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Practical strategies in formative and summative assessment of the flipped math and physics education

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II CONGRESO EUROPEO FLIPPED CLASSROOM
FlipCon6ias
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Libro de actas
Organizan
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dedicados a ti
The flipped classroom
Flipped Learning
Simplified with Jon Bergmann
Universidad Zaragoza

Actas del II Congreso de Flipped Classroom

Comunicaciones y posters presentados

Dr. Raúl Santiago Campión (coord.)

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Parte 3. Educación universitaria

Créditos

Presentación

Santiago Campión, R.
Director Académico del Congreso

El II Congreso Europeo de *Flipped Classroom* se celebró en el Palacio de la Infanta en Madrid los días 6 – 8 Mayo de 2016, con el Patrocinio del Ibercaja y con una nutrida representación de docentes, investigadores y empresas comprometidas con la educación y la transformación del modelo educativo.

Este congreso constituyó la segunda edición del Congreso Europeo de *Flipped Classroom*, y la primera vez que se celebraba en España. El éxito y la amplia participación de especialistas de todo el mundo en este encuentro -412 inscritos, 41 comunicaciones- se materializó en este libro de *Actas*, publicado por el GRUPO MT y Digital Text en 2016.

La estructura del libro constituye una réplica de la propia estructura de las comunicaciones, experiencias y posters presentadas en el congreso. En este libro de actas podrás acceder a experiencias que van desde la utilización de apps para el desarrollo del enfoque, hasta la integración de otras metodologías activas con el modelo de clase inversa. Los docentes que nos aportan su visión y puesta en práctica abarcan todos los niveles educativos: desde la Educación Infantil a la Educación Superior, incluyendo los Ciclos Formativos.

Quiero agradecer a los que habéis presentado vuestras comunicaciones, todas ellas fruto de vuestra experiencia y el trabajo día a día en las aulas: un auténtico tesoro que compartís con el resto de colegas que ven en vosotros un modelo que les puede guiar en este camino irreversible hacia la mejora del cambio educativo.

Espero que la lectura de estas actas resulte inspiradora para el lector, y que se anime a presentar su propia visión y aplicación del *Flipped Classroom* en el próximo congreso: FlipCon Spain 2017 en Madrid.

Practical strategies in formative and summative assessment of the flipped math and physics education

Las estrategias prácticas en la evaluación formativa y sumativa del flipped matemáticas y física

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Abstract
In 2011 at P.J. Šafárik University we completed essential preparations to a pilot application of the flipped learning model in several physics and math related courses. Afterward, during autumn semesters of the last four years (2012-2015), we have been realizing our experimental research and pilot instruction. Through following spring semesters, we have been devoting our attention to modifying or improving learning materials, assessment tools or teaching strategies. From the pedagogical point of view, our version of the flipped learning is based on Just-in-Time Teaching and Question-Driven Instruction.
Here in our contribution, we would like to explain our pedagogical and practical experience dealing with a portfolio of formative and summative assessment tools and strategies, namely structured Cornell notes, two-minute paper, peer-instruction cycle, big moderation, content and attitude surveys, flipped grading, applied in our instruction. As it is typical in the flipped learning, these assessment tools are based or strongly supported by digital technology, which we introduce together with actual examples of mentioned tools. Finally, by our more than four-year-long experience and teaching results, we will discuss the benefits, pitfalls and suggestions corresponding to the mentioned assessments tools and corresponding digital technology, all in the framework of the flipped math and physics learning.

Keywords: Cornell Notes, Two-minute Paper, Peer-Instruction Cycle, Concept Inventories, Flipped Grading.

Resumen
En el año 2011 en la Universidad de P.J. Šafárik completamos los preparativos esenciales para una aplicación piloto del modelo de flipped learning en varios cursos relacionados con la física y matemáticas. Durante los semestres de otoño de los últimos cuatro años (2012-2015), habíamos realizado de nuestra investigación y la instrucción piloto experimental. Mientras que a través siguientes semestres de primavera, nosotros habíamos dedicando nuestra atención a la modificación o aumentación de los materiales de aprendizaje, herramientas de evaluación o estrategias de enseñanza. Desde el punto de vista pedagógico, nuestra versión del flipped learning se basa en La enseñanza justo a tiempo y Instrucción entre Pares.
Aquí en nuestra contribución, nos gustaría explicar nuestra experiencia pedagógica y práctica que trata de un portafolio de las herramientas y estrategias de la evaluación sumativa y formativa aplicada en nuestra instrucción, por ejemplo notas de Cornell estructurados, papel de dos minutos, el ciclo de Instrucción entre Pares, la moderación grande, de contenido y de actitud encuestas, Flipped clasificación. Cómo es típico en flipped learning, estas herramientas de evaluación se basan o son fuertemente apoyados por la tecnología digital que mostramos junto con los ejemplos reales de las herramientas mencionadas. Por último, por nuestros más de cuatro años de la experiencia y por los resultados de la enseñanza, vamos a comentar las ventajas, dificultades y sugerencias correspondiente a las herramientas de las evaluaciones mencionadas y la tecnología digital correspondientes, todo ello en el marco del flipped learning de matemáticas y física.

