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Educating for Science and through Science

1st-5th July 2013
Pavol Jozef Šafárik University
Košice, Slovakia

The Hands-on Science Network

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FOREWORD

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APPLICATION OF THE FLIPPED CLASSROOM MODEL IN SCIENCE AND MATH EDUCATION IN SLOVAKIA

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Abstract. *At the present the flipped classroom model of teaching and learning became one of mainstreams in science and math education research.*
In essence, "flipping the classroom" means that typical activities used to occur in class (like lecturing, explaining, simple demonstrations) is exposed and accessed outside and in advance of class (e.g. at home). The class becomes the place for interactive learning including authentic hands-on activities (inquiry based lab work, interactive demonstrations) and minds-on activities (inquiry based problem-solving, peer and class discussion, or debates).
In our contribution we explain pedagogical and practical details (tenets, benefits, pitfalls) of the flipped classroom based on our three years long direct experience from science and math education in Slovakia at secondary and higher education and training pre-service and in-service teachers. At the same time we explain our view of the technology and teaching methods in the flipped classroom.

Keywords. Science and math education, blended learning, flipped classroom, question driven instruction, digital technology

1. Introduction

Information revolution and digital technology dramatically transforms our society, ways how we work, how we communicate or how we spend our leisure time. These days digital technology is practically everywhere, touches our everyday lives. At the same time it changes demands for skills dealing with active successful life, so the presence of technology in education is inevitable (e.g. [1]).
In connection with using technology in education our department became an integral part of several significant educational projects for training in-service teachers which are just finished or still currently running:

- *the European 7FP project „Establish"* [2,3], where the main objective is dissemination and use of the inquiry-based teaching method for science (enhanced by ICT) with second level students (age 12-18 years) on a large scale in Europe by creating authentic learning environments, involving all stakeholders; http://www.establish-fp7.eu/
- *the national projects „Modernization of the education at primary and secondary schools"* [4], with the primary goal to raise awareness and capability of more than 6800 in-service Slovak teachers in ways how digital technologies can change classrooms into modern student-oriented environments for training, developing and enhancing required student's skills; https://www.modernizaciavzdelavania.sk/
- *the science popularization project „Sciencenet"* [5] that has formed the long-term strategic partnership with high schools called Sciencenet and whose one of main objective was to provide novel education and popularization means (esp. new digital technologies) for high school partners and to train their teachers in using them. http://www.sciencenet.upjs.sk

However it is important to realize that the extensive educational research has shown in many cases [1,6–11] that the effectiveness of digital technologies depends strongly on the pedagogical ways in which teachers use them.
Many well-established and sound pedagogical approaches can be successfully employed in the so-called blended learning [10], where from the viewpoint of technology the key role is played by Web technology. This pedagogical strategy is nothing else as an effective and powerful fusion of face-to-face classroom learning and out-of-class online learning.
Among the most widely used approaches in science and math blended learning belong *Just-in-Time Teaching* [8], *Small group learning* [12], *Question driven instruction* [7] or *Flipped classroom* [13].
Slovak teachers (especially in physics) have been introduced with teaching materials dealing with blending learning in the form of Just-In-Time Teaching and Question driven instruction in mentioned national projects „Modernization of

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the education at primary and secondary schools" [14] and "Sciencenet" [5]. During running these projects some pedagogical problems have occurred, so we have also started to train some groups of teachers in the blended learning based on the flipped classroom model.
In this article we explain some pedagogical and practical details of the flipped classroom model of teaching and learning which comes from our three years long direct experience from science and math education in Slovakia at secondary and higher education.

