success of the effective use of IBSE method enhanced by digital technologies in the class depends on the consonance of several elements that have to be taken into account. Change in curriculum and educational materials available for teachers are a good starting point. But this is not enough. The key element of the teaching process is a well-educated teacher who is familiar with the methodology of IBSE. Hence, the continuous in-service teacher training as well as pre-service teacher training is an inevitable assumption to the successful implementation of this way of teaching. Nevertheless, there are still some open questions, e.g. concerning student assessment within IBSE that have not been answered yet. However, the currently running projects activities indicate a promising start with a hopeful follow-up towards the expected changes in education.

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