TeachING-LearnING.EU – Three years of improving German engineering education and what can be learned for Europe

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INTRODUCTION

Since the signing of the Bologna Declaration in 1999, the European Ministers of Higher Education have met every two years in order to press ahead with its implementation. Today the process has 47 members. The ministers launched the European Higher Education Area on 12 March 2010 by signing the Budapest-Vienna Declaration. Under point 6, the declaration says:

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"Recent protests in some countries (…) have reminded us that some of the Bologna aims and reforms have not been properly implemented and explained. We acknowledge and will listen to the critical voices raised among staff and students. We note that adjustments and further work, involving staff and students, are necessary at European, national, and especially institutional levels to achieve the European Higher Education Area as we envisage it" [1].

This statement alludes to the fact, that the implementation of the process was accompanied by problems. At least in Germany, different voices demanded a reform of the reform [2],[3].

In the middle of 2010 the Stiftung Mercator and the VolkswagenStiftung launched the initiative 'Bologna – Zukunft der Lehre' (in English language: 'Bologna – Future of Learning'). Within this initiative the two foundations financed several degree programs and competence centres for explicit subjects – engineering being one of them. In order to tackle the challenges the Bologna Process has set for engineering sciences in Germany, three large German Universities of Technology (RWTH Aachen University, Technical University Dortmund and the Ruhr-University Bochum) were supported. They founded 'TeachING-LearnING.EU – The Competence and Service Centre for Teaching and Learning in Engineering Sciences' (www.teaching-learning.eu). TeachING-LearnING.EU involved different stakeholders on engineering education and addressed them with specific strategic instruments. All strategic instruments with the corresponding target groups are visualized in Figure 1.

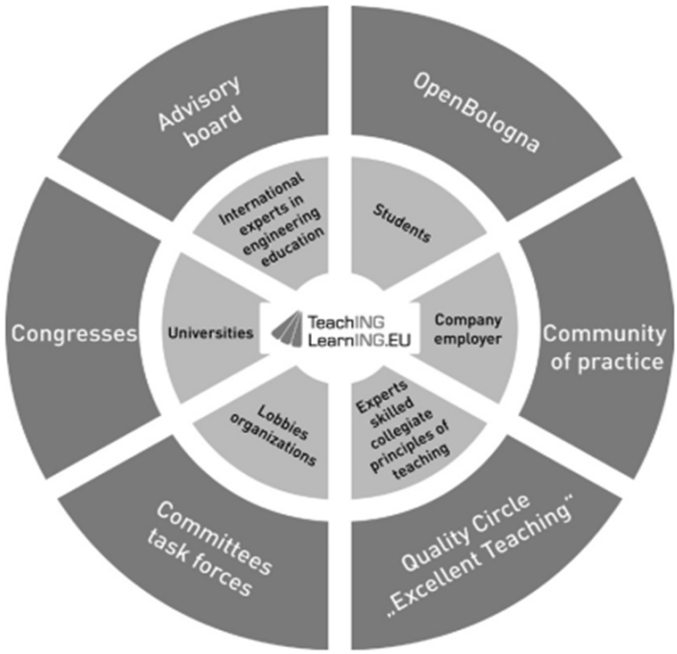

Figure 1: Instruments and stakeholders of TeachING-LearnING.EU

The work in TeachING-LearnING.EU can furthermore be divided in two sections:

- On the service side, the centre organized communication processes between different stakeholders of German engineering education: students, employers, national and international researchers in engineering education, university staff as practitioners of teaching methods, lobbies and organizations like the VDI (The Association of German Engineers). The Open Bologna instrument focused on the involvement of the students. Therefore idea competitions and workshops with students have been organized (see 2.1). To support the trial of new teaching and learning concepts, flexible funds provided lecturers with the financial capital needed for the implementation of innovative teaching concepts (see also 2.1). In addition to that, lecturers of engineering subjects have had the opportunity to participate in trainings, where concepts like problem-based learning were presented and connected to technical content.
- On the research side, TeachING-LearnING.EU focused among others on the challenge to conduct interactive lectures for big audiences (see 2.2).

