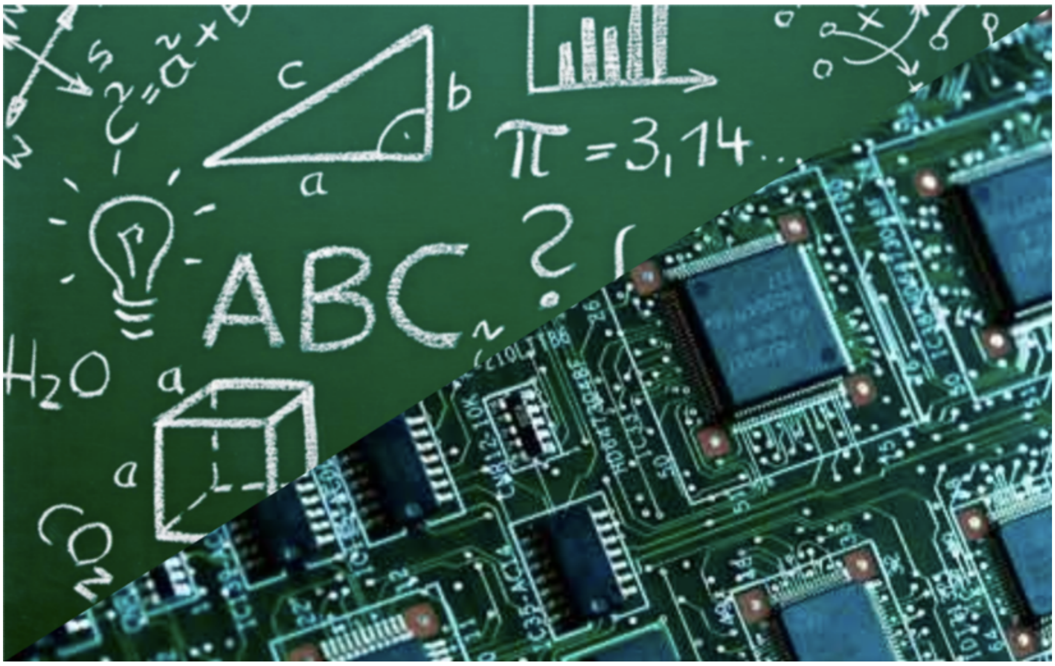
Beuth-Sprachenpreis 2014

„The Digital Revolution"



What influences can modern computer technologies have on the way we teach, learn and do sciences?

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Fall 2014

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Introduction

Starting in the 1970s, the modern computer revolution progressively but drastically changed our everyday life. In the western civilisations, it is nowadays common to be able to have at one's disposal a modern computer or an equivalent technological device with a fast internet connection. As it was already the case with the agricultural and the industrial revolution, the Digital Revolution is a consequence of new scientific discoveries and their application in the society to create new technologies. So science generates technological revolutions and the computer sciences in particular have generated the Digital Revolution. As a result of the interactional complexity lying in our modern western societies, this technological progress also transforms the way we learn and teach. This has a direct impact on pupils, students and teachers. Why? Because it completely changes the way knowledge can be shared. One thousand years ago, if you wanted to get some specific knowledge you would probably have had to go to an abbey and ask a monk to copy a book for you. Today you turn on your computer, check your internet connection and do research on Wikipedia, the first universal encyclopedia entirely written with 0 and 1.

