MEMBERS: The Impact of eLTR-Technologies on Mathematical Education of Non-Native Speakers

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Abstract: Field specific lessons for non-native speakers present a special challenge to teaching. In addition to the language aspects, other issues should be taken into consideration; among them, differences based on the social and cultural background. A field of studies highly affected by such a challenge is Mathematics, as it is based on abstract concepts and ideas, and not on every-day experience. At the same time, mathematics provides the basis for the many other disciplines, such as engineering and natural sciences. It is notable that there have been few scientific studies dealing with "Mathematics and Language" or "Culture-specific aspects of Mathematical Language" at universities. However, the topic has been investigated extensively for elementary, junior and high schools. New media can contribute crucially to the improvement of (mathematical) education, as they provide the basic potential to support the learners according to their individual learning style and profile. So far, however, the potential of the so called eLTR-technologies, has not been realized to the fullest. The visualization of abstract mathematical objects and concepts offers one of the most significant aids in the education of immigrants and foreign students.

In many German universities, the rate of success of non-native speakers is significantly lower than that of their German fellow students. The Berlin University of Technology is the largest technical university in Germany and the university with highest number of foreign students at 20% of the student body. The MEMBERS project aims to support the mathematical education of non-native speakers with the help of the new media, especially by increasing the application of visualization and interactive components.

1 Introduction

Academic courses, such as mathematical education, held in a language other than the student's mother-tongue pose new pedagogical challenges. Languages form concepts, meaning that, as grammatical-linguistic systems, they shape and influence thinking and perception. As a result, language has an influence on the cognitive skills of the individual as well as on the academic system of a given language area.

Structural differences in perception and comprehension mostly occur in *abstract concepts*: a *circle* is always a circle - we associate a concrete image with that geometric object and this image is usually independent of language or cultural background. Universal understanding of the concepts of *set* or *map*, however, is not guaranteed a priori: it has to be formed through the language. This can lead to linguistic and cultural differences in the formation of concepts.

The fact that such cognitive differences are understood from the results of neurophysiological research (see Dehaene et al. 1999), adds additional interest to the topic, but makes it more complex as well. In his 1945 essay on ”The Psychology of Invention in Mathematics”, the renowned mathematician Jacques Hadamard claimed that, in order to have an appropriate research on understanding the process of mathematical thinking and comprehension, both mathematical as well as psychological knowledge are necessary (see Hadamard 1914). Nowadays, neurobiology has to be added to that list. Thus, a successful didactic approach demands a combined analysis of the situation of learning and teaching from the point of view of those three sciences.

In addition, mathematical education at universities is faced with new - huge - challenges: highly advanced computer algebra and software packages have lead to a revolution in performance in applied mathematics and to new possibilities in mathematical modeling, simulation and visualization of more complex engineering and natural science related processes. Engineers or natural scientists need the skill to employ these new instruments expertly. To this end, they need to choose the appropriate tool from several existing computer-algebra-systems and specialized applications, to model the given problem within the framework of the chosen tool and then interpret the resulting data correctly with regard to its reliability and correctness. In order to do so, it is necessary to possess mathematical knowledge that goes far beyond purely mechanical arithmetic skills (see Jeschke 2004). Even though algorithms are comparatively easy to teach (particularly since they can be demonstrated), the understanding of broader mathematical concepts poses a larger challenge - even more so for non-native speakers.

These changes in the concept of mathematical competence apply to mathematical education in *applied studies* in particular. Moreover, the number of foreign students in those fields (engineering, computer science, economics) is particularly high as the technical universities in Germany and their engineering studies attract students from all over the world. The resulting question has to be: “What should a mathematical learning and teaching environment for the education of students of engineering or the natural sciences in a language other than their own look like?”

The MEMBERS project of the Berlin University of Technology (see section 6) aims to approach these problems through the use of new didactic models, which are widely based on the second generation of eLTR-technologies (see section 3) (see Jeschke & Kohlhase & Seiler 2004), with special emphasis on the support of individual learning processes.

2 Mathematical Education and Cultural Background

Although mathematics can be seen as a ”universal language” once it is learned and mastered, a student’s acquisition of mathematical concepts is always influenced by the linguistic structure of his/her native tongue. The different approaches to teaching are closely related to the respective educational culture of the corresponding language area.
It is widely known that mathematics can be taught, learned and understood in a variety of different ways. Poincaré (see Poincaré 1914) separated people according to their basic approach to mathematics into “geometrically” and “algebraically” oriented. Experience shows that people from North America and Western Europe tend to fall into the first category, while people from Eastern Europe or Asia often belong to the second. The method of mathematical arguments can also depend on culture and socialization - as a result, many important mathematic works are turned down; not because they are wrong, but because they utilize a style different than that of the person evaluating it.