Palabras clave: Notas de Cornell, Papel de dos minutos, Ciclo de Instrucción entre Pares, Inventarios del Concepto, Flipped clasificación.

Introduction and Study Background

According to research relevant to teaching physics and mathematics (Donovan & Bransford, 2005; Redish, 2003; Reif, 2008), teaching and learning environments are more efficient and successful when they are learner-centered, knowledge-centered, assessment-centered and community-centered. If we generally talk about pedagogical methods in teaching physics and mathematics, it has also been shown (Hake, 1998; Redish, 2003) that the so-called interactive methods which are "designed to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors" are more effective than traditional methods.

In addition, if we consider the flipped learning, the introduction of flipped learning (November & Mull, 2012; O'Flaherty & Phillips, 2015) to teachers and students accustomed to traditional teaching requires, among other things, clear expectations to be given to students to reduce their frustrations regarding the time taken to do the pre-class activities. Some students also become critical if they have to take responsibility for their learning outside of face-to-face contact time.

In 2008, when we started to think about flipped math and physics learning in the form of Just-in-Time Teaching and Peer Instruction, successfully implemented at Harvard University (Crouch & Mazur, 2001), we faced the same concerns. The most crucial concerns for us were personified by similar questions: (1) Would we be able to draw our students into taking more, much more accountability for the learning process as before? (2) Would our students recognize the benefits of needed responsibility and accept it?

One possible promising way how to transfer accountability to students (Mazur & Watkins, 2009) is to build accountability into the learning process and environment naturally, especially by assessment strategies and tools in agreement with the model of teaching and learning. Such way also leads us to examine other questions, e.g. what assessment tools can help students to take the responsibility for their learning or what are the difficulties faced by students when they need to deal with these tools in the flipped learning?

In 2011 at P.J. Šafárik University we completed essential preparations to a pilot application of the flipped learning model in two courses - *Fundamentals of calculus for physicists and Modern physics from the viewpoint of a physics teacher*. Afterward, during autumn semesters of the last four years (2012-2015), we have been realizing our experimental research and pilot instruction, whereas we have been devoting our attention to modifying or improving learning materials, assessment tools or teaching strategies through following spring semesters.

Our practical experience has been supported by collaboration with teachers and schools in several educational projects, namely the European 7FP project "Establish", the national projects "Modernization of the education at primary and secondary schools" and the science popularization project "Sciencenet" (see more in Hanč, 2013) As for assessment tools and immediate feedback strategies, during 2013-2016, one pillar of our research work also became now finishing applied research project entitled as "Research on the efficiency of innovative teaching methods in mathematics, physics and informatics" (see acknowledgments).

Based on this work, in the next two sections of our contribution, we would like to explain our pedagogical and practical experience dealing with a portfolio of formative and summative assessment tools and strategies applied in our instruction. As it is typical in the flipped learning, these assessment tools are based or strongly supported by digital technology, which we introduce together with actual examples of mentioned tools.

Strategies in Formative Assessment

Since there are a lot of theoretically and practically based publications dealing with formative assessment, e.g. (Black & Wiliam, 2009; Gikandi, Morrow, & Davis, 2011; Keeley, 2015), there is no special need for its detailed description. Here we mention only some important ideas dealing with our chosen assessment tools. Mentioned articles write that all participants of instruction - the teacher, individual learner and peers - are representatives of formative assessment, where the shared responsibility and control are an integral part of this assessment.

Cornell notes

One of our important formative assessment strategy dealing with a student pre-class preparation is the *Cornell-note* taking system. Cornell notes were developed by Walter Pauk from Cornell University, has been adopted by innumerable schools, colleges, and Universities in the United States and throughout the world (Pauk & Owens, 2010). Bergmann & Sams (2012) proposed these notes in the flipped learning not only to improve students' note-taking skills but also train students in asking questions and doing summarizing what they have learned. This learning style based on the so-called retrieval practice (Karpicke & Blunt, 2011) is more efficient than simple rereading or reviewing notes.