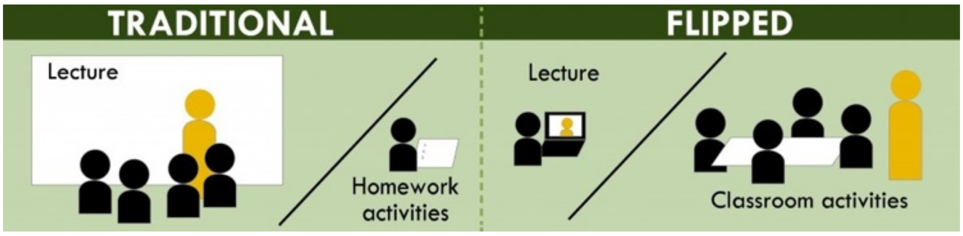
On the other hand, a lot of us do not share this particular interest in the sciences and mathematics. On the contrary, there is a kind of negation towards mathematics which tends to be developed early in children. Why and how does this appear and persist? The teaching of mathematics is most often focused on the ability to calculate. In order to evaluate a child or a student in mathematics, one mostly judges his ability to do arithmetic. Perhaps being able to calculate correctly does not necessarily mean being good at mathematics, otherwise we could say that a computer is an excellent mathematician. Is that true? If we look at mathematics as the skill to resolve a purely numerical problem consisting in operations between numbers, then a modern computer cannot be defeated by a human brain and we should, therefore, acknowledge that it is actually the most brilliant mathematician ever. However, if we look at mathematics as a discipline where cognitive abilities and problem solving skills are developed and trained, then we see that numerical skills are just a part of a much larger activity of the mind. We then see that the computer is playing the role of a powerful tool which helps the mathematician to think and try to find a solution to his problem.

In the following essay we will try to see how some new computer technologies can play that role and how they change the way mathematics, and more generally sciences, are taught and learned. We will discuss online-learning and the inverted classroom model, we will see which role programming can play in the process of teaching sciences and, finally, we will present an example of a kind of fundamental scientific discovery which was made using computer programs. Along this journey, the questions we want to bear in mind are: How do these new technologies change the way we share our scientific knowledge? Can they help us better understanding and exploring the world of mathematics and sciences?

Online-Learning And The Inverted Classroom Model

The accelerating development of online-learning platforms in the last decade carries numerous questions about the way we want to share knowledge. In particular, which role remains to teachers to play if students no longer need them to gain access to the teaching materials? The simple fact that this question arises may show us how little we truly understand the relationship between students and teachers. The vision which stands behind this question is actually one where the teacher is only there to transmit the information he has in the special domain he is teaching. The student is only there to receive this information. In other words, it is like a simple copy-paste procedure between two mental hard drives. One need not to be a genius to understand that this approach to teaching and learning is not the only one available. It is not enough to memorize the Pythagoras theorem to be able to solve a problem where it can be used. The student also needs the ability to observe the problem, understand what he needs to solve and recognise a situation where he can use the mathematical tool. At this point it is the practice among a group of other students, organised and led by an experienced teacher, which then plays a crucial role. We see then that we can consider the teaching-learning process of sharing knowledge under these two dimensions: the purely theoretical transmission and acquisition of information and the practical application of knowledge to concrete situations.

What is the inverted classroom model, also called flip class model? It is a teaching-learning model where these two dimensions previously described are intentionally more separated than in a conventional classroom model. In the latter, students meet together with the teacher to gain the new knowledge and then later work separately at home to try to understand and apply this new material. In the inverted classroom model, students try to gain the basic knowledge on their own at home and then meet together with the teacher and the other students to practice and apply. Online-learning can play a big role here, since the transmission of knowledge to the recipient occurs with online videos for example. This model enhances the role of the teacher as a group leader: he is there more to accompany the student in his own learning process. It also enhances the responsibility of the student, who must first take care of his own knowledge acquisition at home. This way of teaching and learning does not necessarily require a computer nor must it wait for the Digital Revolution to be tried and practiced. However the fact that computers today are available to most of the students shapes a new framework in which this model could be more explored and experimented.