Subsequently, a better support of mathematical education for migrants requires the development of more flexible, alternative methods, which focus on individual, culture-specific learning processes. In addition, culture-specific peculiarities regarding mathematics should be adequately accounted for, as the students join the course with educational knowledge typical to his/her country and culture.

3 eLTR-Technologies - Challenges and Opportunities

eLTR-Technologies (eLTR := eLearning, eTeaching & eResearch) are capable of contributing extensively to the solution of this challenge: support of various individual learning styles (as well as the adaptation to varying levels of previous knowledge, learning pace, individual practice needs, etc.) represent the outstanding potential of the implementation of multimedia technologies in teaching and will thus be particularly helpful for students with a migration background. Another important potential is found in the support of interactive modeling, explorative knowledge acquisition and the realization of innovative forms of communication and cooperation.

Moreover, not all eLTR-developments were equally effective. Many of the “First Generation”-concepts equate learning with the pure acquisition of knowledge and fail to support the actual process of comprehension and learning (see Engbring & Keil-Slawik & Selke 1995). Many of these so-called teaching-platforms are little more than expert document management systems supporting certain organizational processes in educational institutions. The lack of granularity and the use of static typographic objects - combined with monolithic software design - preclude individual, constructivistic approaches to learning as content is not designed with free interaction and experimentation in mind (see Jeschke & Keil-Slawik 2004). In addition, there is a lack of pedagogical concepts. Despite a large number of eLearning-platforms, eLearning-initiatives and vast amount of available eLearning-material there is little scientific data concerning their effectiveness and only limited research into and experimentation in the field of effective eLearning-concepts, particularly applied to field-specific deployment (see Jeschke & Kohlhase & Seiler 2004).

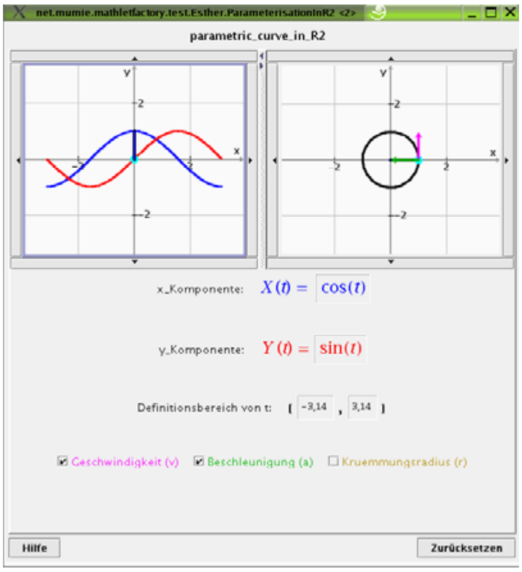

Figure 1: Interactive elements in mathematical education: construction and visualization of a parameterized curve in $\mathbb{R}^2$.

One of the important potentials of eLTR-Technologies lies in their capacity for visualization, especially of abstract and more complex mathematical concepts and results. This potential will be addressed in greater detail in the next chapter.

4 Visualization

The visualization of mathematical objects plays a decisive role in learning as the visualization of abstract facts can be of vital contribution to a deeper understanding of mathematical concepts. Visualization is not limited to the mere clarification of mathematical-scientific data and facts, but also allows the presentation of structural properties inherent in methods and objects. Spatial sense and visual imagination are advanced. Visualization enhances motivation because it facilitates a first quick overview of a previously unknown object.

We can only speculate about the reason for the impact of graphics in comprehending mathematical concepts and methods. It appears that the human brain is, to a certain degree, an image processor. The fact that the number of nerve fibers that connect the eyes to the brain is about a thousand times larger than the numbers of neural connectors between the ears and the brain seem to support this thesis. Experience has shown, that images are more easily committed to memory than words; in general, a lecture with large amounts of visual and graphical aids is more effective than a lecture that relies heavily on auditive approaches.