Structure of Cornell notes. The Cornell note template (Pauk & Owens, 2010) divides paper format A4 into four spaces, two vertical and two horizontal. The upper horizontal part serves for basic information about studying material, author of the book, video, lecturer's name, identification of the subject, theme, and objectives. The right column (the note column) is used to "capture the lecturer's ideas and facts", in the form of classically structured notes during the lecture or studying any educational material. The left column (the cue column) is filled in later with questions matching the key points of the content. At the bottom of the page, space is left for summarizing the main point(s) of the page, which again clarifies meanings and also makes review easier. After the note-taking session (right column), students review their notes and write questions in the cue column (left column) to highlight the main points, meanings, and relationships. The process of writing the questions in the cue column helps clarify meanings, reveal relationships, establish continuity, and strengthen memory.

Digital technology. With the aim of formative assessment, our students are also required to scan their handwritten Cornell notes by their mobile devices, then upload to their Google Drives as shared documents with us. Using a Cornell-notes rubric, we evaluate the Cornell notes, and results of the rubric together with a sample of the best as well of the worst notes are shown as "learning by sample" strategy.

Pedagogical use of Cornell notes. Own Cornell notes are used as a cornerstone for retrieval practice (Brown, Roediger, & McDaniel, 2014) when are studied by students in pre-class activities or used as a review due to exams. We also consider such note-taking skills as essential in subjects like labs or recitations. During in-class activities in our math and physics courses, students are strongly encouraged to use their Cornell notes as a scaffolding material for the effective solving of any tasks or problems. Simultaneously using Cornell notes, students are led to more effective study of all types of educational materials used in the flipped learning approach, such as a blog or web content, e-books, e-documents, videos, educational videos, film shots or video tutorials. Students are also required to apply this proactive approach when they carry out virtual multimedia experiments, simulations or remote experiments (see more in the Peer-instruction cycle section).

Two-minute paper

At the end of any learning activity our students usually give us quick and simple feedback in the form of the so-called *two-minute paper*. This assessment technique belongs to frequently used techniques in math and science classes (Hughes-Hallet, 1999; Keeley, 2015). It represents a good way to gain insight what students are thinking about the learning activity and their learning experience.

Structure of the two-minute paper. The two-minute paper provides several questions to students which are answered by them in a small amount of time, typically a few minutes (e.g. two minutes). We want students to respond to three questions (according to Hughes-Hallet, 1999): what was the most important, most confusing and one unanswered thing which students have discovered during the activity. However, it is possible to use another variations of the questions, which can be found in Keeley, 2015.

Digital technology. In the case of the flipped learning model we use the well-known online Google forms technology (Byrne, 2012). Two-minute papers as e-forms are comfortably answerable on any mobile device. Simultaneously e-forms collect students' answers with minimal effort and give the instructor enough time to sort and analyze them. Then, the results can be easily discussed and shared with students (e.g. at a social net community for a course – we use Google+ community) to improve learning and communication with the class.

Pedagogical use of the two-minute paper. The overwhelming majority of our pre-class activities dealing with content learning or scientific inquiry requires two-minute-paper feedback from students. From psychological point of view, the two-minute paper is not simple recalling pieces of gathered information. Students have to think about what they have been learning and describe how well they comprehend it. From this perspective the two-minute paper trains students in developing higher-order thinking processes as critical-thinking, auto-evaluation and metacognition about their learning.

There are several modifications of the two-minute-paper assignment (Keeley, 2015; Mazur & Watkins, 2009). One of these modifications combines evaluation questions with a slightly provocative, engaging problem (or question) with a real context that is open to several interpretations or solutions depending on a chosen view of the situation (see a particular example in fig.1). Such pre-class assignment incorporates the so-called Just-in-Time strategy and it shortly calls the JiTT assignment (Novak, Gavrin, Christian, & Patterson, 1999; Simkins & Maier, 2009).