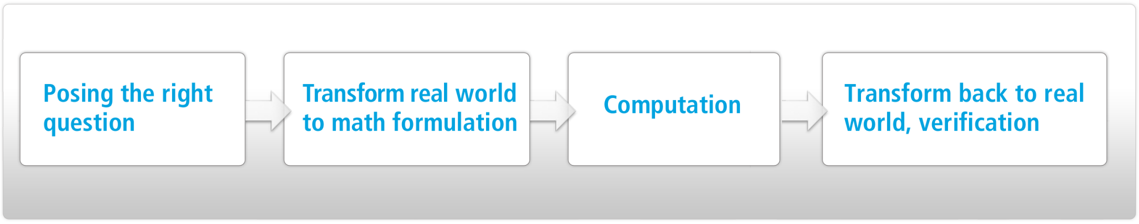


Picture 1: Sketch of the traditional and the flipped classroom models

Jörn Loviscach, a Professor of Engineering Sciences and Mathematics at the Fachhochschule of Bielefeld, is inducting such an experiment, which he describes as having an „icebreaker function" to explore what works and what does not work. He has prepared short videos , 2-10 minutes in length each, focusing on a particular subject of the module being taught. Between each video there is an opportunity for the student to practice and to ask questions. What he tries to avoid, he says, are situations where the professor is giving a magistral lecture for one and a half hours, consisting mostly of enunciating the theorem, proving it, and at the end, giving an example of application. The flip class model allows the teacher to be freed from having to repeat the same things over and over. Jörn Loviscach says the computer and the videos can do this much better. Not every professor would have to create their own videos and somehow they would tend to replace books as the common data support. He is practicing the inverted classroom with the students who then come prepared to the lecture, where more communication and student-student and professor-student interactions can occur. He does not agree with a vision of online-learning which would seek to make the professor obsolete. The big task, he says, is to motivate the student to think and work autonomously, to develop the self-initiative. For this to succeed, new technologies alone will not help.

Mathematica, An Example Of Learning Mathematics By Programming With Computers

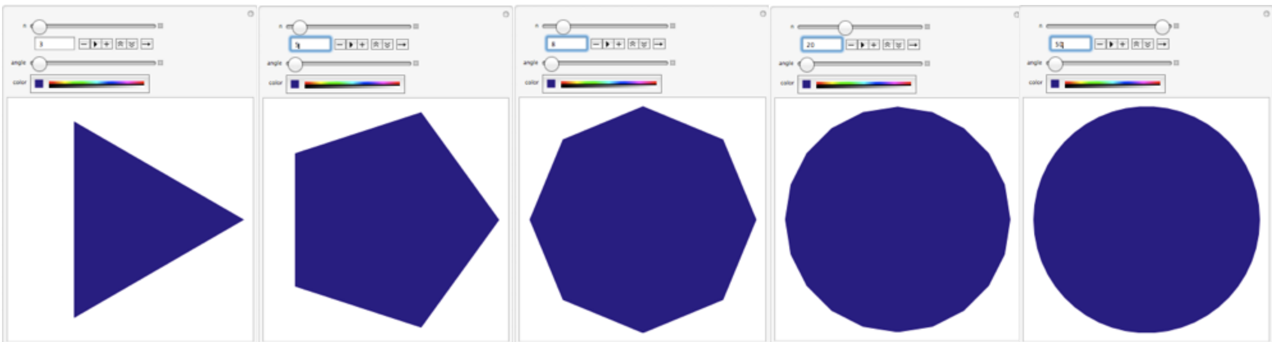
Conrad Wolfram, brother of Stephen Wolfram (creator of the computational software program *Mathematica* in 1988), mathematician and director of the worldwide division of Wolfram Research, presented in 2010 in a TED-conference his vision of what future teaching of mathematics could look like. He starts with the current problem with math education which we already described briefly in the introduction: those learning think it is disconnected from the reality, difficult and boring; and those teaching are frustrated. Conrad Wolfram points out that mathematics has never been so important as now in our society and that there is a paradox today which illustrates the problem: while the interest in math is falling, the world is more and more quantitative and mathematical. In his view, education must be reformed and he claims: „Stop teaching calculating, start teaching math!“. Therefore he proposes the use of computers to develop a computer-based mathematics education. What is mathematics? He answers this question with a list of four successive steps:



Picture 2: The different steps in mathematics and science

Today, math education focuses on the third step with hand-calculating exercises that usually have little to do with the more complex situations found in the real world . It is the third step where computers can actually work better than anyone else. The idea would then be to free the student from calculating, so that he might use his time and energy for steps 1,2 and 4, which the computer cannot do. *„Calculating represents the machinery of maths and should be solved by computers“*. Conrad Wolfram explains we were all traditionally taught to manually calculate because, for a long time, this was the only way for scientists to get the results. Thanks to the new digital technologies, the situation has changed. However, we continue to teach and learn mathematics like before. He argues that, by learning programming on a computer, the student would learn to master the underlying structures, the procedures and the rules and so would thus come to a deeper understanding of mathematics. He says: "If you really want to see if you understand math, then write a program and see if you can make it work". For him, a computer-based math education would be the opportunity for the student to learn simultaneously in a more practical as well as in a more conceptual way. In a more practical way by applying, simulating and studying complex models of reality, and in a more conceptual way, by practicing programming. He deplores the fact that students studying maths often come to think that math consists mostly in "running through a bunch of calculating processes they don't understand for reasons they don't get." He promotes the use of computers and computing programs such as *Mathematica* to teach the basics of math and suggests hand-calculating only there where it is necessary.

Here is an example of a simple geometric program written with *Mathematica* in order to show what happens when the number of sides of a polygon increases, using a dynamical display function, which allows the user to interact directly with the program. The following 5 pictures were taken at 5 different values of n, the number of sides of the polygon:



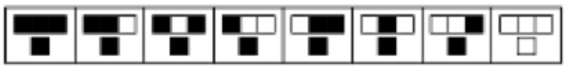
Picture 3: The evolution of the shape of a regular polygon with respect to its number of sides

Although this example is very basic, it helps us to understand that modern computing programs allow to quickly visualize the evolution of situations when some internal parameters are changed. Finally, the question is: does the circle have 1 unique circular side or an infinite number of sides? With these kind of questions and simple basic applications, where the user can directly interact, one can, for example, have a practical approach to the notion of infinity and develop a new kind of intuition for it.

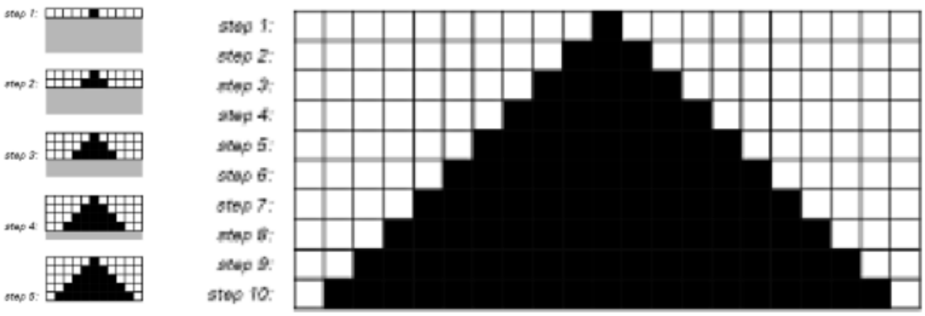
A New Kind Of Science

In 2002 Stephen Wolfram published “A New Kind Of Science“, a book wherein he presents his results after having explored for many years the behavior of cellular automatons when being governed by simple rules or programs. Although his work met with skepticism among the scientific community, particularly when looking at the multitude of potential application fields that the author claims, his research may be considered an example of what can be achieved when using modern computer technologies.

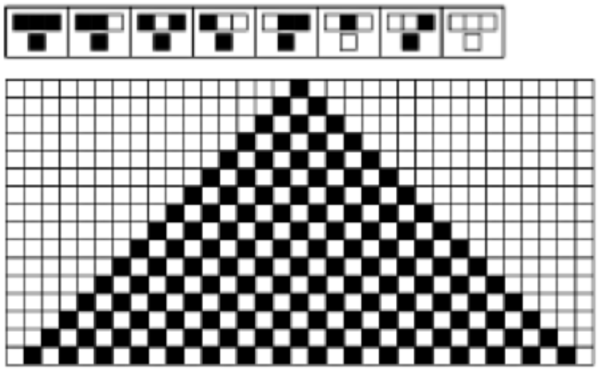
The kind of cellular automaton he explored in the first place basically consists of a range of cells that can be colored either in black or white. A set of rules is programed in order to determine the color of each cell. For example, with the following rule,