2. Theoretical framework, teaching methods and technology

2.1 Concept of the flipped classroom

According to Bergman and Sams [13], two American teachers of chemistry, who coined the term *flipped classroom*, the flipped classroom model of teaching and learning (briefly also the flipped learning) means, that which is traditionally done in class (like exposition of new content, lecturing, listening, making notes, comprehension, simple demonstrations or teacher's experiments) is now done at home, and that which is traditionally done as homework (like solving problems, doing projects, creative writing) is now completed in class.
From the theoretical viewpoint the basic idea of the flipped classroom model consists in the well-known revised Bloom taxonomy [15], which classifies cognitive work in two dimensions – abstractness of knowledge and difficulty (level) of thinking skills.
During the flipped learning, in accordance with this taxonomy, students are doing simpler (lower) thinking activities (gaining knowledge and understanding) and acquiring more concrete knowledge (like factual) mainly outside of class, and practicing the more difficult (higher) activities (applying, analyzing, evaluating, creating) and constructing more abstract conceptual or metacognitive in the class, where they have the support of their peers and instructor.
As a strong benefit the flipped learning has the effect of creating extra time, which in class allows instructors moderating discussions and debates about more difficult topics, identifying and resolving students' misconceptions, doing more complex hands-on activities or training key skills. In other words the flipped learning maximizes the value of face-to-face time – the scarcest learning resource from viewpoint of interactivity. A summary of typical activities during the flipped learning is presented in Table 1.

Time	*Activities*
prior to class	**Reading** blog, magazine, book, textbook; **Writing** notes in Cornell style **Watching** video-lectures, TV news, movie scenes, video manuals or tutorials; **Doing** simple experiments, simulations or remote experiments, field trips; **Playing** games; **Visiting** museum, exhibits, **Finding** out information, **Doing** research, **Communicating** via interview, sms, videoconference, social network;
during class	**Interactive demonstrations** **Inquiry based activities and lab works,** **Workshop experimental activities,** **Inquiry based problem-solving,** **question driven (peer instruction) activities, peer and class discussions or debates,** **Project based activities,** **Cooperative group problem solving** **Creative writing, Critical thinking training**

Table 1. *Activities in the flipped classroom*

The flipped classroom model has also several disadvantages, but there are also techniques how to eliminate them to a negligible level [16].

2.2 Question driven instruction and the learning cycle approach

Question-driven instruction and its activities belong to very appropriate in-class activities of the flipped learning. This interactive teaching method using classroom response systems (e-voting) was created by the physics education research group of University of Amherst (Beatty, Gerace, Leonard, & Dufresne) [7,9]. The typical class session in such case is structured around three or four question cycles per 45-min long time slot. Each question cycle includes the following steps:

1. Posing a question (problem) by the instructor
2. Small-Group work, discussion on the problem

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3. Collecting answers of students by e-voting
4. Displaying the histogram of answers without revealing the correct answer
5. Opening up and moderating a class-wide discussion
6. Closure activities (typically reposing the same question or sending a related question; summarizing the key points or giving a micro-lecture)

From the viewpoint of the well-known constructivist ideas of J. Piaget [6,17,18] we have decided to adjust our flipped learning to a very successful teaching design representing a form of inquiry-based teaching, *the Learning Cycle approach* [18,19]. This approach, developed by Robert Karplus and its team, divides the activities of instruction into three phases (Fig. 1).

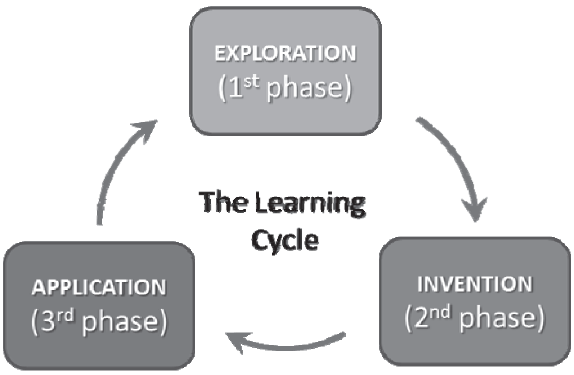

Figure 1. *A teaching strategy called the learning cycle proposed by Karplus and his team*

In the first *exploration* phase (usually through hands-on activities) students alone or in small groups are first given experience with a concept to be developed. This experience is getting without any special instructions, guidance or instructor's intervention.
After that the *conceptual invention* phase follows where students with/without teacher's guidance derive the concept from the previous experience. This phase usually brings students together (to class) with the instructor playing a moderator role.
The final phase, the *application* phase, gives the student the opportunity to explore the usefulness and application of the concept in other circumstances and conditions.
The learning cycle approach is successfully applied in great variety of educational settings, from science subjects (math, physics, chemistry, biology) to humanities, at all levels of education and in groups ranging from 5 to 150 students.

