The paradigm change in STEM Education – has it happened already?

Jan Slovák
Department of Mathematics and Statistics
Masaryk University
Kotlářská 2
611 37 Brno
Czech Republic

Abstract. This short paper aims at collecting observations and thoughts related to the Education in Science, Technology, Engineering, and Mathematics (the so called STEM). In this way we would like to initiate new studies and experiments. In particular, we shall question how the current trends of the massified Education, together with the available technologies and the changes in the attitudes of the new generations of both students and teachers, are reflected in the attitudes, knowledge and skills of the graduates. The method of the paper consists of comparison of well-known general facts and conclusions with the author's own experience in teaching Mathematics. Particular attention is devoted to the (mis)use of new technologies in these areas.

1. Introduction

Over centuries, the main content of teaching and learning swapped repeatedly, roughly speaking, between two main phases: 'teaching facts' and 'engaging the intellect'. These are the two basic approaches to Education and both can be done in a useful and practical way, or the opposite. Actually, another point of view is that these are rather two parts of the same process and it could be only a matter of taste or presentation, whether we focus more on the 'teaching facts' or the 'engaging intellect' part. But definitely, the tendency to stress the first or the latter one swaps in time.

In recent decades, the tendency to teach facts was perhaps stronger than ever before. Moreover, there were many further risk factors appearing in parallel – too much specialisation, fit for purpose training, unrealistic expectation from new web based technologies, etc.

Long back, the Education used to be very *individual*. There were only a few students, all living together with their teachers at colleges, and the entire Education was based on individual learning, and public disputes and discussions with fellows and teachers. Education was very *international* at those days too (linked rather to some religion/church than states or regions).

The current massive education platforms are mostly just the opposite – often very regional and very anonymous. At the same time, the knowledge seems to be available everywhere and for free at the internet, while the usage of all the engineering and information technology inventions seems to be easy without knowing the principles why and how they work.

All these circumstances lead to the belief that the Teaching Facts Paradigm seems to be

- practical (the students perform tasks fast);
- efficient (the students immediately display the 'right' knowledge);
- manageable (even in massified forms of Education);
- easily supported by technologies (accessible even in online and distance education versions).

No wonder that this has been the dominant approach over decades and gets much support now.

But how and why should we engage the intellect then? We should think on the following points:

- learning vs. *understanding;*
- memorizing vs. *thinking and deducting;*
- blindly applying vs. *developing and experimenting;*
- watching vs. *discovering*.

All this is hard to achieve in the massified Education forms, and it is linked to the general problem of perception of information.

2. Impact of personal typologies in Education

In a face to face contact, good teachers always pass their 'experience and opinion'. This is perhaps the best way to help the students to understand the topics really. Unfortunately, this mostly fails with big groups.

One of the reasons is that typology of the individual people varies, which is usually balanced well in the face to face contact (at least in the presence of reasonable social intelligence). But unfortunately, there cannot be a universal method for lecturing in large classes since we cannot address all the types of personalities in parallel. The way out seems to be to invoke thinking and communication among the students, initialised, supervised and amended by the teachers. This is exactly the point where smart usage of new technologies together with relevant changes in the structure of instructions, workgroups and individualised learning should help.

So what is special about the perception during the learning? Perhaps every teacher has noticed that some people need 'intuition' first and only then they can perceive the 'technicalities', though most of the population needs the opposite.

Such questions were addressed by Jung's typology of personalities, and it is remarkable that these obvious facts heavily used in the Human Resource management were given little notices in Education management and practice. There is a rather simplistic version of such typology known as Myers-Briggs Type Indicators, used heavily by HR people nowadays, see [1]. Here the *type* is based on four dichotomies:

- the attitudes are *Extraversion* (E) versus *Introversion* (I)

- the perception functions are *Sensing* (S) versus *Intuition* (N)
- the judging functions are *Thinking* (T) versus *Feeling* (F)
- the lifestyle is *Judging* (J) versus *Perception* (P)

This provides 16 types of personalities, for example ENTJ, ISTJ, etc.

A lot of criticism applies to the MBTI tests and to the use of the typology in the HR practice, see e.g. [2], pointing out the low re-test reliability (caused perhaps by mechanical splitting of the results in the individual dichotomies at a virtual central value, though most of the population displays results close to this value). But for our aim, this seems to be perfect explanation why any universal effort to teaching in big groups based mainly on the teachers' presentations has to be dammed to failure.