After three and a half years of action, TeachING-LearnING.EU now draws a balance. In order to reflect on the project, a series of lessons learned workshops was conducted. The project leaders identified in advance the following four questions on the basis of their daily work experiences with different stakeholders:

1. Higher education researchers, teaching staff, students, and employers - What are their individual perspectives on engineering education and how can they be involved in the improvement of engineering education effectively?
2. Student centred teaching concepts - How can such concepts be integrated effectively and what are challenges that are unique to engineering?
3. Large audience lectures are common - How can this challenge be faced and which communication technologies can help to solve it?
4. The project has been running for three years - What were the major lessons learned on a meta-level and how can this be used to build a roadmap for upcoming projects and activities?

These questions were used in order to guide the workshops and the connected discussions. The central aim for the workshops was to answer these questions in basis in the experiences made during the project. This paper presents the major results of these workshops in the form of lessons learned and conclusions.

1 METHODOLOGY

In order to collect the lessons learned, the participating universities carried out a constitutive series of three workshops. In three parallel workshops of the first round the project-teams of each city met in order to identify the main learnings and results of each work package. In the second round's workshop the three project leaders drew these results together and condensed the qualitative data to results on a meta-level. This step was also conducted in the workshop-format. All results were based on open discussions and were transformed into a working document. This working document was discussed and enriched by the scientific board of TeachING-LearnING.EU in the third workshop round. In the following section, the results are presented in detail, structured by the questions above, while the first two will be simultaneously addressed in 2.1, the third in 2.2 and the fourth in 3.

2 LESSONS LEARNED

2.1 Different stakeholders and their perspective on engineering education – Student centred teaching concepts in discussion

Employers, students and the teaching staff were the most important stakeholders for the work in TeachING-LearnING.EU. All of them have different interests in and totally diverse perspectives on engineering education. Hence, TeachING-LearnING.EU used different strategic instruments in order to address each of them. In the following these stakeholders and the connected TeachING-LearnING.EU action will be explained.

2.1.1 The employers' perspective

Especially for employers, the 'TeachING-LearnING.EU-Community of Practice' was founded to foster the dialogue on their demands regarding student skills. A successful action in this context was to bring master students together with young engineering alumni, who recently had made their way into practice. Even if there are a lot of possibilities for students to get into contact with professionals, there is still a high demand for such exchanges. Furthermore, the Community of Practice once met with a group of students in the framework of the OpenBologna instrument. With the goal of the Bologna Declaration in mind, that students' employability should be fostered, the dialogue had the goal to exchange views on how well students are being prepared for the job. Looking on the employers' perspective on engineering education, their demand can be described as 'activating' teaching concepts. Employers want graduates who are used to being active, out-going and self-organised who know how to solve a problem on their own. Fostering the dialogue between employers and researchers in engineering education turned out to be a valuable step towards a common understanding on how to meet the demands of employers and corresponding teaching and learning concepts. To the employers it became clear, that curricula cannot be "indoctrined" by the industry and

that the humboldtian paradigm of independent universities is to be maintained. To the researchers in engineering education, the strong needs of the universities became obvious in order to tackle the still existing problem of skills shortage in the industrial working sector.

2.1.2 The students' perspective

With the OpenBologna instrument and the Flexible Funds, TeachING-Learning.EU specifically addressed students as well as teaching staff and involved them into the innovation process for student centred teaching concepts. OpenBologna is based on the concept of Open Innovation developed and used by companies in the business sector to integrate customers actively in new product developments. The main methods within this strategic instrument are idea contests and lead student workshops. In Open Innovation Lead users are individuals that are experiencing needs ahead of the market trend and are at the beginning of the innovation process [4]. In the case of OpenBologna, TeachING-LearnING.EU looks for engineering students who are interested in the development of teaching and learning [5].

Six ideas competitions and two lead student workshops were conducted and led to the total amount of one-hundred new ideas for improving teaching and learning in engineering education. The most frequent topics were virtual learning environments, organization and resources and digital technologies in lectures [6]. Examples range from different learning games up to movie competitions, where students can produce their own learning videos for the topics of the course. One group of students enrolled an integrated course program together with their professor in the aftermath of wining the third price in one of the idea competitions. Within their follow-up project, different courses such as constructional design, project management or cost accounting all relate to the same project.

