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CROSS-CURRICULAR APPROACHES IN INQUIRY-BASED SCIENCE TEACHING

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Abstract

One of the most important goals of science education is to develop understanding of natural systems. It is impossible to comprehensively understand the functioning of natural systems only by knowledge of one subject (physics, chemistry, biology, etc.). Therefore the application of the cross-curricular approach in teaching of science subjects is required. Besides the scientific knowledge the understanding of science research methods is important, too. This can be obtained with the use of inquiry-based activities in science lessons that provide possibilities to show students how science works. The aim of this paper is to introduce the strategy for the use of cross-curricular approaches in inquiry-based activities in science education that was implemented within the Chain Reaction project. The project targeted 14- to 16-year-old students who in groups investigated an interdisciplinary research problem and then presented their findings and experiences at national or international events. Cosmic Web Site represents an example of the activity that encourages students to learn various topics of physics as well as to use their knowledge and skills obtained at computer science lessons. The feedback from the teachers involved in Chain Reaction that was gained with the help of evaluation questionnaires indicates a positive impact of the used approach to the development of students' skills and motivation to learn science subjects.

Keywords

Inquiry, cross-curricular relationships, physics, informatics, Big Bang theory

Introduction

Inquiry, increasing an activity of students during science lessons, development of scientific literacy are the most discussed topics within the professional community. Besides these ones the cross-curricular relationship between science subjects is also an interesting topic mainly if we talk about inquiry, inquiry-based activities or about similar methods supporting development of scientific competences.

By Savage (2010, pp. 8 – 9), a cross-curricular approach to teaching is characterised by sensitivity towards, and a synthesis of, knowledge, skills and understandings from various subject areas. It means that the subjects contain more than knowledge and skills, they contain mainly “understandings”.

We can say, just “understanding” is one of the most important goals of science education and the implementation of inquiry-based activities which uses cross-curricular links seems to be a suitable tool for development of this one.

An inquiry-based approach to science education engages students in activities which resemble methods of scientific investigation, with content interwoven with or addressed in the context of inquiry (Kubicek, 2005), (Hruška, Holec and Raganová, 2013). Inquiry is a process in which at first the problem must be recognised, then suitable experiments are suggested together with appropriate alternatives, design of the study procedure, creation of hypotheses, search of informations, creation of models, discussion and formulation of logical arguments (Linn, Davis & Eylon, 2004). Thus inquiry is not concentrated on a passive way of gaining knowledge but on the development of logical thinking, the ability to argue, formulating problems and searching possible solutions (Crawfordová, 2000).

These objectives can be realized through activities with different degree of independence of the student. On one side we can talk about activities that are fully managed by the teacher, on the other side there is an independent activity of the student which begins with the formulation of the problem to be investigated. A hierarchy of inquiry activities (tab. 1) was constructed according to the scale of student independence (Wenning, 2010), (Ješková, Kireš and Kedzierska, 2012).

<table>
<tr><td colspan="2">Interactive demonstration / discussion</td><td>Limited Inquiry</td><td>Structured Inquiry</td><td>Guided Inquiry</td><td>Open Inquiry</td></tr>
<tr><td>Lower</td><td colspan="4">← Intellectual Sophistication →</td><td>Higher</td></tr>
<tr><td>Teacher</td><td colspan="4">← Activity managed by →</td><td>Student</td></tr>
</table>

Tab. 1: Levels of inquiry

Inquiry activities which require an independent work of students and increased support by teaching materials – the guided inquiry and the open inquiry – were chosen as a core approach at the international project Chain Reaction.

Chain Reaction project

Chain Reaction (Chain Reaction, 2016) was a three-year project funded by the European Commission under the 7th Framework Programme, which involved twelve partner countries. The aim of the project was the development and implementation of research activities in science education through solving the problems and inquiry-based learning, which aims to actively engage students in learning science and allow them to experience the excitement and challenges of experimental science and research. Teachers who participated in the project were trained within an introductory course, where they had the opportunity to gain theoretical knowledge of inquiry-based methods used in the teaching process, as well as basic practical skills in implementing and managing such activities. After gaining practical experience with inquiry-based teaching methods, involved teachers taught a series of lessons which formed an introduction to subsequent research activities of students.

