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Changing mathematics education in Estonia: Computer-based statistics project

Terje Hõlm; Carita Hommik; Ülle Kikas

University of Tartu, Estonia

Introduction

The accelerating growth of both quantity and availability of information afforded by new digital technologies has created greater expectations to people's competencies in numerical, statistical and visual literacy, requiring fundamental changes in teaching and learning. Mathematical modeling and processing of large data sets are commonly required skills for jobs in STEM sector, as well as in business and social sectors. According to the OECD Innovation Strategy, data analysis discoveries have become the drivers behind innovation. In the forthcoming years this will call for effective improvement of visual and statistical literacy of a large number of individuals. Currently, only 0.5% of the labor force in OECD countries are specialists working with data, but the request will remarkably increase in coming years (OECD, 2015)

In Estonia, the main goal of mathematics education is to teach students to formulate, employ and interpret mathematics in a variety of contexts, especially in different situations in their lives. The state final exams and the research evidences show that we have not yet achieved that goal. Whereas the performance of Estonian students in PISA mathematical tests is good (in PISA 2012, the average scores of Estonian students were ranked 10th to 14th among 65 countries worldwide, and 3rd to 6th in Europe), only 14.6% of students could solve complex mathematical problems that require mathematical modeling and well-developed reasoning skills (OECD, 2014).

Several studies have indicated that the shortcomings of contemporary math education is the capability to teach and develop skills for applying math outside the context of math lessons and specific textbook tasks. The traditional math education focuses at mastering of mathematical procedures within the context of mathematics itself. However, real-life problems require the ability to contextualize the problem in a way to analyze them using mathematical methods. Unfortunately, students still believe that math competencies are not needed in everyday life. The survey of graduates of Estonian higher education institutions in 2012 indicated that less than a half of these young people recognized the importance of STEM competences in their workplace (17% said it is very important and 24% important) (Laan et al., 2012). One can infer, that many employers do not believe in the usefulness of STEM competencies, and employees are unable to use their math skills efficiently in their jobs.

A survey of general competencies of Estonian lower secondary students (Palu, A & Kikas, E., 2015) revealed that students' procedural skills in mathematics are better than their problem solving skills. The study also examined the subject matter competence versus general math competence. The performance of students was notably higher within the math subject than in using general math competence to solve integrated problems.

The aim of this article is to introduce an innovative way to bring both the technology and the real-life problem solving experiences into the classroom. The computer based statistics project, that is currently being developed and implemented in Estonia, will be described and its positive aspects as well as challenges highlighted.

Computer Based Statistics (CBS) Project

The Estonian Ministry of Education and Research is financing the project on Computer Based Statistics, which aims at a fundamental change for learning data and statistics at lower and upper secondary levels. The first phase of the project in 2012 – 2014 created the preconditions for systematic innovation in mathematical education. The ongoing second phase of the project focuses on teaching CBS in a wide range of Estonian schools.

The new approach will empower students with the knowledge and modern skills for using mathematics and computers in real life (Wolfram, C., 2010). It is based on the innovative vision of Computer Based Math, introduced by Conrad Wolfram (CBM™, https://www.computerbasedmath.org/). A conceptually new curriculum and digital educational materials were developed for the secondary-level statistics course by experts from Wolfram Research, UK and from the University of Tartu, Estonia. The objective was to make the learning of mathematics more interesting to the students, improve their skills of mathematical thinking as well as improve their abilities to implement mathematical methods to real life situations. It also demonstrates how computers make the learning and real-life use of mathematics more diverse and effective. The project was supervised by the Project Advisory Board, consisting of academic experts, active-duty teachers, and representatives from public and private sectors.

The course includes lesson materials for 60 hours (25 at lower secondary and 35 at upper secondary level), and uses Wolfram software such as Wolfram Language, *Mathematica*, WolframAlpha and CDF-documents (Computable Document Format, usable with free CDF player). The number of hours and the main outcomes of the currently valid state curriculum were taken into account. However, the aims and the learning outcomes of the computer-based mathematics (CBM) curriculum are remarkably broader. Besides the specific mathematical skills, the CBM curriculum strongly aims at the achievement of general mathematics skills and transversal skills.

The new computer-based study materials were first piloted in the spring of 2014 with 40 teachers and more than 1800 students participating. The goal of the pilot was to test the suitability of such lesson materials, as well as analyze the attitudes and readiness to teach and learn in a nontraditional way. During the pilot, the reflections of teachers and students on both the course materials and the new teaching/learning method were examined along with its impact on students' performance.