By making all ideas available on the project's website, the students' ideas and interested teachers have been brought together. Moreover, a text analysis of all the contributions showed that students can be considered as competent, active and constructive partners in the improvement of education [6]. The results show the importance to involve students especially in the context, that todays' students all grew up with digital media, whilst todays' teaching staff did not. To work with students as 'experts' for their own learning process helps to integrate their perspective in addition to classical evaluation questionnaires. In combination with didactical expertise of researchers in engineering education, it needs to be reviewed which ideas can be implemented. From the students' perspective, todays' possibilities of virtual and technologically enhanced learning environments needs to be used more.

2.1.3 The teaching staffs' perspective

The Flexible Funds concept directly addressed the teaching staff of the three universities' engineering faculties. TeachING-LearnING.EU published two calls for concepts with special focus on student-centred approaches. Faculty members answering these calls could apply for financial funding by submitting innovative teaching concepts. Funded concepts were additionally supported from TeachING-LearnING.EU in the form of didactical advice as well as training and on-going evaluation. Although the funding was relatively low (max. € 30,000 for personnel expenses only), the demand was high. All in all, twenty-two innovative teaching projects were founded at the three universities. Analysing the supported concepts different thematic clusters were identifiable. The first round led to the following clusters: (1) Engineering experiments, (2) Simulation of practical working processes and (3) Case studies. The second round's projects were clustered as follows: (1) Experimental Learning, (2) Collaborative Product Design, (3) Peer-Coaching and Mentoring, and (4) Digital Tools in Education. Among the funded projects there were several examples of virtual and technologically enhanced learning environments, which matches the students' perspective on the improvement of engineering education. Assuming that the teaching staff at the faculties knows firstly what is important for engineering students to learn and secondly where potentials for improvement in education are, these clusters can be taken as spots to focus on for future enhancement. It is noteworthy that in both rounds special focus was laid on the use of experiments in engineering education and on practical hands-on experiences for students. The evaluation of the lectures where the funded concepts had been implemented show, that students appreciate the added value of student-centred course design. In particular the students evaluated the new concepts positive if it showed

- a high level of practical application or reference,
- a coherent link between theory and practice,

- an intensive communication between teachers and students, and

the independent work on topics in student groups.

In contrast to the positive evaluation results, there was also critical feedback. Some of the students reported, that especially independent learning and working is unusual and led to a feeling of being overwhelmed. Hence the integration of student-centred learning concepts has to act between challenging the students but not overwhelming them. Another positive aspect concerning the Flexible Funds is that even a relatively low funding led to considerable changes in teaching at the participating faculties. In many cases not only the funded projects were implemented. The positive experiences of the funded teaching staff initialized a broader discussion about teaching in general within the whole faculty. Hence a snowball effect on other courses could be observed.

With Open Bologna and the Flexible Funds two strategic instruments were used to generate new student-centred teaching and learning approaches and to put them into practice in engineering education. Each instrument had a different target group. Nevertheless the TeachING-LearnING.EU's bottom-up approach to promote and foster learning innovations in very close collaboration with the teaching staff and the students proved to be effective. Especially those two groups have very explicit ideas and concepts of adequate course design. Working with them in order to put these ideas into practice led to excellent results. Challenges in this context can be primarily seen in the comprehensive adoption of such approaches for the whole curriculum. Even if students and teachers advocated in the outlaid context for such concepts and although they invented new course concepts these innovations remain exceptions in comparison to the amount of courses at the university. Therefore TeachING-LearnING.EU encouraged the teaching staff to publish the results end experiences in order to make it visible for the engineering education community. The future challenge will be to lift these innovative approaches on new a level and to make them even more useful for the whole curriculum. Judging if this is unique to engineering education is difficult, as sufficiently similar approaches for other subjects do not exist.

