X World Conference on Computers in Education
July 2-5, 2013; Toruń, Poland

Learning Mathematics Using ICT in Pre-service Teacher Education

Christine Bescherer, *bescherer@ ph-ludwigsburg.de*
University of Education Ludwigsburg, Reuteallee 46, 71634 Ludwigsburg

Marc Zimmermann, *zimmermann01@ph-ludwigsburg.de*
University of Education Ludwigsburg, Reuteallee 46, 71634 Ludwigsburg

Abstract
ICT in mathematics teaching at schools and at universities is still not 'normal'. In this paper we present a 'holistic' concept to get pre-service mathematics teachers to use ICT as tools for 'doing mathematics'. These learner activating teaching scenarios were introduced at the University of Education in Ludwigsburg in 2008. The evaluation shows a significantly higher increase of mathematical self-efficacy expectations in this group of students than in groups from other universities. Regarding mathematical skills no differences between the two groups can be detected.

Keywords
mathematics teacher education, semiautomatic assessment, activating learning scenarios

INTRODUCTION
There are countless programmes and projects furthering the use of ICT in mathematics learning and teaching at schools as well as at universities. Educational standards and mathematics curricula all over the world declare the use of ICT in mathematics classrooms mandatory. 13 years ago the National Council of Teachers of Mathematics states "technology" as one of the six Principles for School Mathematics (NCTM, 2000, p.11). But still cohorts of mathematics teachers leave universities without being convinced that learning mathematics using ICT is a success story. Consequently these teachers avoid using ICT in their mathematics classrooms (Jancarik & Novotna, submitted; Lagrange, Artigue, Laborde & Trouche, 2003).

Traditionally mathematics is taught at universities in big lectures at some universities with up to 1000 students – accompanied by self-studies and tutorials where students present solutions of the weekly worksheets (Holton, 2001; Thomas & Holton, 2003). During the written exams the use of IT and often even of calculators is forbidden.

There are several reasons for this: One is the tradition of learning mathematics to 'do it first by hand'. Further, in mathematics lectures usually the 'published mathematics' is presented to the auditorium. Meaning mathematical topics, definitions, theorems, proofs, and examples are not presented in a way to recapitulate the history of discovery or the mathematical processes necessary solve the problems but in an 'elegant' and very concise form. And for this kind of presentation IT is only needed as a presentation tool and not as a thinking tool (Bescherer, 2009). Even in lectures of analysis or geometry, where universal tools like a computer algebra system (CAS) or a dynamic geometry software (DGS) can be easily used, mathematics educators use them in a very limited way (Jancarik & Novotna, submitted).

Then there is the technical problem how to ensure that during exams all students use the same software and have no access to help from outside if they are allowed i.e. to use laptops during an exam. (For some good ideas on how solve these problems see the ideas of 'e-exams' by Andrew Fluck, cf. Fluck, 2010.)

In the project SAiL-M we combined activities on different levels always with a 'natural' use of ICT.

SAIL-M – SEMIAUTOMATIC ASSESSMENT OF INDIVIDUAL LEARNING PROCESSES IN MATHEMATICS

The project SAiL-M (Semiautomatic Assessment of Individual Learning Processes in Mathematics) funded from 2008 – 2012 by the German Federal Ministry of Education and Research (BMBF) was part of a programme for 'professionalization of teaching at universities'. The main goal of the project SAiL-M was the development of models to improve the quality of teaching mathematics in early semesters. To reach this goal activating learning environments for mathematics at university were formulated, implemented, and published using pedagogical design patterns (Bescherer & Spannagel, 2009, Bescherer, Spannagel & Zimmermann, 2012, Bescherer, Spannagel, Zimmermann, Hoffkamp & Moll, 2012 or online at http://sail-m.de/sail-m/SAiL-M_en, retrieved 1/12/2013). To deal with the conflict between large numbers of students attending classes and supporting individual learning processes ICT-based tools for the assessment of learning processes – i.e. tools for the documentation and analysis of processes were adapted, developed, implemented and evaluated.