Currently, the second phase of the pilot is taking place with another 40 teachers participating. The original materials have been improved and additional assignments with the necessary assessment criteria have been provided. Participating teachers have received additional training both in statistics and teaching with computers.

CBM curriculum and learning outcomes

Topics of probability, data and statistics are part of the mathematics curriculum in most countries. In Estonia, data and descriptive statistics are taught as a part of general mathematics courses throughout grades 5 to 9, and as a specific 35-hour math course in upper secondary level in grades 10 to 12. The upper secondary course also includes topics on probability and combinatorics along with the basics of statistical data analysis. Starting in 2011, the upper secondary course was enhanced with new sophisticated topics such as correlation, confidence intervals for the mean and reliability of statistical decisions among others. Students need these skills primarily for completing their own research project, which is mandatory for graduating high school.

When developing the new CBS curriculum, the number of prescribed hours and the main outcomes of the currently valid Estonian curriculum was taken into account. CBS curriculum covers a majority of mathematical concepts represented in the traditional curriculum. In addition, the new CBS curriculum expands upon important segments of working with data – e.g., how to collect reliable data using questionnaires, which data visualization methods to use, or how to estimate uncertainties of the results, etc.

The CBS curriculum supports context-based learning. It comprises of narrative-based modules concerning assorted real life problems. The math concepts and tools are learned in the course of problem solving. For example, in the first module “Am I normal?” students collect data in order to characterize themselves among their classmates. They use visualization techniques to learn about the empirical data distribution and its main characteristics. In an upper secondary module, "How many Estonian words do I know?", students see how, using sampling, they could estimate the number of words they understand in a given language. Doing this, they first learn the basics of parameter estimation, then try to quantify how exact their estimation is (using confidence intervals) and finally estimate the right sample size to achieve the desired margin of error.

The learning outcomes of the computer-based mathematics curriculum are remarkably broader than those of traditional math courses. In addition to acquiring the required mathematical concepts and tools, the outcomes like "Abstracting to mathematics concepts", "Designing and managing computations", "Critiquing and verifying", "Interpreting", "Communicating and Collaborating", etc. would be attained.

The study materials guide students to follow the investigative way of learning (see Fig. 1). A learning cycle includes four steps: the exploration of a problem and asking questions about it; mathematical formulation of the questions; mathematical calculations and visualizations; and lastly, interpretation of the mathematical results in the real life context. Preconditions for building a mathematical model, checking the reliability of the model, and consequences from the uncertainty of results are carefully examined. Hence, thinking about the problems is the priority. The objective is to understand the context, complexity and purpose of what is learned – and make the learning exciting.

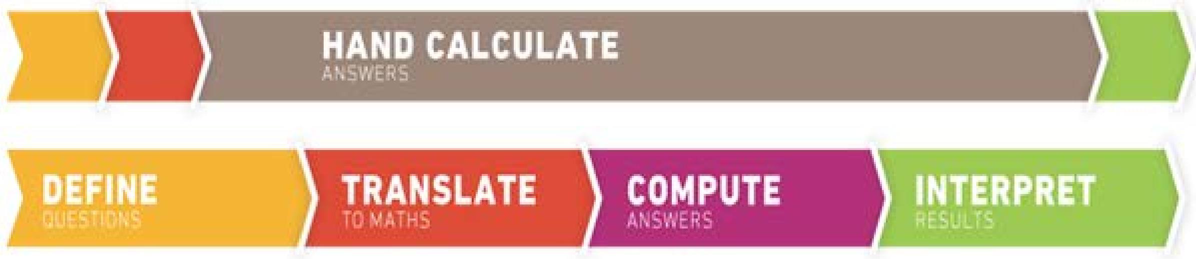

Figure 1. Illustration of the traditional and the CBM learning cycles

There are various learning techniques (modalities) used in the materials to diversify the learning process. Some modalities demand teamwork and cooperation; others support experimentation and creative practical tasks. Miscellaneous information sources and data visualization possibilities enhance interpretation and critical thinking skills, while formulation of written answers and writing essays develop self-expression skills.

Statistical data analysis methods have been advanced along with the development of computers and digital environments. It is natural to apply the concept of CBM at this time into this part of mathematics education. Using computers enables us to decrease the time spent on calculations and other mechanical operations, in order to gain more time for discussion and understanding. Using both students' own data and data from the internet enables us to reinforce the learners' interest in the subject and compose broader context around mathematical solutions.

Another goal of CBM is to embed programming into the mathematics education. The Wolfram language enables to implement calculations and sophisticated visualizations by short coding exercises, which is one of the means for making the CBM learning more efficient. The programming exercises included in the lesson materials will introduce students the possibilities of computerized mathematical modelling.