2.1.4 Conclusion on the stakeholders' perspective

An aspect which is unique to engineering education is the need for virtual and technology enhanced environments. This is both the students' and the teaching staff's perspective. Especially in engineering, students need practical experiences. This is often gained in laboratory work, a widely-used approach to teach the grass-roots of science. Experiments are mostly conducted for basic subjects such as physics or chemistry, but also for manufacturing technology or materials science. Limited physical laboratory space is often the boundary for constant regular access to experiments. Moreover, students need to know the practical relevance of the content they learn. A common approach here is to offer internships or excursions. However, because of the costs, complexity and criticality of industrial sites, it is not possible for a student to explore such instalments freely and experiment on her or his own, on one hand to ensure on-going production and to avoid damage to the machines and on the other hand to protect the student from harm by physical forces or contact to hazardous material. To overcome this, it is possible to rebuild such industrial complexes within virtual environments. In simulations the principles behind the industrial site can be connected with the respective courses.

A challenge unique to engineering to integrate student-centred teaching concepts is to provide more virtual or remote laboratories, to establish more simulations e.g. on production scenarios and thus to provide engineering students with opportunities to experiment freely. Corresponding teaching concepts can foster creativity, self-management and problem-solving skills, which would also meet the employers' perspective.

2.2 Research on large audience lectures and ways to a win-win situation

Teaching and learning in large audiences is a huge challenge to both lecturers as well as students. While lecturers face the difficulty of speaking to a mostly loud and very heterogenic audience, students often lack the opportunity of being an active participant in class. To counteract these difficulties two exploratory studies were conducted at RWTH Aachen University. In addition to that, a set of didactical methods was identified within a workshop series with teaching staff of different universities. The design of the study as well as two of the methods, an audience response system and the approach of the flipped classroom, are explained in the following section.

The exploratory observational study started in the winter semester 2010/2011. A second observational study followed and was carried out with optimized detection methods in order to obtain a comprehensive picture of the situation in the following winter semester 2011/2012. For both studies, the same 13 lecture sessions were selected with a number from 250 to over 1000 students. The focus of the observation was primarily on the media use, the auditorium situation, the course structure and the interaction between lecturers and students. The results of the analysis confirmed the assumption that the classes with large audiences are mostly designed as a classical frontal lecture. The applied media was rather used to support this one-way communication, e.g. by power point slides with text, grafics [7]. The workshop series had the goal to reveal best practices for interaction with a large audience. The various solutions and actions were collected and supplemented by the experience of the individual participants. This collection was published in late 2013 as a methods manual under the name "VorlesBAR" and provides teachers of large audiences with a selection of methods suitable for lecture situations with different demands [8]. In order to illustrate the results of this research field of TeachING-LearnING.EU, two of these methods will be explained in the following. They were both implemented in lectures of the RWTH Aachen University with audiences of 1000+ students. Of the two methods, one represents the category of technology enhanced learning (audience response systems) and the other one the category of virtual learning environments (flipped classroom). Apart from matching those categories, both concepts fulfil the general requirement of a lecture to have a physical face-to-face learning component.

In several lectures, audience response systems (in literature also known as "clickers" or TED [9],[10] was introduced in order to support the active participation of all students. Using this method students anonymously answer questions posted by the teacher during the lecture - e.g. with the help of a mobile app. This way of interaction between teacher and students has been used several times since 2012 in the lecture “Informatics in Mechanical Engineering I” – always accompanied by an evaluation. It turns out that students in general welcome the use of this interactive method. It promotes a better understanding of the lecture’s content. Moreover, it helps the students to be more attentive as well as motivated. The experience shows that the participation rate in such anonymous polls is higher in comparison to orally asking the students in the lecture hall. Following the evaluation’s results this is because the students appreciate the anonymity. The fun factor while using the mobile app is also important, as it reminds of TV-shows like ‘Who wants to be a millionaire?’. Furthermore the experiences show that there are several ways of using such systems. Firstly they can be used in order to refer back to content from the last lecture or even former semester. Asking for ‘old’ content the teacher can see in how far it is remembered by the students and adjust the own lecture to that. Secondly questions concerning the actual content are possible and give the teacher the opportunity to see if and by how many per cent of the students the actual content is understood. A third way of using this technique is to ask specific questions, from which is known that students normally give wrong answers - e.g. because of common misconceptions. Based on such firstly negative results a deeper discussion on the content can be initiated and by discussing the right answer an ‘Ah, now I get it’-effect can be provoked.