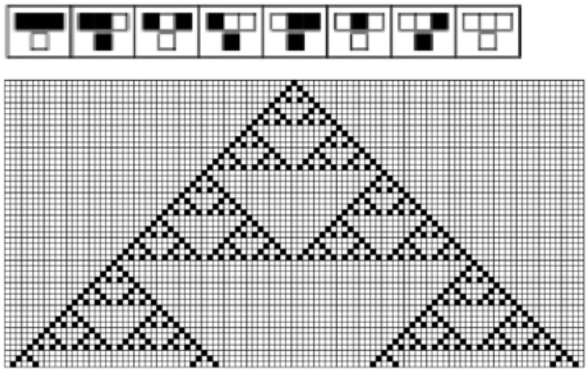


where we can read the color of a cell regarding the colors of the same cell and its two neighbors at the previous level of computing, we obtain line after line the following pictures, which correspond to the different levels or steps of computation:

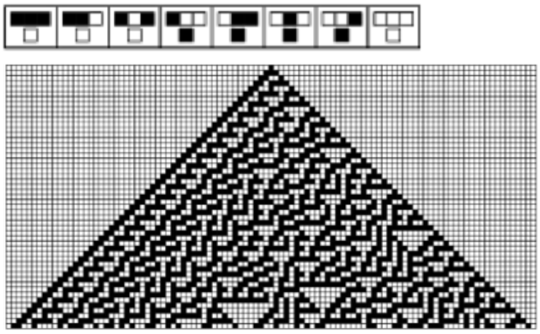


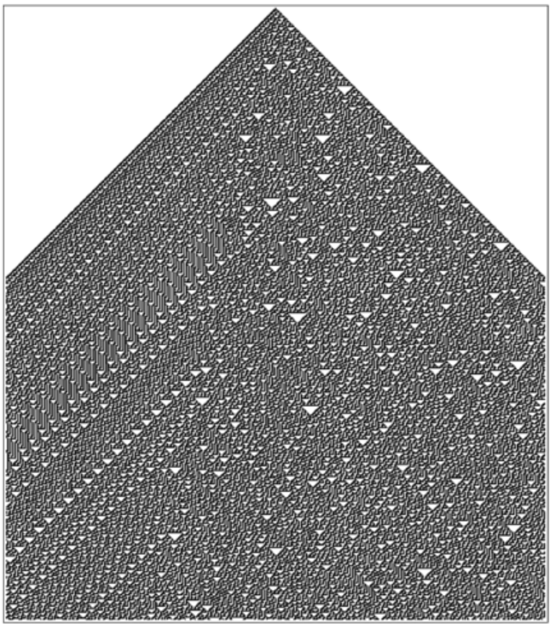
Here we can see that a simple rule leads to a simple behavior. In the following two examples, although exhibiting different types of structure and behavior, the logic remains the same: a simple program or rule leads to a structured and regular pattern:





S.Wolfram explains that what he discovered while running similar cellular automatons and exploring the different combinations of rules (2 possibilities each for 8 cases brings a total of 2^8 = 256 different rules which, without a computer, tends to be quite an onerous task), is that in some cases, *simple programs can lead to great complexity*, particularly when the computation of this rule runs for a sufficient length of time. This is the case with the following rule, which was then applied 500 times in the second picture:





What we see here is quite astonishing and unexpected: a simple rule and a simple initial condition lead to great complexity, that is a global structure which is fundamentally irregular and unpredictable in its regularities. As S.Wolfram says: „the only way to effectively find its outcome, is just to watch it evolve“. This experiment made him develop a conceptual framework where he explains the importance of what he calls the „principle of computational irreducibility or equivalence “. This emphasizes the role of computation in the evolution of systems and behaviors and brings new perspectives to our traditional way of thinking sciences, where we are too often expecting complicated rules in order to understand complicated behaviors.

