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ABACUS, ITS HISTORY AND FUTURE PLANS

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2019

Introduction

- **What is STACK?**
  An open source platform for implementing automatically assessed mathematics exercises featuring algebraic and graphical input.

- **What is Abacus?**
  A joint project of higher education institutions for creating a database of royalty free high quality STACK assignments.

Integrate

$$\int_0^1 x^2 \sqrt{x^3+7}\ \mathrm{d}x$$

using the substitution $u = x^3 + 7$.

$\mathrm{d}u =$ [ ] $\mathrm{d}x$

The new lower limit: [ ]

The new upper limit: [ ]

$\int_0^1 x^2 \sqrt{x^3+7}\ \mathrm{d}x =$ [ ]

Abacus in a nutshell: Project aims

- Developing a set of standard, ready to use STACK-based problem assignments for mathematics and physics.
- Materials are designed by experts, fully tested and maintained.
- Teacher does not need to become a software developer.
- Users have full control of the content and underlying software platform.
- Teachers are allowed to make and share changes.
- Institutions are not tied to a single supplier.

Abacus in a nutshell: Collaboration

- Abacus started as a Finnish project, but was designed for extensive national and international collaboration from the start.
- The goal is to further reduce cost and speed up development of the platform through expanding its user based.
- The main cost is in programming and pedagogical development – translations are relatively easy.
- Standard open source models are not well-suited as source code of assignments can be shared between teachers but should not be seen by students.

Abacus in a nutshell: The initial consortium

- Abacus was started in 2015 as a consortium of the seven Finnish technology universities (universities which have a graduate level program in engineering).
- Initial focus on undergraduate level engineering mathematics, building heavily on experiences from my project MatTa at Aalto University.

Aalto-yliopisto
Aalto-universitete
Aalto University

LUT
Lappeenranta
University of Technology

OULUN YLIOPISTO
UNIVERSITY of OULU

TAMPERE
UNIVERSITY OF
TECHNOLOGY

Åbo Akademi

Vaasan yliopisto
UNIVERSITY OF VAASA

Turun yliopisto
University of Turku

National collaboration in Finland

- Abacus was designed from the start to allow seamless integration of new partners.
- First partners to join were existing STACK users University of Helsinki and Metropolia University of Applied Sciences.
- Since then, the consortium has expanded to cover almost all STEM higher education in Finland.
- We are working to integrate high schools to the project as well through Extended Abacus (EMPA) initiative.

HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

VAMK
VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES

UNIVERSITY OF JYVÄSKYLÄ

HAMK
HÄMEEN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES

TAMK TAMPEREEN AMMATTIKORKEAKOULU

UNIVERSITY OF EASTERN FINLAND

Metropolia

LAMK
Lahden ammattikorkeakoulu
Lahti University of Applied Sciences

JYVÄSKYLÄN AMMATTIKORKEAKOULU
JAMK UNIVERSITY OF APPLIED SCIENCES

International partners

- Abacus is open to partners from any country.
- We accept materials in any language, although the goal is to have English versions of all materials available.

THE UNIVERSITY of EDINBURGH

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

ІВАНО-ФРАНКІВСЬК НТУ

UNIVERSITY OF AGDER

Julius-Maximilians-
UNIVERSITÄT WÜRZBURG

TARTU ÜLIKOOL
1632
UNIVERSITAS TARTUENSIS

GMIT
INSTITIÚID TEICNEOLAÍOCHTA NA GAILLIMHE-MAIGH EO
GALWAY-MAYO INSTITUTE OF TECHNOLOGY

RUHR UNIVERSITÄT BOCHUM
RUB

NTNU
Norwegian University of Science and Technology

TALLINNA TEHNIKAKÕRGKOOL
TTK UNIVERSITY OF APPLIED SCIENCES

EPF
GRADUATE SCHOOL OF ENGINEERING

IPL
instituto politécnico de leiria

Future goals of the consortium

- Developing a database of stable, high quality materials for undergraduate level in mathematics and physics.
- Expanding the consortium to cover major STACK user countries to expand the user base and general brain share.
- Extending collaboration to secondary education.
- Spreading STACK into new geographic areas such as Asia.
- Helping STACK to become the internationally leading software platform for e-assessment in mathematics and related fields through expanding the user base and speeding up its development.

Why do we need STACK and Abacus?