2.3 Technology in the flipped classroom

Implementation of the flipped learning in practice means creating conditions for completing various activities. As you will see in particular examples mentioned in next section 3 (or in [13]) the flipped classroom depends heavily on technology, especially Web 2.0. For managing education it is appropriate to use an LMS like Moodle or based on [20] we are trying to use the social network Google+ and blog (Blooger).
In case of not using LMS any communication and discussions can be provided by social network Google+. Students are doing experiments via computer interactive simulations (Geogebra, Phet, Google maps), digital probes and special software. Special software is also used in case of recording videos via screencasting (Camtasia, Jing, OneNote). Storing, hosting, e-voting is easily performed by free cloud services (Youtube, Google disk, Polleverywhere).

3. Two flipped-learning examples

3.1. Calculus in higher education

Usually the higher mathematics as the calculus of single variable is taught at universities by deductive scheme: definition of a concept, theorem (property of the concept), proof (rigorous logical argument), and example (concept illustration). This method invented by ancient Greeks has great importance to mathematics itself, to its theoretical foundations.
However, if we look at the deductive learning in light of the constructivism and the learning cycle, such approach cannot principally work for majority of students. For example in traditional deductive introduction to the key calculus concept derivative, students should be familiar with the theory of limits based on the delta-epsilon technique. And as a result many science students (especially those who are not majors in math) if they are able to find derivatives, consider the concept mysterious, do calculations only mechanically and fail to solve practical science problems because they have often little idea what derivatives mean.
Students do not understand calculus not only conceptually, but have also problems with their own metacognition about learning science and

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math. In other words students have wrong ideas about answers to questions like what does it mean to understand math and physics? Is physics or math about memorizing and applying rules and equations or about reasoning and making sense of the physical world? Do I understand what does it mean if I am doing science and how scientific method work?, etc.

The second important problem of our instruction is a sample of students who came to study science at our University. According to our test of mathematical literacy from high school (administrated every year before the course) average quality of students continuously drops and gap between what students need to know and they know extends. Moreover our calculus classes are more and more heterogeneous in skills and performance. Many of our students start to struggle with course content after a few lessons.

If we tried to adjust our instruction to average students, we run immediately into problems with time and it was practically impossible to follow our syllabus. Time becomes immediately the scarcest learning resource.

Another frequent and not minor problem in university courses deals with absentness of a teacher, students or mere instruction (lectures, recitations) due to holidays, illness, school or scientific events.

We have tried to solve these pedagogical problems in our course Fundamentals of math for physicists using the flipped learning applying ideas of the calculus reform [21] which took place in US during the 80's and 90's of the twentieth century and completely re-thought the calculus curriculum for non-majors in math.

Most important for us were two central ideas of this reform which are fully consistent with the-learning-cycle strategy: (1) calculus: a pump, not a filter (less details in logical rigor, but clear and transparent in presenting key ideas; substantially more real applications), (2) using technology, inductive learning method and "Rule of Four" for presenting ideas at the same time graphically, numerically, symbolically and verbally [21,22].

To get better idea we present an example of the flipped calculus class connected with our introduction to the concept of derivative.

In the first exploration phase, prior to class, students start with motivational reading, Conquer the third pole, from the science popular magazine Geo about the first successful attempt to climb the highest mountain in the world. They are also said that this activity is important in getting good intuition and idea about derivative.

To get own first experience student also follow Hillary's and Norgay's expedition to Mount Everest virtually in a simple interactive hands-on activity – doing 3D simulation of the climb complemented by watching real Youtube videos and photos offered by Google maps (Fig.2). Exploring on own students submit their answers to a simple task: Try to draw a profile of Mount Everest during Hillary's and Norgay's climb of Mt. Everest and mark the most difficult point of this climb. Give reasons for your choice.