Activating learning scenarios in pre-service mathematics teacher education

At the University of Education in Ludwigsburg about 75% of the students are in teacher study programmes either in primary education, lower secondary education or special education. So all mathematics courses include relations to teaching mathematics in schools – either addressing specifically pedagogical content knowledge or 'elementary mathematics from a higher viewpoint' (c.f. Krauss, Neubrandt, Blum & Baumert, 2008).

The changes in the learning settings for introductory mathematics courses concerned the lectures itself, the accompanying tutorials and the form of the written exams. An overview over the measures taken is shown in Figure 1.

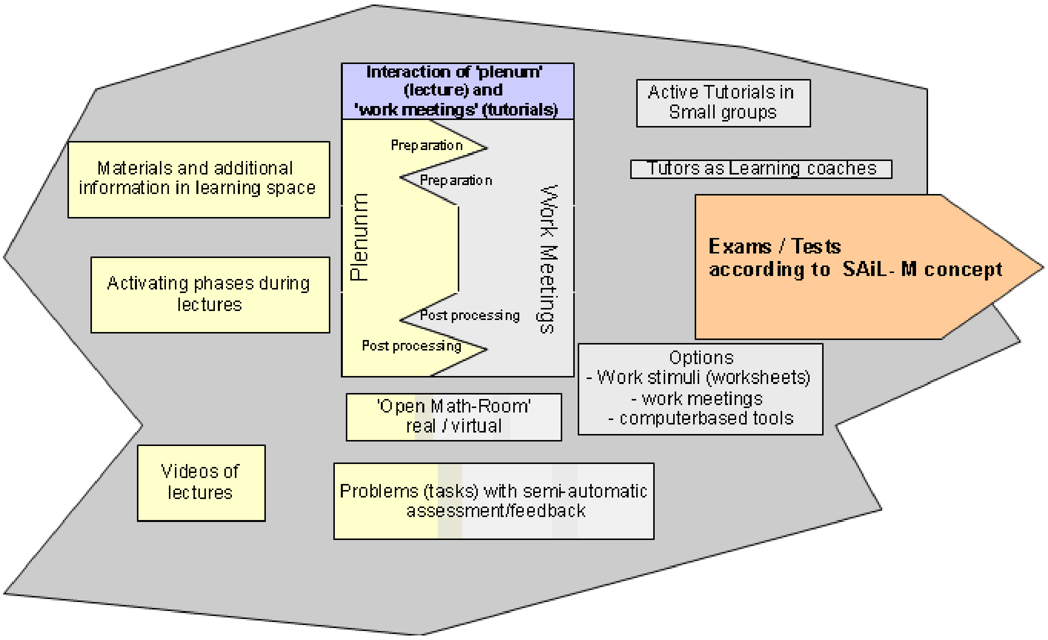

Figure 1: Leaner activating measures taken in the project SAiL-M

Some details of these measures are given here:

- The lectures included ‘active phases’ where students worked for about 10 minutes individually. The ideas / solutions/ … were then discussed in the ‘plenum’.
- The weekly worksheets consisted of three different types of problems: ‘preparation problems’ where students could gain experience with or ideas for mathematical properties or correlations. These individual experience and ideas were formalized in mathematical definitions or theorems in the following lecture. Whereas the usual ‘problem solving task’ addressed the application of content presented in the previous lecture. The third type of problems dealt with more technical skills required to solve mathematical problems like transformations, geometrical constructions or proofs,.... These were often supported by the semi-automatic tools described below.
- The ‘open math-room’ offered an additional support for students during the week. It consists of a room with text books, computers, … and tutors to support the learning processes open to everybody.
- The written exams were changed. To allow students some autonomy 10 problems were given out of which students had to choose five to submit at the end of the 90-minute-exams.

More details and other measures can be found online at http://sail-m.de/sail-m/SAiL-M_en, retrieved 1/12/2013.