Teaching students to do scientific inquiry involves teachers engaging their students in the practices of science. These practices include various activities and processes carried out by scientists to answer questions and develop explanations and models using logic and critical thinking. As they engage in scientific practices, both students and scientists use observations and inferences to develop conclusions and evidence-based explanations.

Earth & Universe Pupil Research Briefs

The ambition of the Chain Reaction project has been to provide teachers strong and continuing support in inquiry-based science education not only in the form of courses and workshops, but also in the form of teaching materials. For this reason, a set of materials called *Earth & Universe Pupil Research Briefs (EUPRBs)* was created containing 11 research activities in various fields of natural sciences. Eight of them were adopted to suit Slovak context: (1) *Collision Course*, (2) *Green Light*, (3) *PHEPPS*, (4) *Feed the World*, (5) *Ozone Conference*, (6) *Cosmic Web Site*, (7) *Plants in Space*, (8) *Green Heating* (full texts of these materials are available at the project website www.chreact.umb.sk).

The structure of each activity (fig. 1) corresponds with a simple model that has been designed to allow teachers and students to understand, as far as it is reasonably possible, how researchers in the field of science and technology think and work.

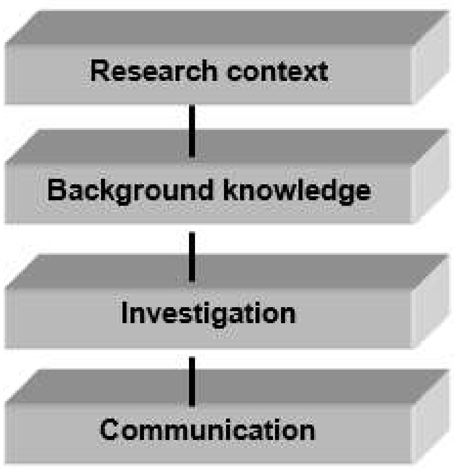

Fig. 1: The EUPRB model (EUPRBs, 2013, p. 4)

The proposed model shows the steps of the research which are divided into a structured methodology. Scientific research, whether real or school, is not straightforward and it is impossible to accurately determine the sequence of steps that need to be implemented. A research project can have numerous false starts and blind alleys, and work can be carried out along several lines of enquiry at once. Activities which tend to come only at the end of a school science investigation (such as report writing or communicating findings) tend to occur at all stages in a research project. Discussions with science and engineering researchers showed that all four categories of activity could be going on simultaneously within any one research project (EUPRBs, 2013, p. 4).

The four stages of the EUPRB model

A) Context setting

All research projects exist for a reason: the personal interests of the researcher, a particular issue/question raised by the research community, a link to a commercial enterprise etc.

In attempting to simulate this professional world of research, it is important to construct curriculum scenarios where the purpose of the investigation is made clear to the students. The EUPRBS have been constructed so that the students are led in by means of one or two activities which establish the context for what is to come. This is brought about by a number of types of documents – emails, press releases, newspaper or journal articles, letters, etc. These have been designed to simulate 'reality'.

B) Background knowledge

In the beginning, obtaining sufficient information on the subject (the literature review), and the results of other studies carried out in this area (exploring various information sources) is important for the successful solution of the research project.

The EUPRBs attempt to represent this range of activities by means of 'research papers' specially written for the purpose, reports, meeting summaries, extracts from books and notes. All, written at a language level the students can understand. The documents used in the context setting and background knowledge categories of the EUPRBs involve students in a wide range of active learning approaches such as small group discussion, problem solving, active reading and brainstorming. These activities will help them to think their way into the investigation which is the focus of the EUPRB.