In a way, what we can observe here is how modern computer technologies have a retroactive effect on the way we are practicing or engaging in science and research. As S.Wolfram explains, these kinds of rules do not strictly require a computer to be studied, but in order to get pictures where the rules are computed thousands of times over and for several different sets of rules, the speed of a computer and a computing program become substantial tools to explore what would otherwise take a couple of years of time and an astronomical dose of patience to be realized by hand…

Conclusion: The Place Of Sciences And Technologies In The Human Society

Computers and modern communication technologies have pervaded our everyday life. As it is the case with most any human evolution, this Digital Revolution brings great advances as well as great difficulties, too. Today, professors are facing a new kind of student in the classroom: the technologically equipped student. Twenty years ago, the student would still have utilized books and writing utensils. Today, the student brings a smartphone, a tab, or a laptop and connects to the internet which is available throughout the campus. Some professors are prohibiting the use of these devices during the class, others try ignore their use and focus on delivering their lecture. It is difficult to say whether it really helps the student to go along with his studies. Sometimes it appears quite obvious that the constant presence of technology can also be a source of distraction and undermines one's ability to concentrate. On the other hand, as we saw with the different examples, modern computer technologies are offering new possibilities for teaching, learning and doing the sciences. The most important question may be the following: what place do we want to give technology in our society? We must not forget, that technology should be considered a tool, and not as end in itself. We can envision a world, where technology has found its optimal place, serving some particular needs of humanity, such as helping to meet physical requirements for human survival, promoting education or serving scientific research.

With the "Digital Revolution", mankind unleashed great powers on the earth. But how do we master them? Do we see where they are leading us? Modern computer technologies are also being currently used to create more effective tools of destruction, such as drones. Is that not a tragic and very high price to pay?

The question of what is the appropriate place of technology in teaching and learning sciences is far from easy. The opinions are diverse and the financial interests are not to be ignored. Maybe we should approach the problem in a scientific way: let us not fear the exploration, but let us also not fear to say stop. Perhaps we should think more often about this.

List Of Pictures

Cover picture: Editing of two pictures that were found online at the following two addresses:

-http://www.theguardian.com/technology/2012/sep/18/chris-anderson-internet-industrial-revolution

-http://diaryofanelearner.com/wp-content/uploads/2013/11/maths-ftr.jpg

Picture 1: Sketch of the traditional and the flipped classroom models

-source: http://www.washington.edu/teaching/teaching-resources/flipping-the-classroom/

Picture 2: The different steps in mathematics and science

-source: Transcript of C.Wolfram's TED-conference, available at http://www.computerbasedmath.org/resources/reforming-math-curriculum-with-computers.html

Picture 3: The evolution of the shape of a regular polygon with respect to its number of sides

-source: Editing from the *Mathematica* transcript of C.Wolfram's TED-conference, available at http://www.computerbasedmath.org/resources/reforming-math-curriculum-with-computers.html

All the pictures from the part „A New Kind Of Science“ were edited from the Book „A New Kind Of Science“ from S.Wolfram, chapter 2: „The Crucial Experiment“ (see Bibliography).

Bibliography

Lester, F., & Charles, R. I. (Eds.) 2003. Teaching mathematics through problem solving. Reston, VA: National Council for Teachers of Mathematics.

Loviscach, J. 2013. Mathematik online erklärt und geübt, live vertieft, Proceedings 11. Workshop Mathematik in ingenieurwissenschaftlichen Studiengängen, Wismarer Frege-Reihe 3/2013, Teil 2, pp. 5-11

Loviscach, J. 2013. The Inverted Classroom Model: Where to go from here, in: J. Handke et al. (Eds.), The Inverted Classroom Model, The 2nd German ICM Conference – Conference Volume, Oldenbourg, 2013, pp. 3-14

Tripathi, Preety N. 2009. Problem solving in mathematics: a tool for cognitive development. In epiSTEME-3. International Conference to Review Research in Science, Technology and Mathematics Education, 168-173.

Wheatley, G. H. 1992. The role of reflection in mathematics. Educational Studies in Mathematics. 23(5), 529-41.

Wolfram, S. 2002. A New Kind Of Science. Wolfram Media.

Websites:

Conrad Wolfram's website about learning mathematics with computers:
www.computerbasedmath.org

Jörn Loviscach's website: http://www.j3l7h.de
especially the following two interviews:

- Mit Videos lernen - ein Experimentierfeld
- Der Flipped Classroom: Wie funktioniert der umgedrehte Unterricht?