Technology enhanced learning scenarios in university mathematics education

Following the idea that using ICT in teaching mathematics should not be an ‘add on’ or ‘nice to have’ but as a matter of course in learning mathematics ICT was used nearly in every context throughout the SAiL-M concept except during the exams where no communication tools like mobile phones or laptops were allowed due to legal reasons. Beyond the – not very exciting – offer of all materials (slides, links, additional reading,...) via our learning management system Moodle more e-learning components such as videos of the weekly lectures, discussion forums, a virtual form of the ‘open math-room’, Twitter, etc. were used to support the students.

The use of these offers was not mandatory, according to the ‘on demand’ – principle (Bescherer, Spannagel & Zimmermann, 2012; Eisenberg & Fischer, 1993) students could decide for themselves whether they use ICT or not. (‘On demand principle’ means that students get help or feedback, if and when they ask for it and not in advance. Basically this means that teachers don’t solve the students’ problems before the students even have the problem. – Of course in educational settings the ‘demand’ can also arise from given tasks by teachers.) Further they could – if possible – choose among different software or technologies. Even the tasks using the specially developed computerized tools with semi-automated assessment were optional (Bescherer, Herding, Kortenkamp, Müller, & Zimmermann, 2011). But the skills which could be trained using these tools were necessary to pass the exams.

ICT in lectures and weekly tutorials

Students working on their weekly problems were supposed use different tools (spreadsheets, DGS, CAS …). Therefore, the given tasks had to be complex enough in a way that using ICT is helpful either to test ideas, to do difficult and time consuming calculations or … For example, to proof or to disprove a given proposition some examples had to be generated first. The worksheets included suggestions of learning and process strategies for each problem. They also contained information of possible use of ICT, in particular the use of software (spreadsheet, CAS, DGS, online sources, applets ...). Students were encouraged to bring laptops to the tutorials to use it when needed (‘technology on demand’, Bescherer & Spannagel, 2009).

Prototypical tools for semi-automatic assessment

Besides the use of software such as spreadsheets or DGS in the weekly tutorials specific tools for practicing mathematical skills with individual feedback were developed as part of the project SAiL-M. All these tools are based on the intelligent assessment approach (Bescherer, Kortenkamp, Müller & Spannagel, 2010. Students work individually on their tasks and get feedback – on demand. Since the tasks are implemented as computer based tools the feedback for standard solutions and 'expected' mistakes can be given by the computer. And 'non-standard' solutions or errors which cannot be automatically identified are passed on to human tutors. These tutors also get automatically the status quo of the solution process documented within the tools so they can reconstruct what was done up to the demand for feedback. The evaluation and optimization of all these tools are part of several ongoing doctoral theses. Detailed descriptions and first research results can be found in the papers mentioned with each tool. (Some of the tools are translated into English and can be explored online at http://sail-m.de/sail-m/Software_en, retrieved 1/12/2013.)

During the project SAiL-M the following tools were developed:

ColProof-M (Herding, Zimmermann & Bescherer, in press) is a tool for guiding students performing geometric proofs following the method of 2-column proof (Herbst, 1999). The learner can drag and drop given statements into a proof-table and choose reasons why the selected statement is valid. An interactive illustration realized by the DGS Cinderella (Richter-Gebert & Kortenkamp, 2012) helps to understand the statements. According to the 'on demand' – principle, the student can check his solution or parts of it for errors whenever he wants . If ColProof-M cannot give automatic feedback a tutor is asked for individual feedback (Bescherer et al., 2011).

ComIn-M: The e-learning application ComIn-M (Rebholz & Zimmermann, 2011) is a web-based learning tool that allows students to practice proofing by complete induction. From a list of available tasks, the learner first selects one task. An electronic spreadsheet opens in which the necessary proof steps must be insert. Every aspect of the proof can be checked if needed. The learners will get an automatic feedback on accomplished solution steps on time. If the given feedback isn't sufficient the student may request additional tips or personal feedback from the tutor. The tutor can check on the solution steps already taken by the students.