The first two phases of the EUPRB help to create the appropriate 'mind set', where the purpose of the investigative work is clear to the students, and where they have some stake in its successful outcome.

C) Investigation

The EUPRBs involve students in carrying out one or more investigations. The students begin by framing the question, hypothesis or prediction, or taking an idea presented to them and planning a procedure for the investigation. After carrying out their investigation they analyse their findings, draw conclusions and evaluate the outcomes.

D) Communication

Students are involved in communicating science in a variety of ways, reflecting the diversity of media and methods used in the professional world. Some EUPRBs require students to write up a standard laboratory report. Others involve writing proposals for funding or articles for journals, construct websites etc. (EUPRBs, 2013, p. 4).

The application of cross-curricular links in inquiry activities

The character of the majority of the developed activities requires the application of cross-curricular relationships. Science cannot operate as separate units as in solving various science projects it is important to use knowledge from different fields. For example, in the activity *Feed the World*, in the first step, when students need to produce a fertilizer, they have to intensively use their knowledge of chemistry. Subsequently, in the cultivation of crops (beans, watercress, etc.) they have to use their knowledge of biology. The situation is similar in solving the activity

Plants in Space, when students use their knowledge of biology, chemistry and partly also of physics.

In all of the proposed activities, the use of computer is commonplace, at least for preparation of presentations or other materials, which form results of the activity.

Cosmic Web Site

The situation is different in the case of activity Cosmic Web Site that has a different character and method of realization than other activities. The aim of this activity is to create a website to explain the theory of the Universe origin known as the Big Bang theory and other concepts and phenomena related thereto. At the beginning students are provided with the basic text and are asked to provide illustrations to go with the text and to identify words and phrases that need further explanation. New concepts together with their explanation will be included in the glossary. Text can contain more words and phrases that will require explanation. Students are to identify these and allocate the tasks of providing hypertext pages between them. They are required to look for the information to be put onto these pages and to find suitable images to accompany the text. The exercise should provide a comprehensive explanation of the Big Bang theory and how research currently being conducted is helping to shed light on the likely fate of the Universe.

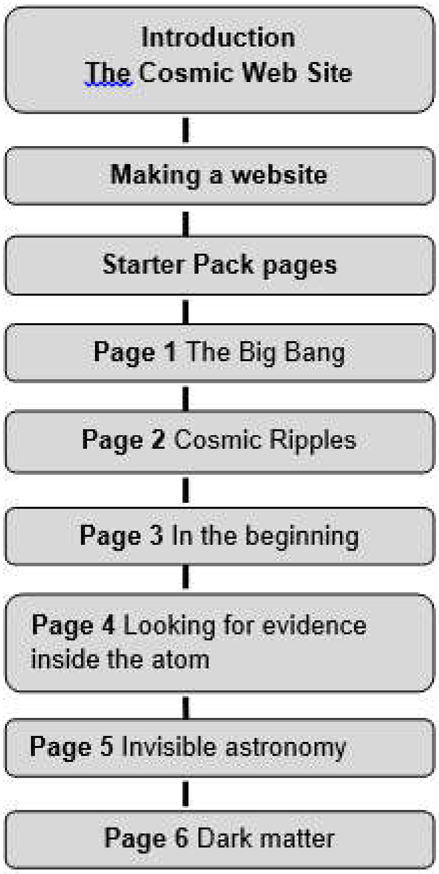

Fig. 2: Route through the activity (Cosmic…, 2013, p. 2)

The teacher's guide contains also a proposed route through this activity (fig. 2), which of course, may not be strictly adhered to. Students can work in different ways.

As the character of the activity shows, students must use the knowledge of physics and also of informatics at their work. In this case, the computer does not serve just as a mean of creating the presentation, in which the results of the work are discussed. The computer is an essential part of the activity and without its use it would not be possible to fulfil the stated objective.