In my own practice, I have been most interested in the polarized (NT) opposed to (SF) subgroups of students (or teachers). The members of the first group heavily need `intuition' first, they want to think on the general picture, on the reasons why to deal exactly with the discussed phenomenon etc., and only then they can perceive the `technicalities' and work on real practical tasks. The people from the (SF) group are just the opposite. Needless to say that there are many more SF's than NT's in the population! We shall return to this point in the realm of my Mathematics courses in a moment.

3. How are the colleges/schools performing?

Next, we come to the obvious question how the colleges should develop their approaches to curricula and the teaching/learning standards. Nearly all studies and statistics say that the outcomes are poor and some of the authors relate this fact with our question raised above: *too much of teaching facts and too little of engaging the intellect*. But we can also rephrase this as a perhaps *wrong balance and order of practicing intuition and technicalities.* A nice interview with Dr. Jo Handelsman, Howard Hughes Medical Institute Professor in the Department of Molecular, Cellular and Developmental Biology at Yale University, can be found in [3]. Roughly speaking, the students of Biology are getting many fragments of facts in individual sub-disciplines, but they lack both global picture and understanding. She claims that using the conventional science instruction, only 10 to 20 percent of lecture content is actually retained by students, while the professors spend hours explaining to them. Opposed to that, active learning schemes have proven to be more effective, she says.
Actually, there are even much more pessimistic results of recent studies explained in the two books by two sociologists, Richard Arum and Josipa Roksa, [4], [5]. Their first book is based on the study of more than 2300 bachelor students in24 schools of different image claiming that, with a bit of exaggeration, the students learned a lot of bad habits while their critical thinking and readiness to work got often even worse. In the second book they extend the study to the general changes in the social behaviour in the last 40 years. Their observations include:

- earlier, rather introvert people having their behaviour and values copied from their teachers and parents were admired as wise and serious;
- now, the immediate response from the colleagues is the guiding principle and the extrovert people with no values of their own are winning;

- university teachers are too much under pressure of student evaluations and their standards have developed in similar way too, and thus, the students have never had studied as little with as good marks as nowadays.

Although their study is criticised for using exclusively the Collegiate Learning Assessment (CLA) Performance Task to test the outcomes, which is not believed to cover all the abilities to be tested, their results match very well the lack of the 'engaging the intellect' part of the educational process, combined with further sociological data.

Let us pose another provoking question. Can the students and teachers mutually understand each other? We could guess from other studies that, at least, this will not be easy. As shown in the *Generation Z survey*, the current teenagers are, unlike their teachers:

- multitasking across 5 screens;
- keeping attention for less than 8 seconds only;
- collaborate better, but more than 10% of them suffer hyperactivity and further neurological deviations;
- live in virtual realities.

4. Do the new technologies help?

In the last decade we have witnessed the very wide use of the web based technologies:

- more communication and working in groups in diverse e-learning collaborative tools (or just using general tools like Skype, Hangouts, etc.);
- easy capture of lectures;
- sophisticated on-line learning schemes provided on large public platforms (Moodle or BB platforms, all the MOOC's etc.);
- virtual web based universities (and virtual diplomas).

All this burst of ideas, approaches and tools has got many good flavours. Watching the popularity rankings of the tools and platforms on the web, we learn about Adobe Connect, Blackboard, Canvas, Coursera, edX, ePals, FaceTime, iTunes U, Moodle, Schoology, but also Google Plus Hangouts, Skype, YouTube and many more general purpose communication platforms. Some of them are used internally at schools, some of them provide free public service for everybody.

There are many questions in place here. Does this all always lead to real learning? Which part of the crowd does it support best – the average, the best ones, or the laziest and weakest ones? Does the technology strengthen the 'teaching facts' or the 'engaging intellect' parts? Does it help to balance them right for the different types of personalities? And the most appealing question – will regional universities need their own real teachers at all?