MoveIt-M (Fest, 2010) is an interactive learning tool for exploring congruencies and their dependency on line reflections. In different 'laboratories', students can explore and apply the theorem that any congruent transformation can be generated by at most three line reflections. As a first feedback the user can check his solution using the geometrical representation implemented by the DGS Cinderella. A second possibility is to check the solution automatically to get textual feedback. If automatic feedback is impossible, the student can send an email with a screenshot of his or her current solution state to his or her tutor.

SetSails!: Students can use SetSails! (Zimmermann & Herding, 2010) to proof the equivale**nce of terms in set algebra or B**oolean algebra. To show the equivalence of two terms the user has to transform the terms using algebraic rules. At each step the student first has to choose a rule he might want to use (e.g. commutative law) and in a second step the resulting term. Users can also enter their own terms and check their equivalence. A special feature of SetSails! is that the learner is not forced to do the transformations in a predefined way or even in one direction only. The transformations can be entered 'backwards' or it is even possible to change directions. At any time during the solution process, the student can request feedback on his previous working steps. If possible the tools gives automatic feedback and if not an email will be sent to a tutor.

Squiggle-M (Hiob-Viertler & Fest, 2010) is an open experimental environment for functions and their properties. Several laboratories deal with the concept of functions, e.g. with totality and uniqueness as well as functional properties like surjectivity, injectivity and bijectivity. Students use the tools by themselves, i.e. to practice and explore these properties. The student gets again semi-automatic feedback on his or her solution process.

EVALUATION OF THE PROJECT

The evaluation of the project shows that students taught in the SAiL-M project increased significantly more their mathematical self-efficacy than students taught at other universities (Bescherer et al., 2012).

At the beginning of the project SAiL-M we started with several hypotheses considering changes in the self-efficacy expectations of the students, their motivation and their mathematical competencies or skills. These constructs were tested using adapted or specifically developed questionnaires. Of course these measurements could only give results regarding the whole SAiL-M learning concept and not on details i.e. the use of specific software or the choice of problems during the exams. So we give now the evaluation results of SAiL-M learning scenario compared to responses from students from different universities of education. Since the teacher programmes at the Universities of Education in the German state of Baden-Württemberg are determined by the state Ministry of Education the courses in the first two years are quite similar and the students comparable.

Methods

The setting was a quasi-experimental treatment study comparing the treatment group at the University of Education Ludwigsburg with groups studying in the same teacher programmes from different Universities of Education in the state of Baden-Württemberg.

There were three evaluation runs during the duration of SAiL-M. Each cohort of students was asked three times: in their first math lecture at the beginning of the first year at university, the end of the first semester but before the exams took place and the end of the second semester. The table 1 gives an overview over the dates and measures employed:

Table 1: Dates of measurements during the three evaluation runs

1st evaluation run			2nd evaluation run			3rd evaluation run		
Oct. 2008	Feb. 2009	July 2009	Oct. 2009	Feb. 2010	July 2010	Oct. 2010	Feb. 2011	July 2011
MaSE-T	MaSE-T	MaSE-T	MaSE-T	MaSE-T	MaSE-T	MaSE-T	MaSE-T	MaSE-T
	Moti-vation	Moti-vation		Moti-vation	Moti-vation		Moti-vation	Moti-vation
							Math-matical Skills	

Due to several organisational and personnel changes at the ‘comparison universities’ the ‘death rate’ during the three runs was immense. So the results of the motivation are not comparable because of the small numbers of students (1st run: 32, 2nd run: 59; 3rd run: 57 in the different groups whose data were available at all data points. Some detailed analysis of the SAiL-M students will be done in Marc Zimmermann’s doctoral thesis.

The purpose of testing the mathematical skills was to make sure that the students learning mathematics in the SAiL-M concept didn't acquire less skills than those at other universities in more traditional settings.

The explored hypotheses will be discussed now separately including some more details concerning the questionnaires and the results.

Mathematical self-efficacy

Hypothesis: Students with a lower mathematical self-efficacy will show an increase of the self-efficacy during the treatment. High values of mathematical self-efficacy will not decrease.