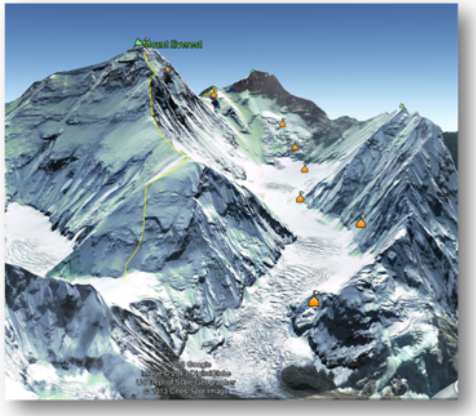

Fig. 1: An example of the JiTT problem (adopted from Hanč, 2013). Students follow the first successful expedition of Hillary and Norgay to Mount Everest on a 3D simulation offered by Google Earth. Exploring on own students try to answer the following problem: *Try to draw a profile of Mount Everest during Hillary's and Norgay's climb of Mt. Everest and mark the most difficult point of this climb. Give reasons for your choice.*

Peer-instruction cycle

At the beginning of 1990s during the testing clickers in real school conditions (the classroom response system Classtalk II, Banks, 2006) two pedagogical approaches for in-class activities were fully established – Peer instruction (Crouch & Mazur, 2001) and Question-driven instruction (Beatty, Gerace, Leonard, & Dufresne, 2006b) The approaches, which are based on ideas of constructivism, formative assessment and cooperative learning, belong to interactive methods mentioned in the paper introduction. At present both approaches can be viewed as very similar and their main component is the question or peer-instruction cycle.

Structure of the peer-instruction cycle. The typical class session is structured around three or four cycles per 45-min long time slot. During one question cycle in a face-to-face instruction we realize with students the following steps (Hanč, 2013): (1) posing a question (problem) by the instructor (see fig.2); (2) small-group work of students on solutions – peer instruction; (3) collecting answers of students by e-voting; (4) displaying the answers without revealing the correct answer; (5) class-wide discussion; (6) closure (e.g. summarizing the key points or giving an explanation).

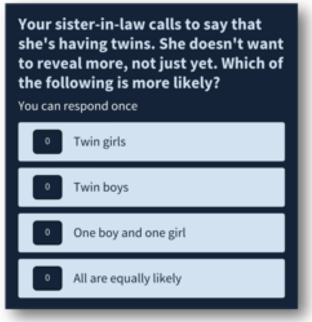

Fig. 2: An example of the peer-instruction problem (adopted from Bruff, 2009) presented via Poll Everywhere service on a mobile device.

Digital technology. The questions or problems which drive in-class activities have not only the traditional text form but they can be posed in the form of multimedia (e.g. interactive video), probeware-based laboratory experiments (e.g. using Vernier or PASCO wireless sensors or probes connectable to mobile devices, www.vernier.com, www.pasco.com), virtual experiments (e.g. simulations in Geogebra, www.geogebra.org; Hanc, Lukac, Sekerak, & Sveda, 2011; or PheT simulations, phet.colorado.edu; Wieman, Adams, Loeblein, & Perkins, 2010) or online remote experiments (e.g. ISES remote laboratory, www.ises.info; Krbeček, Schauer, & Lustig, 2013).

As for a classroom response system for e-voting providing immediate feedback, we recommend the use of mobile devices (as clickers) and Google forms (as a response system; www.google.com/intl/en-GB/forms/about/) or online service Poll Everywhere (also as a response system, www.polleverywhere.com).

Pedagogical use of the peer-instruction cycle. A careful choice of questions or problems (Beatty, Gerace, Leonard, & Dufresne, 2006a; Crouch & Mazur, 2001; Mazur, 1997) can probe all levels of the Bloom-taxonomy thinking processes. In math and science, questions can be directly oriented to predictions of the explored phenomena. Together with work in pairs, small groups or class-wide discussions it allows us and students to cover more difficult topics. But it also allows to confront students' ideas, sort out contradictions, identify and resolve misconceptions which leads to active learning, increasing understanding of key concepts and principles and developing metacognitive skills.

Strategies in Summative Assessment

Whereas the primary objective of formative assessment is learning, which is not clear to students at all, in the case of summative assessment it is evaluation. Regarding summative assessment, we focus on knowledge, conceptual understanding and metacognitive competencies.

Content and attitude surveys

From 1982 to 1995 at Arizona State University, two American researchers, Ibrahim Halloun and David Hestenes were working on the development of the first content survey -- Force Concept Inventory (FCI). Their goal was to explore students' conceptual understanding of key concepts from Newtonian mechanics, and to determine the extent of misconceptions. FCI consists of 30 multiple-choice questions (5 choices) grouped into six major concept dimensions. Nowadays, FCI appears as one of the most carefully researched and most extensively used content surveys. It initiated the development of content surveys not only in almost all areas of physics but also in math and other science disciplines. For example, we use the Calculus Concept Inventory (CCI) -- a test of the conceptual understanding of fundamental calculus concepts, which consists of 22 multiple-choice questions.