- Digital education is coming: Be prepared!
- Higher education cannot be based only on commercially produced, pre-canned materials.
- A professor needs to be the pilot, not a passenger.
- Universities need an open source, royalty free platform that allows them to keep the control and avoids becoming a cash-cow for companies controlling IPR of the platform.
- Digital education is not only about cost savings and distance learning: Its quality has to match or exceed traditional solutions.
- Success of the platform depends on users and materials.

Strengths

- Free and open source platform is attractive to many potential partners.
- Integrates to the popular Moodle platform, which also allows seamless integration to institutional tools.
- Much more advanced features than the competition including:
  - Randomization of assignments
  - Handling of algebraic input
  - Advanced visualizations
  - Visual input types
  - Support for non-English and multi-lingual content

Where we need to improve

- STACK still has a user base that is small for sustainable long term development.
- STACK plugin is difficult to install without specific experience and lacks sufficient documentation.
- Mistakes in installation may lead to performance problems and loss of functionality.
- The required time and effort to get started with the platform is still too high.
- Support for multilingual content is complicated to use and sometimes unreliable.
- Integration with mobile technologies is not perfect.

Opportunities

- Becoming the “industry standard” platform for the purpose
  - This is not an impossible goal in particular what comes to the higher education where the market is too small be attractive to for-profit companies and very splintered because of language and curriculum requirements.
- Fostering overall spread of free/open digital learning solutions and resources.
- Advancing level of digital learning solutions and use of automation STEM education in general.
- Quantitative study of learning processes and other advanced questions in teaching mathematics by using data analysis and big data techniques.

Risks

- Low quality materials and solutions damage the reputation of the platform.
- Other platforms will emerge in future and competition will become tougher.
- The market probably is not sufficient for more than one popular solution.
- Any technologies will eventually become obsolete: The platform needs to continuously develop in order to remain attractive.

Extended Abacus Material Bank: EMPA

- Since Abacus was introduced, there has been discussion about using the STACK platform in high school level mathematics education as well.
- Some Finnish high schools have been using STACK for more than five years.
- The problems here have been that STACK is not available in high schools (who typically do not use Moodle or maintain in-house learning platforms) but also lack of suitable materials.
- Recently, we received a very large donation of high school mathematics materials from Eira High School (City of Helsinki) developed with Finnish government funding.

Pedagogy: Motivation

- In general, one should not expect new technologies to be straight-forward improvements over existing solutions.
- That is, always when established technologies and approaches are replaced with new ones, the new solution tends to do something much better than the old one, but typically not everything.
- Therefore, one should look for approaches where advantages of the technology are utilized to the maximum extent and shortcomings do not play a significant role.
- We discuss creative uses of automatic assessment in view of this analysis to overcome the perception that it is only a system for drilling technical computation skills.

Pedagogy: Conceptual understanding

- The ontological nature of mathematical objects is a well-known philosophical question.
- From a strictly formalist point of view, mathematical objects do not have any meaning or interpretation beyond that as symbols and the role they play in certain axiomatic structures such as the set theory.
- However, for learning and understanding mathematics it is helpful to learn to interpret mathematical objects through certain intuitive examples and real world situations.
- This topic is hard to teach through traditional methods since there is no one-to-one correspondence between objects and their interpretations.

Teaching conceptual understanding

- The idea in using automatic assessment to teach conceptual understanding is to automatically generate large collection of assignments where the mathematical concept appears or does not appear.
- The task given to students is to recognize the situations where the concept is present and distinguish them from ones where it is absent.
- Assignments like this may be of multiple choice type, just making use of STACK as a visualization tool and means of generating randomized assignments.
- However, they can also make use algebraic and graphical input types.

Example: Matrix equations and geometry

Let's solve the system of linear equations

$$\begin{cases} -6 \cdot x_1 - 5 \cdot x_2 = -2 \\ 12 \cdot x_1 + 10 \cdot x_2 = -4 \end{cases}$$

using Gaussian elimination. First transform the system into matrix form $\mathbf{Ax} = \mathbf{b}$ where $\mathbf{A}$ is the coefficient matrix, $\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$ and $\mathbf{b}$ contains the constant terms on the right side of the equations.