The construct of mathematical self-efficacy was chosen as one of the evaluation measure because it is 'broad' enough to give an idea whether this 'holistic' approach to change traditional mathematics courses into learner activating scenarios is successful. Also self-efficacy is not a fixed personality trait but can change according to a specific treatment (Bandura, 1997).

The self-efficacy questionnaire for pre-service math teachers (MaSE-T) was developed during the semester 2008/09 based on different existing measures for mathematical self-efficacy. It consists of 15 items with three subscales: 'purely mathematical problems', 'real life mathematical problems', and 'reasoning problems'. The questions are on an adequate level for beginners of math teacher programmes. The internal reliability measured by Cronbach's Alpha, indicates a high internal consistency (alpha=0.84, N=1273). The alpha values of the three dimensions of the scale are acceptable. (For a detailed description of the questionnaire and its validation see Zimmermann, Bescherer & Spannagel (2011). The full questionnaire in English can be found at http://www.sail-m.de/sail-m/tiki-download_file.php?fileId=166, retrieved 1/13/2013.).

During the first evaluation run the MaSE-T scale was still developed and therefore the results of the inconsistent questionnaires were not explored further. The second and the third run started with 1165 respectively 832 participants. But because of organisational reasons like changes in personnel or students decided to take the second course not during their second semester but later the death rate was huge. Data for all three dates could only be identified for N=59 respectively N=57. (The questionnaires were matched via a code which didn't allow identifying students.)

An analysis of variance with repeated measures – of the 59 students whose MaSE-T measures were available over all three data points – didn't show a significant difference between the two groups over all three data points. Treatment group and control group both increased their mathematical self-efficacy over the test intervals. The average increase of the treatment group was 5,95 of 75 points of the control group 2,50 points (s. Table 2).

Table 2: Means of MaSE-T second evaluation run October 2009 – July 2010

	Treatment group		control group	
	N	mean MaSE-T [a)]	N	mean MaSE-T
data point 1	100	54,9	825	51,4
data point 2	74	60,8	322	55,5
data point 3	35	59,0	99	57,4

a) Minimum: 15; Maximum: 75

An analysis of variance with repeated measures – of the 57 students whose MaSE-T measures were available over all three data points – shows significant differences between the two groups over the second and third data points. In the beginning (data point one) there were no differences. Treatment group and control group both increased their mathematical self-efficacy over the test interval ($p<0.001$). The small decrease from data point 2 to data point 3 is not significant. Both groups differ significantly in the increase of their mathematical self-efficacy ($p<0.001$).

Students from the SAiL-M project show a higher mathematical self-efficacy after 1 respectively 2 semesters of math than those from the control group.

Table 3: Means of MaSE-T third evaluation run October 2010 – July 2011

	Treatment group		control group	
	N	mean MaSE-T b)	N	mean MaSE-T
data point 1	97	53,9	252	54,7
data point 2	69	62,3	73	58,0
data point 3	43	59,8	22	57,1

b) Minimum: 15; Maximum: 75

Mathematical skills

Hypothesis: The mathematical skills of the students in the treatment group don't differ from that of the students in the control groups. More specifically, the learner centered scenarios in SAiL-M don't succeed at the costs of mathematical technical skills.

Innovative learning scenarios especially ones which include ICT are often accused of succeeding only because students spent less time learning basic mathematical skills. To prove that it is possible to get students to 'do mathematics actively' themselves thereby learning mathematical processes and still acquire the same skills as in comparable but traditional mathematics courses we developed a specific skills test. This test was designed to match the mathematical content of the first semester mathematics of the Baden-Württemberg teacher programmes. It consists of 18 mathematical statements and the students had to decide whether the statement was true or false (cf. Table 4).

Table 4: Excerpt of the math skills test (4 of 18 questions)

true	false	
		A function between two equinumerous sets is always surjective.
		There are 4! possibilities to place 4 different cards next to each other.
		If a natural number a is a divisor of the natural number b then every divisor of a is also a divisor of b.
		The relation '... is sister of ...' is an equivalence relation.