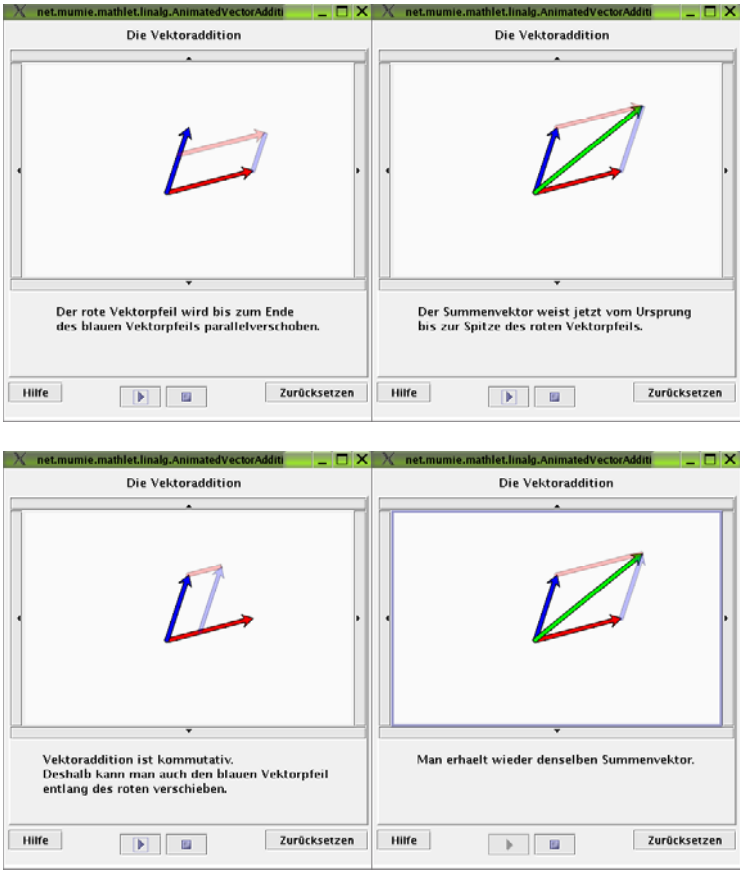

Figure 2: Animation: addition of vectors

However, this is not the only reason why the visualization of mathematical concepts and results play a crucial role in the learning process. *Learning* in mathematics and natural sciences is closely related to *discovery*, the discovery of abstract objects, modeling mechanisms and abstract concepts. Thus, the learner passes (in an accelerated fashion) through the same recognition process as the original inventor of the process did. Visualization plays a particularly significant role in this process as the explorer, or rather, the learner, is conceptualizing objects and concepts for which he or she has no verbal terminology available yet! The learner is in good company, in fact even beyond the earlier stages of his or her learning process, as Albert Einstein - amongst other things famous for his refined speech - explained his personal work methods to the psychologist Max Wertheimer: “I very rarely think in words at all [...] I have it in a sort of survey, in a way visually.”

Visualization offers additional and important advantages to the mathematical training of migrants: on the one hand, the visualized objects are often understandable without a language, thus enabling a quick approximation to the subject despite possible language barriers. On the other hand, the interpretation of pictures and graphics is subject to certain cultural features (there are culture-related differences in interpreting colors and shapes for example); concerning the presentation of abstract concepts through visualization, the ”visual language” represents a universal language concept that is understood beyond cultural boundaries. Good examples of this are strongly stylized images, such as arrows, pictograms, and flowcharts.

Beginning in 2005, visualization of mathematical content has been successfully implemented in a course on linear algebra for undergraduate engineering students, resulting in a noticeable improvement in the finals exams when compared to participants of the “old” courses.

5 Mathematical Education of Engineering Students at the Berlin University of Technology

The Berlin University of Technology is the German university with the highest percentage of foreign students (currently about 20%). In addition, a large group of students come from a migrant background who, while registered as German citizens, still have to be counted among the group of non-native German speakers. As these students are usually very proficient and skilled speakers of the German language, the role of the language in lectures is not frequently taken into consideration. Independently of how these students master the German language, the linguistic structure of their mother-tongue differs from that of the language used in class. This has an important impact - as discussed above - on the formation of concepts and the optimal teaching method.

The rate of success of foreign students in the Berlin University of Technology lies at about half of that of their German fellow students; an unacceptable result that the Berlin University of Technology is determined to rectify through extensive efforts. These include the MEMBERS-Project, introduced in this article, the MUMIE (see Mumie community, funded by the BMBF - German Federal Ministry of Education and Research) and the VIDEOEASEL (Virtual Laboratories in Mathematics and Natural Sciences), a project funded by the DFG-(German Research Foundation) Research Center MATHEON.