Input the augmented matrix $[\mathbf{A}|\mathbf{b}]$ as the first intermediate step:

$$\begin{bmatrix} & & \\ & & \end{bmatrix}$$

Next compute the reduced row echelon form of the augmented matrix using row operations. Input the resulting matrix $\mathbf{rref}\,[\mathbf{A}|\mathbf{b}]$:

$$\begin{bmatrix} & & \\ & & \end{bmatrix}$$

From this matrix we can deduce the amount the solutions to the system and the solutions themselves. Input the number of solutions to the system. If there are an infinite number of solutions, input **inf**.

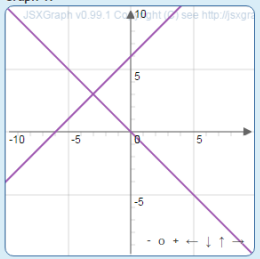
Check

Every pair of equations can be geometrically interpreted as a graph of two straight lines. Here we have four pairs of equations and four graphs. Connect each pair of equations to the correct graph.

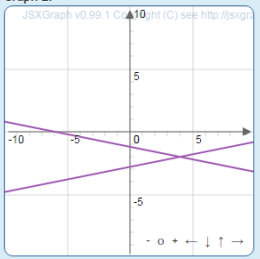
a) $\begin{cases} 8 \cdot y - 8 \cdot x = 48 \\ 2 \cdot x - 2 \cdot y = -20 \end{cases}$ b) $\begin{cases} -5 \cdot y - x = 6 \\ x - 5 \cdot y = 14 \end{cases}$

c) $\begin{cases} 2 \cdot x - 2 \cdot y = -12 \\ -2 \cdot y - 2 \cdot x = 0 \end{cases}$ d) $\begin{cases} -2 \cdot y - 2 \cdot x = 0 \\ -10 \cdot y - 10 \cdot x = 0 \end{cases}$

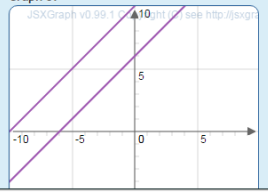
Graph 1:



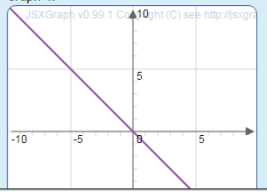
Graph 2:



Graph 3:

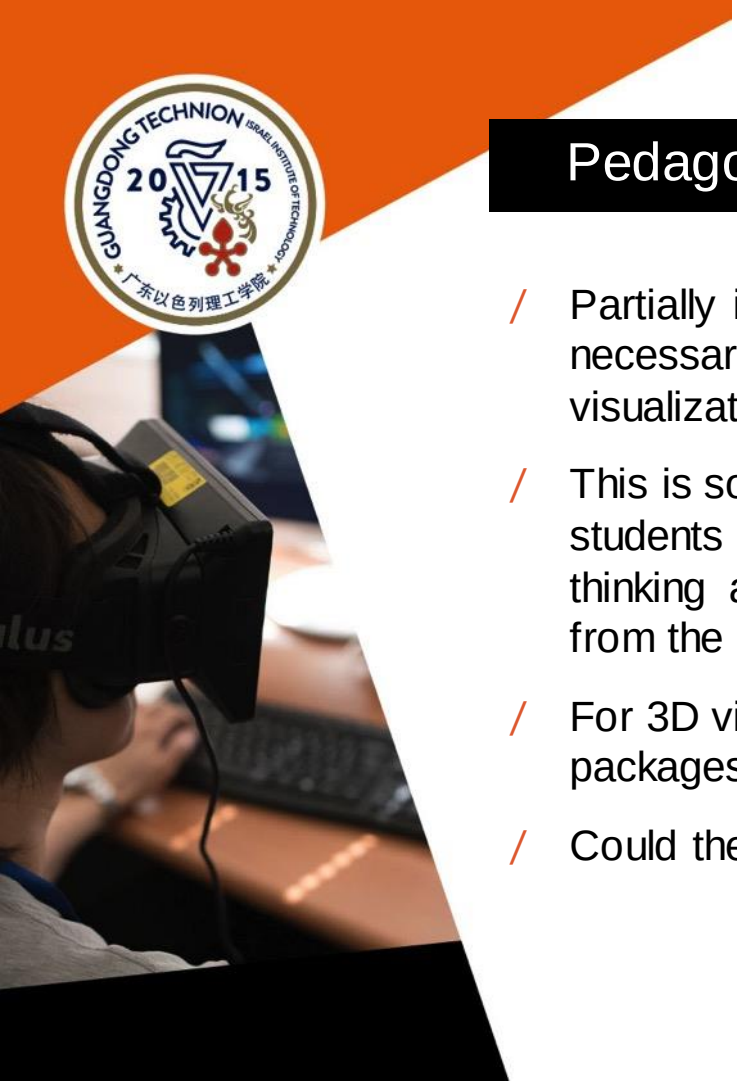


Graph 4:



Conceptual understanding: further discussion

- Conceptual understanding is challenging to teach, in particular in a classroom environment with a large number of students (as opposed to 1-1 mentoring) and when the starting level is low ("mathematics is only calculations").
- Therefore, there is a lot of potential for use of online learning environments in this topic. For example, one could make assignments related to
  - Choice of deltas and epsilons in limits and continuity
  - Curves in continuity of multivariable functions
  - Various topological properties like boundary points, accumulation points, open/closed sets, etc.
  - Classification of extremal points
  - Various problems in linear algebra



Pedagogy: Advanced visualizations

- Partially in relationship to the previous topic, it is necessary to connect symbolic mathematics to visualizations of ideas for building student intuition.
- This is something that becomes clear when working with students from mathematical traditions where conceptual thinking and topics like analytic geometry largely missing from the school curriculum (unlike Finland).
- For 3D visualization, there are some great existing packages like MathBox.js.
- Could these be connected to STACK?

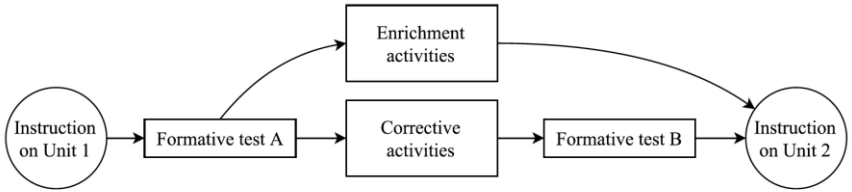
Pedagogy: Mastery learning

- Mastery learning (ML) is an approach developed to Bloom in an attempt to find classroom teaching methods that are as efficient as 1-1 teaching.
- This question is known in literature as Bloom's 2-sigma problem, meaning that 1-1 teaching yields two standard deviations better learning outcomes than usual 1-30 classroom arrangement.
- Bloom found that so-called Mastery Learning arrangement (that uses frequent formative testing and corrective measures to ensure that nobody will drop out) can improve learning outcomes by one standard deviation.
- Obviously, automatic assessment can be used here.