Before attempting this activity, students should have a basic knowledge of stars and galaxies and an understanding of the structure of the atom would be a great advantage, as well. Besides, students should also have basic skills in using the Internet and in creating of websites. However, the creation of websites is not as unknown as it was in the past. The creation of websites has been incorporated into the state educational programme for secondary grammar schools within Informatics subject. Therefore, the technical realization of this activity should not be a problem for students. There is not strictly given, what tool should be used to create the website at the performing the activity. It depends just on the experience of students, which tool they choose.

Cosmic Web Site in the school practice

Research objective

The created activity was designed for physics lessons at secondary schools. After finalization of the teacher's and student's guide of this activity, our aim was to test how the activity described above could be implemented into physics lessons.

Target group

The activity was tested within the project during three school years – from 2013/2014 to 2015/2016. Each year, five secondary schools were involved in the project. As it was mentioned, at the beginning of the school year teachers of participated schools were trained within an introductory course with the aim to gain theoretical knowledge and practical skills in using of inquiry-based activities. After this course the teachers chose activities which they wanted to implement into their lessons.

The activity *Cosmic web site* was chosen by five schools. The best teams had an opportunity to present their work at the national conference organized each year within the Chain Reaction project.

Experiences and results

Feedback from implementing the activity into physics lessons was obtained by interviews with teachers. The results indicate several difficulties concerning time, needed preliminary knowledge and required computer skills.

The time consumption of this activity stated in the teacher's guide was estimated at three lessons. Realization of the activity, however, due to its comprehensiveness and technical difficulty, has required a significant amount of the free time of students. Three lessons were devoted to the performance of physical part of the activity as well as its technical implementation. Finally, it was necessary also to devote close attention to motivating students to carry out this activity.

The school practice has shown that in the beginning of the activity, students have to find, sort and study the amount of information related to the Big Bang theory. As it is a considerably abstract topic which is difficult to understand for students, lectures from experts were needed in many cases. Experts introduced the topic to students in a way appropriate to their level of knowledge. As mentioned earlier, the character of the activity requires a strong cross-curricular work. Therefore students had to devote some time for choosing the appropriate tool for creating web sites and design of its structure during lessons of Informatics.

The results obtained during the three school years showed that most pupils were more focused on the technical side of the activity, such as a web graphic design, a source code, interactivity and functionality of the web site. Thus the physical nature of activities was downgraded. This may be caused by the complexity of the physical basis of the activity. Based on these results we must conclude that a given activity is preferable to use in the informatics lessons, where students learn to work with graphics and to create websites.

a) b)

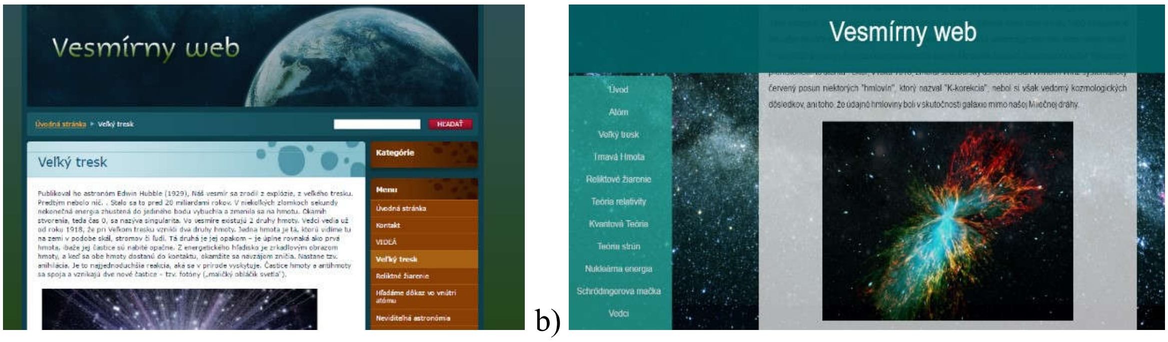

Fig. 3: Samples of portals Cosmic web site created within the project
a) vesmirny-web.webnode.cz b) www.egymbb.sk/vesmir/

Despite the complexity of the topic, students' motivation was so great, that they devoted almost all their free time to realization of this activity. It is gratifying, that in many cases (e. g. examples shown at fig. 3), students update the website up to now, even though they are no longer involved in the project and have no obligation to continue to work on it.