The answer to the latter question is, of course, yes and the reason is the same as with theatres and musicians/actors. Although there are all the recordings of the absolutely best ones, still the people enjoy real live concerts. Simply, they want to experience the emotions, experience, and passion live, and the same applies to teaching. Let us add a few further observations suggesting some partial answers:

- movies are good for initiating interest and more, but it is difficult and extremely labour-intensive to make them to provoke critical thinking;
- thinking goes better with still images, schemes or texts which is typical in STEM, but also in Medicine etc.;
- the right technology should allow for 'live' appearance of teachers/speakers combined with classical slides displaying the topic to be discussed – this very much imitates the standard way of consulting in someone's office;
- the technology should invoke symmetric discussion the same way in any kind of groups;
- should allow the teacher to create the messages/lectures easily, in order to keep the feeling of rather real time discussion than a perfect anonymous performance;

All this can hardly work just with videos from the classrooms or some universal MOOC presentations, as we mostly know them.

5. Mathematics and STEM

All the questions raised above are particularly urgent within the STEM programmes. Moreover, there are the following observations to make:

- the individual components (Science & Technology & Engineering & Mathematics) should not be taught separately, rather we should like to build a global picture;
- the 'understanding' part of the process is the more important one, while mere memorizing of facts can be even dangerous;
- it is extremely hard to manage the STEM education in big crowds due to various perception schemes (and abilities) of the individual students;
- the technologies can be very helpful here, but they also can spoil the game completely.

Mathematics is a quite specific part of the STEM which could be understood as the common language or one of the possible approaches. Unfortunately, this often is not the way how it is presented. Mathematics should help to the 'engage intellect' part of process.

I am intensively teaching Mathematics for big classes of Informatics students and my own experience says that the videos with lectures or further similar material are very appreciated by the students, but they do not help much to their real understanding. Rather, their existence is often misleading them in the belief that they will be able to browse through the videos before the exams like they watch the sitcoms. Just the really serious students use them the right way, coming back to unclear points when revisiting or filling gaps later.

Thus, I was rather seeking for a structure of the teaching process and the exploited support technology which would allow for a combination of the following parts:

- a flipped-classroom approach based on up to date prepared presentations amending the practical aspects of the lectures, available to the students short before the main lectures;
- standard lectures (in the rather classical big lecture hall standard, coming with usual tutorials in smaller groups) combining the practical use of the mathematical tools with rather intuitive explanation of the methods and procedures;
- practical seminars devoted to the numerical and computational aspects (computer based activity in small groups with a tutor);
- individual problem solving (perhaps in small groups, invoking mutual discussion between students).

In general, there are many ways how to teach Mathematics. Mostly, the instructors try to do *everything completely 'right'* (from the pure Mathematics point of view) and they believe, one day the students will themselves understand how beautiful and useful the Mathematics is. The other possibility is to *focus on the 'right things'* and to present them as useful tools and we hope that the best students will come to understanding of the tiny details too, while the average students will at least remember the usefulness of Mathematics.

Another point is the overall structure of the exposition. Usually the instructors try to provide 'complete' exposition of the phenomena the first time already. But this makes it nearly impossible to gain complete understanding. The other approach is touching topics in a *simple way first* and 'coming back' with new understanding later again.

Perhaps, we should like to specify what we mean by Mathematics first. Since Mathematics became also the name of one of the subjects taught at Grammar School level, the people obviously think that they have met Mathematics, they have perhaps hated it, and they believe Mathematics is just playing with numbers or, even worse, the abstract letters representing them. The etymology of the word Mathematics displays a quite different picture. The Online Etymology Dictionary reveals (abridged):

<u>mathematic (n.)</u> late 14c. as singular noun, replaced by early 17c. by <u>mathematics</u>, from Latin mathematica (plural), from Greek mathematike tekhne "mathematical science," … from mathema (genitive mathematos) "science, knowledge, mathematical knowledge; a lesson," literally "that which is learnt;" related to manthanein "to learn," … (cognates: Greek menthere "to care," Lithuanian mandras "wide-awake," Old Church Slavonic madru "wise, sage," Gothic mundonsis "to look at," German munter "awake, lively"). As an adjective, 1540s, from French mathématique or directly from Latin mathematicus.

The etymology itself suggests that Mathematics should be following rather the questions of "WHY" then those of "HOW" and it should be rather understood as many diverse ways of consistent thinking.