In the course of the MUMIE project, a cooperation of the Berlin University of Technology with the RWTH Aachen (see Enß & Holschneider & Jeschke & Paehler & Seiler 2005; Paehler 2005), the TU Munich and the University of Potsdam, an interactive learning and teaching environment for mathematics lessons was developed and tested by a small team of students in the summer term 2005 for the first time (TUMULT Project).

After promising results, a larger test has been performed with about 200 engineering students, during the winter term 2005/06. Intensive use of visualization and interactive components (Java-Applets) has been integrated into various parts of the learning program. They have been used in traditional lectures to introduce and present new concepts and terminology; in the future, these components will be directly integrated into the lecture with help of the electronic whiteboard-system ”eChalk”.

The MUMIE eLearning environment consists of several interwoven layers: the first layer contains the knowledge network of the mathematical content to be learnt, the second contains the corresponding demonstration, training and practice environment, to be used in the tutorials (small groups) and homework assignments (individual exercises). The problems are individualized and are automatically corrected on the server. In addition, providing several different, yet similar problems - with immediate automatic feedback about the correctness of the solution - enables the student to adjust the amount of training to the pace of their own progress. Due to the large amount of visual/interactive components, this model is particularly suited for lessons with a large number of non-native students. Further tests are already planned in the framework of the MEMBERS project.

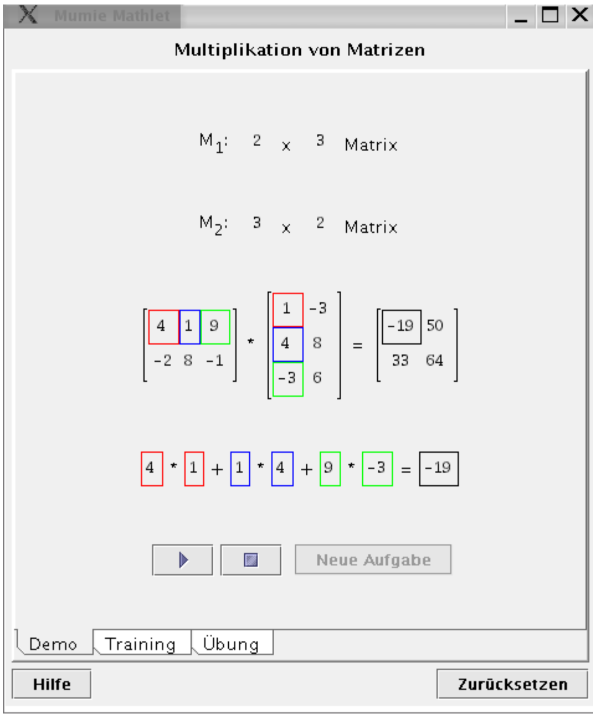

Figure 3: Demo: Matrix Multiplication (incl. animation).

Figure 4: Training: Matrix Multiplication.

6 Summary - The MEMBERS-Project

The purpose of the MEMBERS-project is to examine the effects of language contexts on the learning of mathematics, in particular testing alternative options of support for non-native-German-speaking students through the deployment of new media. Visualization holds a key-role among these concepts, as the interpretation of visual objects is only marginally dependent on the specific cultural background. The results are to be prototypically applied to the eLearning-platform MUMIE and the MATHLETFACTORY and tested in the mathematical education of engineering students, as those courses have a high percentage of students with migrational background.

As we have already pointed out, there are not many scientific studies on ”Mathematics and languages in higher education” (or, respectively, ”culture-specific aspects of mathematical practice”), even though the topic was extensively researched for elementary, junior and high school. The most recent project ”German as a foreign language: terminology in engineering studies at the Berlin University of Technology" was realized ten years ago by Prof. Steinmüller of the Humanities School (Education and teaching sciences). This project examined the language usage in engineering studies at a German university. It was shown that studies in the field of engineering require language skills differing considerably from those usually taught in preparatory German courses (see Steinmüller 1997). Most "German-for-foreigners" language courses are designed to impart language skills based on a mix of every-day usage and German literature. They fail to address the fact that the language necessary for communication in a technological or natural science related environment can differ drastically from these styles of language.

In summary, the learning difficulties and low success rates of non-native students and students with an immigration background can be attributed to a complex combination of several factors, including differences in language proficiency as well as social and financial aspects. The MEMBERS project concentrates on the language difficulties encountered by foreign students in the course of their studies. The focus of the study in mathematics is based on the importance of this field as a basis for all other engineering studies, and the resulting "multiplication factor".

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