Benefits of implementation the inquiry-based activities within the Chain reaction project

Besides the teacher interviews we used additional methods of gaining teachers' feedback: evaluation meetings at the end of each project year and a survey with the help of evaluation questionnaires.

The evaluation meetings were focused on a deep evaluation of various project aspects in the given year. Teachers in groups discussed the overall organization of the project activities and then concentrated on in-school delivery. After separated discussions the groups met and presented their opinions. The view of project organizers was compared with a view of the teachers.

The questionnaires were completed by teachers twice – at the beginning and at the end of the school year. By the first questionnaire we intended to find out expectations of teachers connected with an implementation of inquiry-based activities into their science lessons. At the end of the school year, after incorporating at least one long-term inquiry-based student project during science lessons, all teachers were asked to reflect on the outcomes they and their students gained.

Teachers' view on outcomes gained by the students who had a chance to experience Chain Reaction approaches is shown at fig. 4.

Students' outcomes

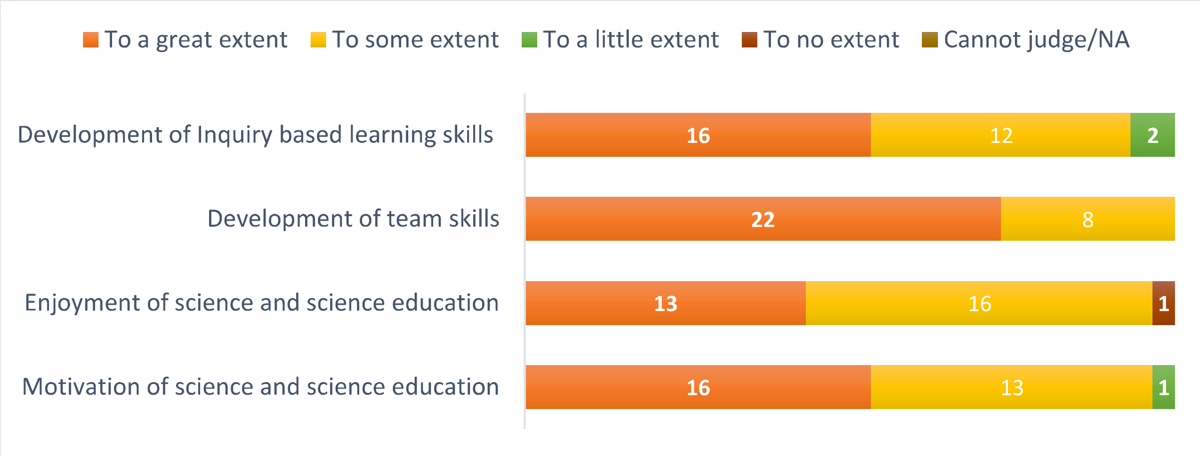

Fig. 4. Students' outcomes after practising inquiry-based activities during a school year

As graph shows teachers have thought that students' outcomes at the end of the school year were very positive. All teachers agreed that the using of inquiry-based activities helped to develop team skills of students. A similar situation was in the case of the development of inquiry-based learning skills, although 100 % of teachers' answers were not positive.

Answers on items about enjoyment and motivation of science and science education were more than satisfactory because, as school practice shows, in addition to developing competences in science it is important to address motivation of science among students. As results show, used activities could contribute not only to the development of scientific competences but also to the increase of students' motivation and enjoyment of science and science education.

The positive impact of the project to students engagement in physics was clearly expressed e.g. by Zuzana Polakova, teacher participating at the Chain Reaction public seminar who said: "*An interest of students to learn physics has increased significantly – the students choose optional physics lessons and physics themes for their projects, they are interested in participation at physics competitions and other physics activities, several students decided to study physics at university*" (Koctúrová, 2016).