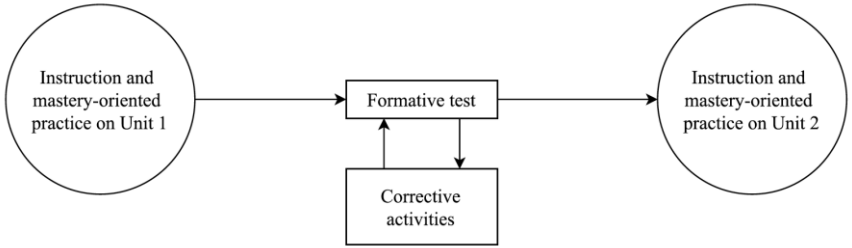
Mastery learning: Piloted model

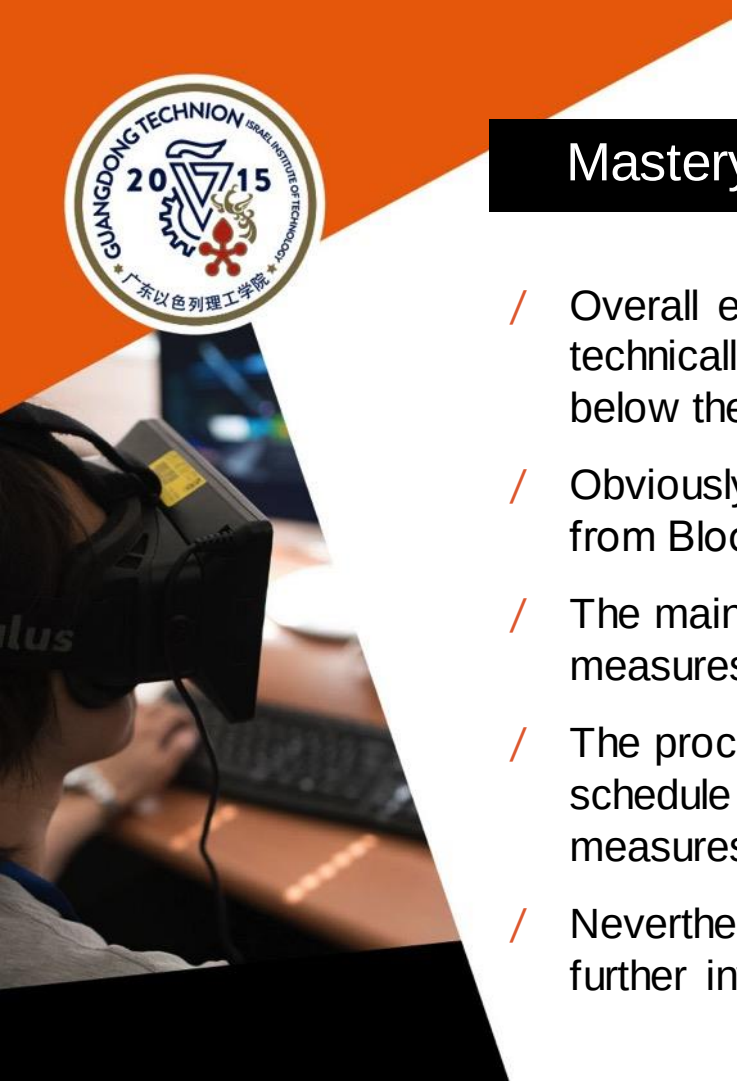
- We made an experiment at Aalto University, where we tested suitability of STACK for the purposes of implementing formative tests and corrective measures.

Bloom's LFM



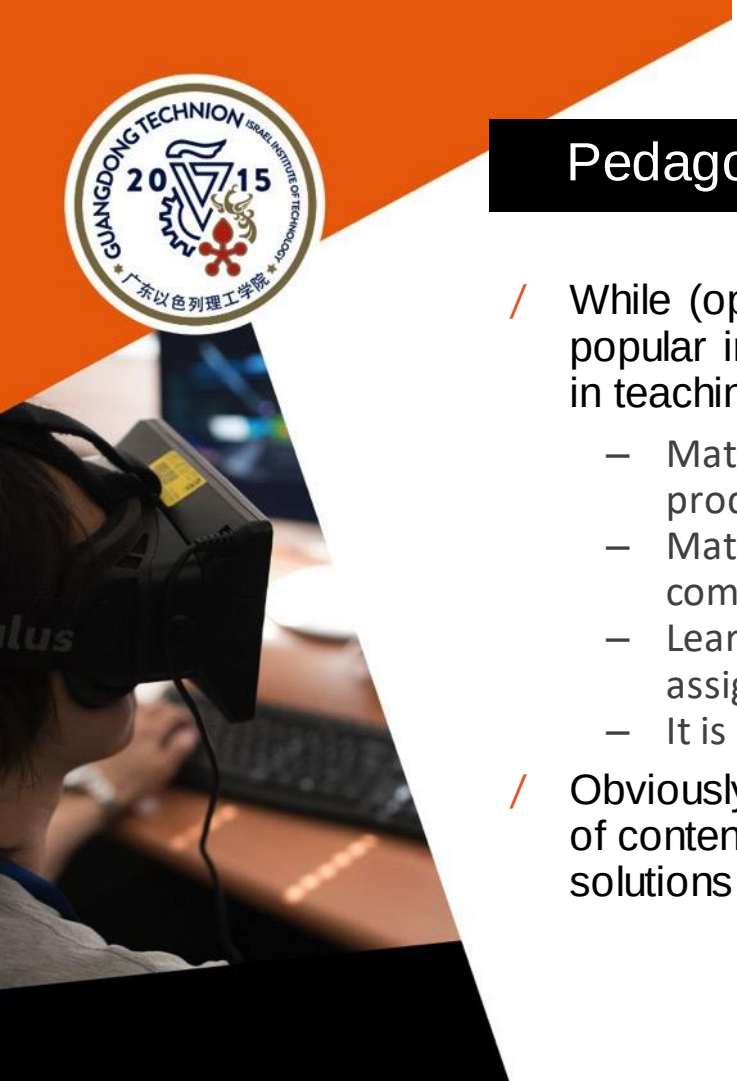
Piloted model





Mastery learning: Discussion

- Overall experience was that the arrangement worked technically, and yielded some positive results (albeit much below the level of improvement reported by Bloom).
- Obviously, the piloted model was substantially simplified from Bloom's original.
- The main issue here seems to be that the corrective measures were not sufficient for reaching true ML.
- The process would probably be more efficient if the course schedule was more flexible (more time for corrective measures to take effect).
- Nevertheless, this is a promising approach that is worth of further investigation.