So why do people remember Mathematics so much differently, even those very knowledgeable ones? For example, J. W. Goethe said `*Mathematicians are like*

Frenchmen: whatever you say to them they translate into their own language and forthwith it is something entirely different'; or St. Augustine wrote in his book (De Genesi ad Litteram, Book II, xviii, 37) `*The good Christian should beware of mathematicians and all those who make empty prophecies. The danger already exists that mathematicians have made a covenant with the devil to darken the spirit and confine man in the bonds of Hell.*'; even worse, M. Luther wrote '*Medicine makes people ill, mathematics make them sad and theology makes them sinful*.'

6. The `Brisk Guide to Mathematics' project

Following the wish of the Faculty of Informatics management at the Masaryk University in 2004, I took up the challenge to reshape the Mathematics instruction for the entire faculty.

My initial strategy was:

- to focus on practical topics with easy going intuition and rather simple algorithms (and be aware that the intuition is too difficult to perceive without any knowledge);
- to work in spirals, i.e. to come back to the topics with a better supply of tools and more tasks to be solved (and be aware that this might also lead to "spirals of misunderstadings");
- to experiment with the format of the lecturing in order to match as many types of personalities as possible.

The immediate consequences included:

- we are building discrete models first, the continuous analysis comes later to deal with convergence and robustness;
- we avoid splitting Mathematics into Algebra, Analysis etc.;
- we use innovative technology to invoke the thinking part of the process and to activate the students.

All this is following the main goals of the four semester long course:

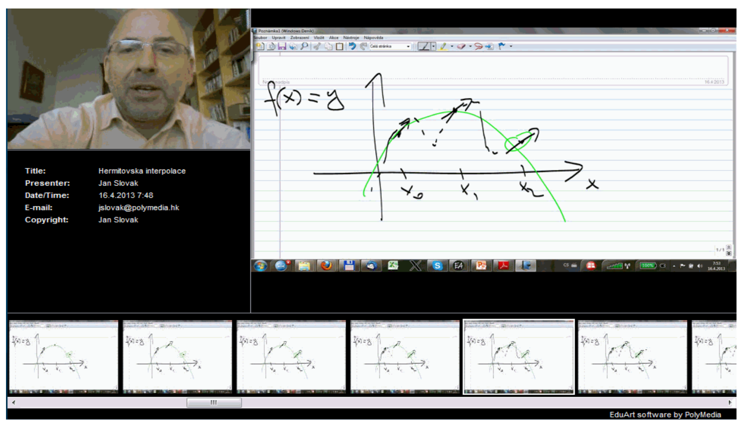
- the students should be able to formulate precise definitions of basic concepts and to prove simple mathematical results;
- the students should perceive and understand the meaning of roughly formulated properties, relations and outlooks for exploring mathematical tools;
- the student should master tools and algorithms behind mathematical models and they should appreciate their usage.

Given the time frame and the available formats of the instruction, these goals are ambitious and they require a very rough and active approach. The students have to find their own paths and they should be enforced to do so.

With a wider team of collaborators, we have prepared the unconventional textbook underlying this course which we have called 'Brisk Guide to Mathematics' and we hope this book should also help to push the students to their own paths. The book is printed in two columns which are rather independent of each other, one focused exclusively on practical tasks and examples, while the other column provides a complete exposition of theory and usage of the individual concepts and tools. Moreover, the theoretical column is very inhomogeneous in both the details and the complexity of the exposition and the readers should be self-navigated by the so-called emoticons acting as switches between the characters of the individual blocks of text. The electronic version of the Czech book is available at http://www.math.muni.cz/Matematika_drsne_svizne.html and we are working on the English version now.

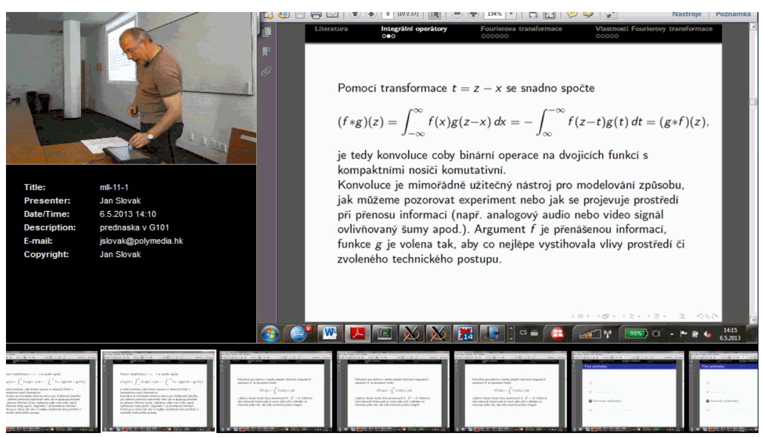
The instruction itself has been supported by software tools allowing for easy capturing of any presentation, based on the full resolution slides (as they appear on the screen) combined with a full audio-video recording of the speaker. The result is an open format html5 web presentation available freely on all platforms.