Teachers' outcomes

The analysis of teachers' responses to the initial and final questionnaires shows that the teachers went into the project with relatively high expectations. Fig. 5 shows, for example, the level of those expectations in the area of teacher professional development and compares it with the teachers' views on the outcomes in this area. The comparison indicates that teachers' expectations were more or less met. Positive impact of the used inquiry-base activities in the educational process is obvious also from teachers' responses to other questions of the questionnaires.

But implementation of these activities to the lessons was not without complications. During evaluation meetings teachers expressed also a plenty of difficulties they had to cope with during the in-school delivery period.

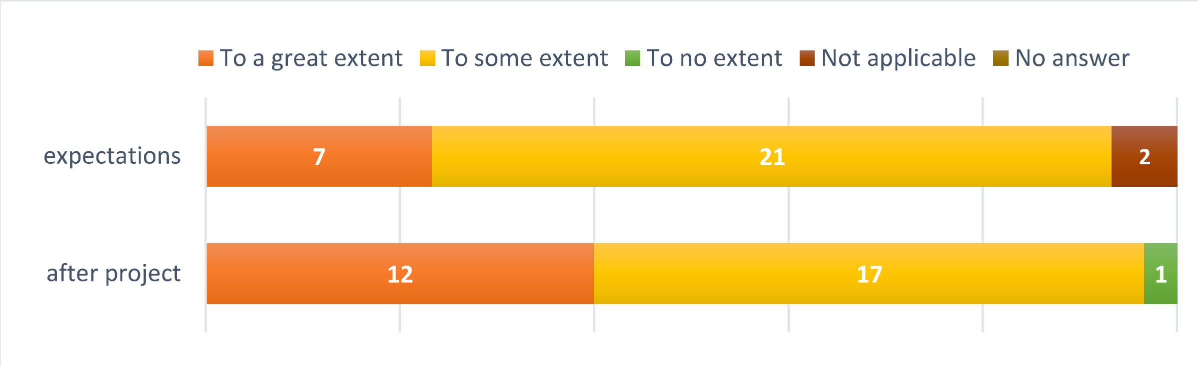

Fig. 5: Teachers' view about an increase of their positive attitude to professional development

As the most serious problem seemed to be the time because the incorporation of student research projects into science subjects program requires too long time. Students had to conduct some experimental work during their free time, after their classes. The conducting of the experimental part of the students' projects in classes with many students was the second important issue for the teachers. Another problem was related to preparation of students for admission procedure to universities. The teachers felt to have a very limited time for inquiry-based activities at physics lessons, because the students wanted/had to be prepared for entrance exams to universities and for school-leaving exams and they needed to have a lot of theoretical knowledge.

Conclusion

The main objective of the activities developed in the Chain Reaction project was to support experimental and investigative work through exciting and realistic situations that link the acquisition of scientific knowledge and skills to the exploration and solving of problem. Inquiry allows students to use the skills, knowledge and experience in a flexible and creative way. Productive work in small groups and the ability to plan their own work motivate students and enable them to understand science research as a human activity. Each of us learns in different ways. Most people just do not learn linearly and inquiry provides them an opportunity to do it in different ways.

As a sample of the activity Comic Website indicates, realization of this activity requires longer time than a few lessons. Therefore, the motivation of students is one of the most important factors, which affect the successful implementation of these activities into the classroom. Another factor influencing the successful implementation of this kind of activities is the application of cross-curricular relationships. For this reason, it is important to take into account the level of knowledge of students from other science subjects to enable successful integration of these activities into the learning process.

Nevertheless, the school practice shows that the character of the inquiry activities strongly supports the intrinsic motivation of students and contributes to their increased interest in sciences also after the project. Precisely prepared inquiry-based activities and set up of appropriate teaching conditions can lead to a significant development of a wide range of students skills and understanding how science work.

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