Pedagogy: Online courses

- While (open) online courses have become increasingly popular in various topic, there are several known difficulties in teaching mathematics online. In particular:
  - Mathematical symbols and notations are difficult to produce in popular online environments.
  - Mathematical text is not always convenient to read from a computer or mobile phone screen.
  - Learning mathematics is based on solving exercise assignments that need to be implemented online.
  - It is usually necessary to arrange exams for the students.
- Obviously, these difficulties become worse when the level of content goes up to the university level, where advanced solutions are needed.

Online courses: Implementation

- Since 2009, we have implemented several on-line courses on mathematics:
  - Introductory university mathematics on-line course ABC – Approach to Basics of Calculus in collaboration of Aalto University and Bavarian Virtual University VHB
  - Open online Matrix Algebra course (in Finnish) as a part of the Aalto Online Learning (A!OLE) initiative.
  - Partially open online course Single Variable Calculus (in Finnish, English and German) as A!OLE/VHB collaboration.
  - Finnish-Chinese online course on use of differential equations in mathematical modeling.
- Automatic assessment with STACK has played a key role in all these courses except the last one, with Matrix Algebra reaching about 90% level of automation.

Online courses: Discussion

- Online courses have a clear need and implementation is relatively straightforward by using Moodle, STACK and vide lectures.
- There are several clear needs and advantages:
  - Opening university courses to students that cannot participate regular lectures, tutorials, etc.
  - Allowing dropouts to complete their degree.
  - Providing window to higher education for high school students and their teachers.
- However, there are still some issues to be addressed:
  - Moodle is not a very attractive environment for producing online textbook style resources.
  - Exams are a major bottleneck (in Finland, there is a project called EXAM that provides a partial solution to this).

International aspects

- Since relocating to Guangdong Technion at Shantou, China, I have observed first hand certain challenges in starting to use STACK and Abacus materials.
- I believe this is something we need to overcome for STACK and Abacus to realize its full potential.

STACK at GTIIT: Technical observations

- One of the core strengths of Aalto University and other Finnish universities I collaborated before had been readily available in-house technical expertise.
- Indeed, this was the key reason why we started to play with an open source solution at Aalto University in the first place, after finding that none of the available software provided exactly the functionality we wanted.
- However, at GTIIT this is not really the case, as our Moodle installation is provided by an Israeli company OpenApp and the local people are only able to do basic maintenance.

The role of the teacher

- The key question here really is what should be the role of a teacher in use of automatic assessment.
- One solution is that everything is provided by a commercial entity, teacher merely “serves” “pre-canned” content.
- This leads to unwanted side effects like excessive cost and lock-in. It is also against academic ideals and traditions.
- Another extreme is that the teacher needs to become software developer, to maintain own servers, etc. This is usually not feasible because of time and other constraints.
- The ideal solution is somewhere between; this is what I have been trying to achieve with Abacus.

User perspectives

- STACK/Moodle integration and testing with mobile devices is less than perfect at the moment. In China (and the rest of Asia), this is a problem as the most students want to use STACK with a mobile phone.
- Multilingual content is a big strength but its also somewhat problematic because it requires installation of an additional module and works unreliably. It is unnecessary for institutions teaching only in one language and often makes the assignment core rather unreadable.
- JSXGraph is another great addition, but it is difficult to get working and integration is not well undocumented.

What we need (an opinion)

- A website and support forum for STACK, including use and installation. Information about the system should also be included into Wikipedia, etc.
- A book or a comprehensive set of online manuals for teachers and students (cf. the Finnish language manuals from the University of Oulu).
- Some re-branding to make searching STACK related content easier? For example, “E-assessment system STACK”.
- A tool to remove unwanted languages from problem assignments. A simple Python script would do?
- Ability to plot 3D surfaces and contours.

Main references

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- A. Rasila: E-Assessment Material Bank Abacus. 8th International Conference on Education and New Learning Technologies 4th-6th July 2016, Barcelona, Spain. *EDULEARN16 Proceedings*, 898-904.
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