The screen-shot on the right hand side illustrates one of the practical presentations prepared before the main lectures and displaying the main algorithms and tools to be discussed soon. These presentations are available[1] to the students a few days in advance, so that the people who need the practice first can watch them in time.



Indeed, the students have reported the extreme usefulness of such presentations before the lectures (perhaps the "SF" subgroup of types, in particular).

Next, the theoretical lectures are presented and their recording by means of the same technology is available to students too, followed by regular tutorials. This is usually followed by wide discussion on the individual practical problems supported by the general e-learning platform provided by the university.



In general, the exploited technology allows for completely symmetric mutual communication combining audio-video and slides, which is very lean and effective, since

[1] I have been using the software EduArt™ developed and distributed by Polymedia Technologies, see www.polymedia.cz for more details.

the slides remain in their jpg format full resolution all the time and thus the data flow of the presentation is very low. Unfortunately, the university has not acquired a multilicense for this technology solution and so this form of communication is not yet widely spread.

The experimental teaching within the "Brisk Guide to Mathematics" project has got the graduates for several years already and the responses are diverse, quite as expected.

Clearly the new model of structuring and presenting Mathematics teaching is more than welcome by the best students. We have not got a detailed statistics, but the general university questionnaires reflecting the opinions and feelings of students suggest at least those in the 1st quartile of students by their results of study find the model very good (at Masaryk University we are still strict with having about 1/3 drop rate in Mathematics in general, and the 'A' or 'B' marks are rather exceptional). Also their skills seem to be very good, while the average students (or those less motivated ones) have not got worse. This was exactly my main goal.

In general, it seems that the existence of the practical presentations (closely related to the main lectures and tutorials in both topics and time) and the recordings of the lectures, together with the consequent returning to topics in spirals and with different complexity of the parts of the exposition, help to find the individual paths for each student. Some of them might come back to the practical parts after they enjoyed the theoretical lectures (the NT subgroup), others enjoy the practical presentations before the lectures already (the SF subgroup) and all of them can gain a lot from the mutual discussions among the students themselves.

There are two typical complaints. The first one is pointing out the lack of explicit lists of detailed simple tasks to be mastered in order to pass. This is exactly what the students are often used to in other courses, cf. the comments in section 3 above. The students also complain about a too wide scope of the course making it too difficult and demanding.

The students report positively on the unconventional use of the technologies and would like to see it spread more widely across the faculty.

References

[1] Myers, Isabel Briggs, Mary H. McCaulley, Naomi Quenk, and Allan Hammer. (1998) *MBTI Handbook: A Guide to the development and use of the Myers-Briggs Type Indicator* Consulting Psychologists Press, 3rd edition. ISBN 0-89106-130-4
[2] Hunsley, J.; Lee, C.M.; and Wood, J.M. (2004). Controversial and questionable assessment techniques. *Science and Pseudoscience in Clinical Psychology*, Lilienfeld SO, Lohr JM, Lynn SJ (eds.). Guilford
[3] Fischer, C. N., Changing the Science Education Paradigm: From Teaching Facts to Engaging the Intellect, Science Education Colloquia Series, Spring 2011, Yale J Biol Med. Sep 2011; 84(3): 247–251.

[4] Arum, R., Roksa, J., Academically Adrift: Limited Learning on College Campuses, Chicago: University of Chicago Press, 2011.
[5] Arum, R., Roksa, J., Aspiring Adults Adrift: Tentative Transitions of College Graduates, Chicago: University of Chicago Press, 2014.
[6] Generation Z survey, Sparks & Honey, USA, April 2014 (< 18, compared to 20-30 and elder)