Digital lesson materials and learning process

The lesson materials were primarily created for regular school-based learning process where the teacher and the students are in the same classroom. Everyone has to use a computer with an internet connection. The lesson materials enable both digital communication between students and their teacher, as well as traditional verbal communication in the classroom.

Teacher's and student's materials have different screen views, whereas the teacher can also see student's view and show it on a screen. In addition, teacher's materials include ideas for activities, technical tips, recommendations for teaching, problem introductions, and (when available) the right answers to the questions. Both the student's and the teacher's materials have links to the theory files. The theory files are separate documents resembling Wikipedia articles. The theory files create theoretical background for the entire set of materials.

The lesson materials guide students to implement the consecutive steps of problem solving, illustrated in figure 1. Students can send their answers and opinions to their teacher, who can then summarize the student's answers, and give immediate feedback to the whole class. The teacher's main role is to direct the student's learning. Teachers should keep a balance between the context of the problem and the mathematical concepts needed to solve the problem.

The digital lesson materials have been created for a use in the Wolfram's *Mathematica* software environment and can be opened from a dedicated CBM menu. The lesson materials are also available as the Computable Document Format files (CDF files) applicable with the free CDF player. The materials in CDF-format enable all the interactivity described above; however, they cannot be changed without *Mathematica* software and one cannot complete the programming activities provided within the materials. Nevertheless, thanks to the innovation of Wolfram technologies, the new CDF-format materials now enable the programming exercises to be completed in the Wolfram cloud.

Teacher feedback

Each school in Estonia had an opportunity to volunteer for participation in the computer-based statistics project. The project leaders selected the schools who participated to be a representative sample of Estonian schools in terms of their sizes, location and previous performance on state math exams. Participating teachers were involved in the project starting at the very beginning of the first version of materials, and they received around 100 hours of training before piloting these new materials. The training included familiarizing the teachers with the CBM concept, discussing and practicing lesson materials, teaching with computers, and learning to program in the *Mathematica* language. In-depth training helped them to adopt the innovative educational approach, and conduct the pilot with high proficiency.

Throughout the pilot, all teachers continuously reflected upon the piloting process by sharing their experiences in the online forum, and filling in the questionnaires about learning activities and modules (Hommik, C. & Hoim, T., 2015) In return, they received technical and educational support from the project leaders and technical staff.

One vision behind the CBM curriculum is that all learning should take place in real-life context to be more meaningful and motivational for the students. This goal was well achieved and teachers appreciated that topics and tasks were creative, practical and in a real-life context. They also mentioned that this approach facilitated discussions with students in the classroom. However, some teachers were concerned about "learning too little mathematics". Their concern might have been focused around the state exams, since the CBS course does not drill typical tasks and definitions asked on the state final exams. Several teachers noted the lack of post lesson assessments, saying that by not having these assessments, it was difficult for them to get an overview of how much students had learned and how to grade them accordingly. To address this concern, the new version of CBS materials is now supplemented with extra practice problems at the end of each module. The first pilot also revealed the need for additional teacher training about contextual learning and application of statistical methods.

All participating teachers adjusted well to computer-based teaching owing to the teachers' overall positive attitude and experience of teaching mathematics with computers. The majority of Estonian math teachers use internet resources and specialty educational programs such as GeoGebra, Wiris, or the spreadsheet programs in their lessons. Participating teachers were able to overcome any technical difficulties in due course, and consistently maintained a positive opinion about technology-based teaching. The overwhelming majority of the teachers expressed their willingness to teach in the future with the CBS materials or combine CBS approach with the traditional curriculum. However, it also came out that they would prefer to have only half of the CBS lessons in the computer class. The reasons for this opinion are not clear yet, but hopefully the currently ongoing second pilot will clarify some of these questions.

Student feedback

The results of the first pilot showed that students assessed the new teaching approach and the learning materials highly. Various visualization possibilities, interactive charts, computer based learning, practical and realistic tasks, possibility to work in groups, and gaining new interesting knowledge were the issues more frequently mentioned as highly liked about the course. Interestingly, a smaller group of students marked the same items as disliked ones. The technical problems, working with charts, level of difficulty of the material, too much verbal reasoning, no new (mathematical) knowledge gained were mentioned as the most disliked aspects. The opposing opinions about these issues exhibit the diversity of attitudes towards innovation among students.