According to Donovan & Bransford (2005) or Redish (2003) supporting students to become aware of and engaged in their own learning (shortly called metacognition) is also the important component of effective and successful learning and should be the standard part of education. To see what progress our students are making in the development of their metacognitive beliefs and skills about learning math and science we administrate the Maryland Physics Expectations (MPEX).

Structure of the surveys. Typically a content or attitude survey (Redish, 2003) is a set of qualitative multiple-choice questions (similar to the question on fig. 2 or fig.3) with appropriate attractive distractors connected to the most common students' misconceptions. The questions are formulated by a common language, instead of the scientific one. Time for completing the survey is reasonably short (10 to 30 minutes).

"Understanding" physics basically means being able to recall something you've read or been shown.

(1) Strongly Disagree (2) Disagree
(3) Neutral (4) Agree (5) Strongly Agree

Fig. 3: One of the MPEX questions.

Digital technology. We collect data from surveys via Google forms, which are filled by students on their mobile devices. Then we export the data to a dynamic document in R knitr (R Development Core Team, 2014; Xie, 2013) which allows a very smooth and quick data processing and statistics analysis.

Pedagogical use. After the completion of a theme from physics or math, we evaluate our instruction with these research-based surveys whether our instruction is meeting our goals. To probe students' thinking, misconceptions or metacognitive beliefs we use standardized content and attitude surveys like mentioned FCI, CCI or MPEX. However, it is important to know that these surveys serve for evaluation of the instruction not for certifying students. This has three important implications in delivering the surveys (Redish, 2003): (1) we have to be careful to teach the given subject not teach to the test; (2) survey solutions should not be distributed to students; (3) surveys should not be graded, but required with motivation of a promised credit.

Flipped grading and moderations

Before leaving with written exam hardcopies, our students send their scanned copies to a cloud drive shared with us. This step serves as a prevention against cheating, which could occur in next corresponding activities. The students have 24 hours for a decision to undergo the so-called *big moderation*. Then after 48 hours, students are asked for self-grading of their exams. They use a video tutorial with detailed teacher's explanation of correct solutions and way of assigning points for students' original solutions. Simultaneously students fill a corresponding rubric for an immediate collection of assigned points for each task in their written exam. At the end, they again upload their graded written exams with correct solutions to the cloud drive for our final control. Since students, not teachers, are grading their work, we call this assessment *Flipped grading*.

Structure of the big moderation. If students decide to go through the big moderation, they are advised to choose up to half of exam problems and solve them by a cooperative group work. Then during the moderation, one randomly selected student from the given group defends a group solution of the chosen problem as it would be on an oral exam. The received points or grade is the same for all his peers. The same process is repeated for all chosen problems as it is depicted by fig. 4.

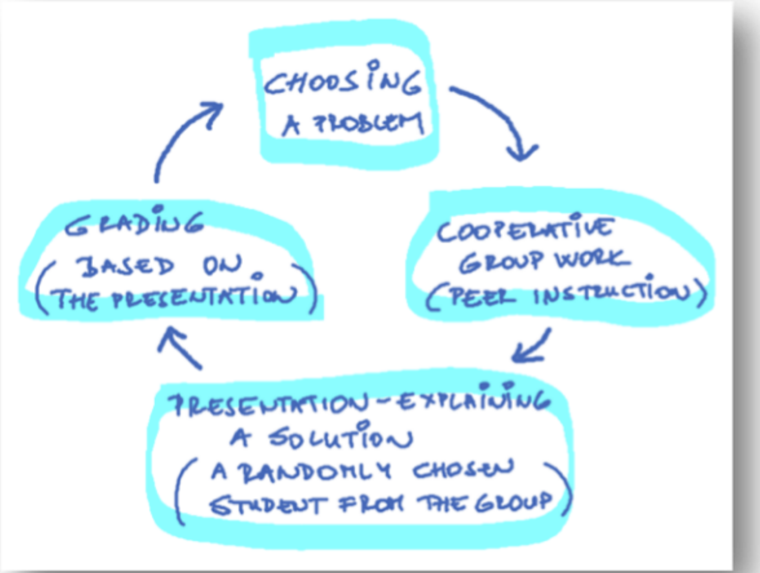

Fig. 4: A schema of the big moderation.