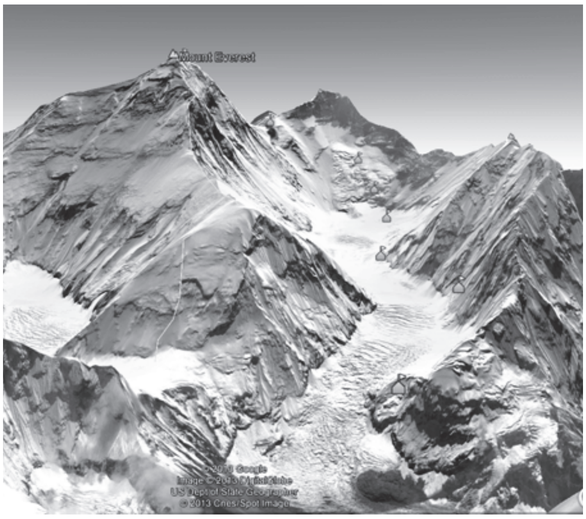

Figure 2. *A simple interactive exploration activity using 3D Google maps*

The exploration phase continues with watching our mini YouTube video-lecture (10 minutes) about "steepest location" of Mount Everest's profile. Students prepare and submit own notes by using Cornell note-taking method [13] together with completing a simple assessment rubrics containing their reactions. The result of the phase is student's clear and intuitive idea that the derivative of a function at a point means geometrically a synonym for the slope (steepness) of the profile (curve or graph) or physically an instantaneous rate of change of considered quantity in time (or instantaneous growth).

In the second invention phase, in class, thanks to in-class minds-on and hands-on activities (Geogebra simulations) students in question driven instruction are trying to answer a series of questions using an e-voting response system based on their mobiles and web service http://www.polleverywhere.com

This phase leads students in formulating the exact calculus definition of the slope of linear

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function and also a geometrical definition of slope of nonlinear function as the slope of the line tangent to the curve representing the graph of the function.
The invention phase is finished again out of class where students watch our Youtube collection of four recapitulating videos and submit own Cornell notes summarizing their learning.
In final application phase (again in the form of question driven instruction) students extends the range of applicability of the concept and finish with the limit definition of the derivative. The limit concept is discussed only intuitively as expressing the slope of the line between two infinitesimally close points on the graph of the function.

3.2 Popularization of science at secondary schools

One of objective of the partnership Sciencenet (the project mentioned above) is to realize regular popular scientific activities like lectures, workshops, and public science days for students and their parents, which have a strong potential to show fascinating world of physics and science. As a successful example of such activities becomes an interactive popularization lesson Could Spider-Man really stop a subway train?, which can be also treated as the form of flipped classroom based on the learning cycle mentioned above. The main objective of the lesson is to show the power of applying scientific models to real situations. In this case students will invent and apply a simple kinematical model of the situation – constant deceleration model.
At least one day before the popularization action and out of class students are encouraged to create informal groups and asked to complete the first exploration phase of the learning cycle. Without any special instructions or guidance or intervention they are getting own experience by watching one of Spider-Man movie scenes (5 minutes long), when Spider-Man stops a New York City subway train. Investigating the video students submit their answers to this simple task: Try to find in the video as much scientific information as possible.
The beginning of the face-to-face interactive lesson represents start of the second invention phase of the learning cycle. Using question-driven instruction students try to make sense of the data collected during the exploration phase and connect to the key question: Could Spider-Man really stop a subway train? Using e-voting for answering multi-choice questions together with peer and class-wide instruction and applying the Ockham razor (metaphorically illustrated by a joke about a spherical cow) they develop and invent a simple kinematical model of the situation (“constant deceleration model”). With teacher guidance they find that the power of the superhero is not exaggerated at all and it is comparable to strength of a very mighty gorilla.
Later students deploy the model in a real life situation (airbag in car) which represents the third last application phase of the learning cycle. As homework in a simple lab activity (video-analysis of a crash test according to video manual) students complete the application phase by checking in the developed model.

4. Conclusions

At the present the flipped classroom model of teaching and learning becomes one of mainstreams in science and math education research. This approach allows instructor to create and maximize the use of the scarcest learning resource from viewpoint of interactivity - classroom time. It means more student-student and student-instructor interactions, students learning at own pace, addressing absenteeism and helping struggling students.
Our first results supports the conclusion that the flipped learning can result in greater achievement in math and science, better understanding and retention of concepts, improved attitudes toward science and science learning, better reasoning ability, and superior process skills than would be the case with traditional instructional approaches.

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