Similar to their teachers, student answers also revealed the imbalance between gaining the mathematical skills versus the context-based skills. Students thought that in the CBS lessons they mostly learned about the context-related issues (e.g. how happy are people in various countries), and did not clearly perceive the acquisition of mathematical concepts and procedures. Nevertheless, they successfully used those skills in the final test.

Students' attitudes and performance were measured before and right after the course. Students turned out to be more confident in their skills and more positive about their feelings (e.g., competence) when applied to statistics once they attended the CBS class. Tests given demonstrated improvement of knowledge and skills in both groups, the CBS group and the reference group taught in a traditional way. Unfortunately the final test administered at the end of the course paid insufficient attention on the extended learning outcomes and transversal skills achievable by CBM method and rather assessed the traditional mathematical skills. The final test results of the two groups were nearly the same (at 5% significance level) regardless of the fact that the CBS students enjoyed minimum workload as there was no homework and the course assessment was very liberal (mostly formative assessment in the classroom). It is therefore worthwhile to mention, that the CBS pilot group students achieved the same test results with less time spent on learning.

Only a small percentage of students (around 5%) were willing to tackle the programming exercises included in the lesson materials during the first pilot. Thus, only the most innovative students tried programming as a part of the statistics course. The most obvious reason could be that there was "too much innovation at once". Teachers also didn't emphasize programming because they already had to assimilate an entirely new teaching process. Since the context based learning is quite time-consuming, the average students did not have sufficient time for additional programming exercises. However, it is necessary to go on with the idea, and search for new ways to motivate students to link mathematics with programming.

Summary and conclusions

We believe that the CBM concept and the ongoing CBS project in Estonia are important first steps towards increasing the efficiency of mathematics education and improving application of mathematics in real life using digital resources. The CBS project has created a new curriculum and lesson materials, and tested their implementation in real school situation. The process has revealed a number of important issues, worthy of further discussion and research.

All participants in the project have praised the CBM approach, which enables mathematics education to evolve in line with the changes in the world around us. Teaching of data and statistics by computers is a natural step in math education and provides students with necessary skills for successful working in modern-day professions. The digital *Mathematica* environment facilitates efficient understanding of mathematical concepts by using data, formulae and visualizations. The various methodological tools (such as inquiry, experimentations, self-tests, strategy choosing, verbal reasoning, convincing, essay writing, etc.) support diversity of learning outcomes and develop both the mathematics and transversal skills.

In contrast to the traditional teaching, the CBS course places the mathematical tools into a broad context. It introduces different stages of the statistical problem solving process starting from data collection and verification, moving on to strategy selection and ending with the mathematical reasoning and contextual interpretation. Along with it, the CBS project brought up important curriculum issues concerning the role of context-based learning in mathematics. The following questions would emerge: Is it possible to acquire good mathematical skills in a problem solving course? What prerequisites in mathematics should students have for a successful contextual learning? What teaching methods would achieve the balanced outcomes in both the mathematical skills and contextual understanding? How to fit the more time-consuming contextual learning into the existing curriculum?

In a broader perspective, the question about the placement of the data and statistics course in a school curriculum is also worthy of discussion. Should the computer-based statistics course be a part of a math curriculum? Would it be reasonable to introduce an independent statistics course servicing the STEM but also the social subjects?

Overall, the teachers and students liked the CBM approach and the new interactive lesson materials. However, the generally positive attitude varied, depending on the lesson's theme, participating school and person. Most of the dissatisfaction of teachers was caused by different requirements in the valid curriculum and assessment compared to CBS. Fluent innovation in education assumes simultaneous changes in the curriculum, teaching methods and assessment. The inappropriate assessment criteria would remarkably lower the effect of innovative learning and teaching.

Piloting also helped to determine the requirements for technical equipment and support for CBS teaching. Good internet connection and up-to date server connections are crucial for teaching CBS at schools. The participating schools coped well with the installation of lesson materials in their schools. However, different operating systems with different versions caused additional complications. Ideally, the lesson materials should be accessible over the internet, which would decrease the need of technological support to schools.

Feedback from both the teachers and students will be taken into account for further development of the materials. The program advisory board has given their positive recommendation for step by step advancement with the CBS teaching materials to all schools in Estonia. The transition to using CBS in all schools will not be a quick process due to the fact that, in general, it is hard to give up long-time beliefs and values of traditional teaching and learning. In addition, the implementation of CBS will also require financial commitment to invest into school's infrastructure and well-functioning teacher training program.

The results from the first pilot indicate that computer-based learning was a success and necessary first step on the road of innovating classroom mathematics education overall. The currently ongoing second pilot is testing the improved course materials along with the post lesson assessments and additional mini-projects.

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