Digital technology. The scanned copies of written exam hardcopies are made by students using mobile devices and corresponding applications (e.g. Google scanner in Google drive app or CamScanner app) and uploaded to a shared folder of Google drives. All used rubrics are created as Google forms. During the flipped grading students study video tutorials at YouTube platform that has the possibility to either slow down or up videos with respect to viewer needs.

As for the big moderation, we make a random selection of the students by random number generator app. Since the moderation is considered as an oral exam, we also use e.g. virtual experiments (simulations) to evaluate student's understanding quickly and more precisely.

Pedagogical use. Educational research has proved that self-grading, just as peer-grading, are contributing to deeper understanding much more than common grading (Sadler & Good, 2006). One of the disadvantages in traditional teaching is that a student frequently perceives his summative assessment passively. Many times students do not fully understand teacher's notes written on their exam or test hardcopies. Sometimes they are not interested in them at all. Typically, self-grading or peer-grading skills of students are low.

To prevent wasting of teacher's work and especially to train self-grading, our students are required to do the flipped grading after each midterm or final written exam. Student's wrong grading is fixed by us without any penalization during the final control. On the other hand, correct grading is rewarded by extra points. Regarding the big moderation assessment strategy, students are able actively to correct up to 50% of their exam grades. In this case, we were inspired by the team-based learning approach (Michaelsen & Sweet, 2008; it is also used by Mazur), which use benefits of peer-grading and peer-instruction (Crouch & Mazur, 2001; Sadler & Good, 2006).

In line with mentioned ideas, these summative strategies do not only evaluate instruction or students but also give students a great opportunity for learning and improving as it is typical in the case of formative assessment.

Empirical Reserach and Results

Our four years long experience in the pilot flipped learning with a sample of totally N=88 university students in two courses gave us approximately twenty times more feedback data per student than in previous traditional teaching. Despite the fact that now we perform a detailed quantitative analysis (also with the use of the results of the applied research project VEMIV; Lukáč, 2015), we have important qualitative results indicated from our observations and summative data from exams.

From teacher's viewpoint the pilot flipped learning positively resolved two standard problems of traditional instruction (Hanč, 2013): (1) managing our instruction in very heterogeneous groups in skills and performance; especially any adjusting of our instruction in the freshman math course to average students did not allow us to follow the planned syllabus; (2) absentness of an instructor, students or mere instruction (lectures, recitations) due to holidays, illness, school or scientific events.

Moreover, in the flipped learning our students resolved three times more problems than before. Our summative strategies allowing students' improvement led to no repeat exams and to real enhancement of students' conceptual understanding and computing skills.

In contrast, the majority of our students had metacognitive problems in understanding the role and value of high quality structured notes, retrieval practice and formative assessments especially in pre-class activities or group work in class. Even explaining to students at the beginning of the courses much more carefully the importance of our formative assessment strategies in promoting their learning was not fully satisfying. Our experience also tells us that a lot of university students (mainly those who are not majors in math) need a special training how to effectively watch or study learning materials for physics or math (videos or texts) or how to create and use structured notes.

Besides usual problems like not working systematically, meeting deadlines, instructions, overlooking important information there are also metacognitive problems connected directly with the very nature of math and physics. Many students come from high schools with typical expectations from the traditional way of teaching math or physics (described e.g. in Hughes-Hallet, 1999). Some of them are the following: students expect that math or physics problems should be written in a way clearly implying what method or formula to use for their solving; solutions of math or physics problems are results of students' individual work without any discussions or peer instruction; well taught mathematics or physics lesson allows to learn any material if you pay attention in class, no self-study of learning materials is required.

Empirical Reserach and Results

According to the current flipped-learning definition (Flipped Learning Network, 2014), direct instruction moves from the group learning space, which is typically carried out in a classroom, to the individual learning space mostly represented by home. To get an effective flipped math and physics learning, this essential transformation requires not only learner-centered environments, but we also have to build naturally a high level of accountability in the learning process, especially by assessment tools we use.

The essential implication in using assessment tools in pre-class and class activities of the flipped learning is not connected with technology or learning content, but with students' metacognitive expectations and thinking. Therefore, it is extremely to pay attention and develop students' understanding the role and value of formative assessment strategies as natural in promoting learning, better conceptual understanding and developing key skills important for students' next life. Considering educational and psychological research, this conclusion dealing with the flipped math and physics learning is in accordance with conclusions about metacognition in the frame of the JiTT pedagogy (Simkins & Maier, 2009) or with general pedagogical conclusions about the importance of metacognition in the learning process (Donovan & Bransford, 2005; Hattie, 2015).

Acknowledgments

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