A single factor analysis of variance didn't give any significant differences ($p=0.340$). So the mathematical skills of the treatment groups and control groups did not differ significantly from each other.

Unfortunately, the evaluation doesn't show the impact or importance of the use of ICT specific to the SAiL-M concept. We cannot isolate the impact of the ICT activities from the impact of the whole concept. The different tools were evaluated separately with regard to the usability and the semi-automatic assessment. But these results are too 'microscopical' to show the impact of the learning scenarios.

CONCLUSION

At the University of Education in Ludwigsburg the SAiL-M conception were introduced into the pre-service teacher studies for middle schools since October 2008. Even if the project has ended, teaching mathematics according to the SAiL-M concept goes on.

In our opinion ICT cannot find its way into classrooms just by making special classes on 'ICT in mathematics' mandatory. Consequently and following the SAiL-M concepts students have to decide autonomously when to work with ICT doing mathematics. To reach this goal the 'on demand' – principle is a good way to support students developing a sense whether and when using ICT or not. Therefore ICT shouldn't replace paper and pencil in mathematics, it should just be an additional support to do mathematics individually and actively.

ACKNOWLEDGMENTS

Work described in this chapter is funded partially by the German Federal Ministry of Education and Research.

REFERENCES

Bandura, A. (1997). *Self-efficacy. The exercise of control*. New York: Freeman.

Bescherer, C. & Spannagel, C. (2009). Design Patterns for the Use of Technology in Introductory Mathematics Tutorials. In A. Tatnall & A. Jones (Eds.), *Education and Technology for a Better World* (pp. 427-435). Berlin, Heidelberg, New York: Springer.

Bescherer, C. (2009): Learning Mathematics in Technology Enhanced Scenarios – SAiL-M. In C. Bardini; P. Fortin, A. Oldknow. & D. Vagost (Eds.). *Proceedings of the 9th International Conference on Technology in Mathematics Teaching*. Metz, France: ICTMT 9. Retrieved from http://www.ictmt9.org/contribution.php?id=86&lang=en.

Bescherer, C., Herding, D., Kortenkamp, U., Müller, W., Zimmermann, M. (2011). ELearning Tools with Intelligent Assessment and Feedback. In S. Graf et al. (Eds.), *Adaptivity and Intelligent Support in Learning Environments*. Hershey: IGI Global.

Bescherer, C.; Kortenkamp, U.; Müller, W. & Spannagel, C. (2010). Research in the field of intelligent computer-aided assessment. In A. McDougall (Ed.), *Researching IT in Education: Theory, Practice and Future Directions*. (pp. 200-205). London: Routledge.

Bescherer, C., Spannagel, C. & Zimmermann, M. (2012). Neue Wege in der Hochschulmathematik – Das Projekt SAiL-M. In M. Zimmermann, C. Bescherer & C. Spannagel (Eds.), *Mathematik lehren in der Hochschule – Didaktische Innovationen für Vorkurse, Übungen und Vorlesungen*. Hildesheim: Franzbecker.

Bescherer, C., Spannagel, C., Zimmermann, M., Hoffkamp, A. & Moll, G. (2012). *Semiautomatische Analyse individueller Lernprozesse in der Mathematik – Schlussbericht des Teilprojekts der Pädagogischen Hochschule Ludwigsburg. Retrieved from* http://www.sail-m.de/sail-m/Publikationen [1/11/2013]

Eisenberg, M. & Fischer, G. (1993). Symposium: learning on demand. In: *Proceedings of the Fifteenth Annual Conference of the Cognitive Science*, (pp. 180–186). Hillsdale, NJ: Lawrence Erlbaum Associates.

Fest, A. (2010). Creating interactive User Feedback in DGS using Scripting Interfaces. *Acta Didactica Napocensia*. 3(2), 79-88.

Fluck, A. (2010). eExaminations development and acceptance. In N. Reynolds & M. Tursanyi-Szabo (Eds.). *Proceedings of the Key Competencies in the Knowledge society: IFIP TC 3 International Conference, KCKS 2010* (pp. 126-135). Brisbane: Springer.

Herbst, P. (1999): On proof, the logic of practice of geometry teaching and the two-column proof format. *International Newsletter on the Teaching and Learning of*

Mathematical Proof January/February 1999. Retrieved from http://www.lettredelapreuve.it/OldPreuve/Resumes/Herbst/Herbst99.html.

Herding, D., Zimmermann, M., & Bescherer C. (in press). A Learning Tool for Mathematical Proofs with On-Demand Hints. In Y. Mor et al. (Eds.), *Practical Design Patterns for Teaching and Learning with Technology.* Sense Publishers.

Holton, D. (2001). *The Teaching and Learning of Mathematics at University Level: An ICMI Study.* Dordrecht, Boston, London: Kluwer Academic.

Jancarik, A., & Novotna, J. (submitted). The role of computers in pre-service teacher training – are our graduates ready for the challenge?. Submitted for the *CERME 8*, 6.2. – 10.2.2013 in Antalya, Turkey.

Krauss, S., Neubrand, M., Blum, W. & Baumert, J. (2008). The professional knowledge of German secondary mathematics teachers: Investigations in the context of the COACTIV project. Online paper for the 11th *International Congress on Mathematics Education (ICME 11) in Monterrey*, Mexico (TSG 27). Retrieved from http://tsg.icme11.org/document/get/397, 12/1/2013

Lagrange, J.-B., Artigue, M., Laborde, C., & Trouche, L. (2003). Technology and Mathematics Education: A Multidimensional Study of the Evolution of Research and Innovation. In A.J. Bishop, M.A. Clements, C. Keitel, J. Kilpatrick & F.K.S. Leung (Eds.), *Second International Handbook of Mathematics Education*.(pp. 239-271) Dordrecht: Kluwer.

NCTM (2000) *National Council of Teachers of mathematics: Principles and Standards for School mathematics.* Reston, Virginia, USA.

Rebholz, S. & Zimmermann, M. (2011). Applying Computer-Aided Intelligent Assessment in the Context of Mathematical Induction. In *Proceedings of the 4th International eLBa Science Conference*. Rostock: Fraunhofer Verlag.

Richter-Gebert, J. & Kortenkamp, U. (2012). *The Cinderella.*2 Manual. Berlin, Heidelberg: Springer.

Thomas, M., & Holton, D. (2003). Technology as a Tool for Teaching Undergraduate Mathematics. In A.J. Bishop, M.A. Clements, C. Keitel, J. Kilpatrick & F.K.S. Leung (Eds.) *Second International Handbook of Mathematics Education.* (pp.351-394) Dordrecht: Kluwer.

Zimmermann, M., Bescherer, C. & Spannagel, C. (2011). A questionnaire for surveying mathematics self-efficacy expectations of Prospective teachers. In *Proceedings of CERME 7,* 9. – 12 March 2011 in Rzeszow, Poland. Retrieved from http://www.cerme7.univ.rzeszow.pl/WG/14/CERME7-WG14-Paper-Zimmermann,-Bescherer-&-Spannagel-REVISED-Dec2010.pdf. 4/29/2013

Zimmermann, M. & Herding, D. (2010). Entwicklung einer computergestützten Lernumgebung für bidirektionale Umformungen in der Mengenalgebra. In A. Lindmeier & S. Ufer (Eds.) *Beiträge zum Mathematikunterricht 2010*. (pp. 951-954). Münster: WTM.,

Biographies

Prof. Dr. Christine Bescherer is a full professor in mathematics Education. Her fields of interest are – among others – computer in mathematics education and mathematics education at universities. She is also vice-president of the University of Education Ludwigsburg.

Marc Zimmermann is a scientific assistant at the University of Education Ludwigsburg. After studying teacher for Secondary School he graduated as M.A. in pedagogy for mathematics and physics. He is currently working on his Ph.D.