The flipped classroom is a teaching concept, in which the classical parts of a lecture are being swapped. Students watch the typical lecture via video, where the lecturer explains new content, calculates exemplary problems etc. Oftentimes those videos have been recorded in the previous semester. The part of the learning process, where students mainly have to listen, is done at home. Therefore, they can repeat sequences which they found difficult and acquire new information at their own pace. Nevertheless, during the “regular lecture time” students meet with the professor in person as well. In this meeting, students can ask questions and problems are being calculated together. A big advantage is that by this switch of activities the face-to-face time with the professor is much more interactive. A challenge is, that the efficient use of the regular lecture time for interaction highly depends on the preliminary work of the students [11],[12].

To answer the questions posted previously in this paper, lectures with large audiences need to be more interactive in the future. This result is in line with the employers’ idea of employability, that students need to be more active and out-going. Letting students answer content-related questions with audience response systems helps them to solve problems on their own. Letting them learn the content at their own pace in the first place, like in the flipped classroom approach, supports their skills of self-management. Several other solutions towards more interaction in classes with large audiences have been identified by TeachING-LearnING.EU. Many of them specifically meet the needs of teaching staff and students.,

3 FINAL CONCLUSIONS AND RECOMMENDATIONS FOR THE FUTURE

After more than three years of close collaboration with teaching staff a lot of experiences have been made. Although mainly focussing on the situation in Germany, the centre still seeks to foster the professional dialogue with other international associations in the field of engineering education. Especially for countries, which have to deal with similar change processes in the field of higher education, it is indispensable to exchange ideas and learn from each other. Therefore this paper and the presented results are mainly to be seen as inspiration and information how such a process can be put into practice. Based on the main results explained above, TeachING-LearnING.EU draws the following conclusions and offers recommendations for future Engineering Education innovation:

- Establishing and supporting specialized competence centres directly in the universities is a key concept to bring didactical and field experts together. Both sides bring their own perspective to the discussion and in close collaboration new teaching concepts can be worked out. In addition, the various stakeholders appreciated the fact that the competence centre acted as a communicator between them. Bringing all perspectives (researchers in engineering education, students, teaching staff and employers) together not only leads to a fruitful dialogue, but to new concepts that meet the different demands. Only with the help and the perspective of all stakeholders, engineering education can be made fit for the future.
- Providing such centres with financial support effectively supports innovations in teaching. Every financial support for teaching improvements increases the appreciation of teaching amongst the teaching staff. This positive perception of teaching innovations is urgently required.
- A strong connection between university and employers is needed more than ever in order to build adequate learning environments fitting both the industry's and the universities' demands. In this context the involvement of university alumni is very fruitful for both sides. They can take the students' perspective on the one hand and give profound recommendations on the other hand. Therefore they can act as adequate role models for young students as well as young graduates.
- Students should be seen as competent, active and constructive partners in the context of designing and improving higher education environments. They do know very well what is needed and have ideas how courses should be designed in order to make them as successful for their personal learning process as possible. Idea competitions as well as lead student workshops guide this development very well, and in combination with engineering education expertise can lead to the implementation of innovative teaching concepts.
- High potentials for future improvements are seen in fostering and developing technology enhanced learning in all its diverse forms. After several years of testing and development in e-learning as well as online learning, the engineering education community now is able to use their advantages in a targeted way. Special focus in this context is to be seen in providing more resources for virtual or remote laboratories and for programming simulations. Within the TeachING-LearnING.EU project basic as well as application-oriented experiences have been made in this context. All of them are and will be developed further in the ELLI project, which also is conducted by the four TeachING-LearnING.EU universities [13].

The latter, technology enhanced learning, at the same time is a central context for future research. Based on the experiences made in the TeachING-LearnING.EU project there are still high potentials in this area and with new technical achievements every day more potentials can be identified. As a very famous example at the moment Massive-Open-Online-Courses (MOOCs) are discussed very controversially. Are such courses only hype? Are they a promising business model for private universities? Are they an adequate way to face the big audiences lecture in higher education? If so, what on the didactical level has to learned in order to utilise all possible advantages of MOOCs. These are questions that have to be discussed and answered in the near future. Similar questions - and this is a topic very unique to engineering education – can be made in context with the use of remote laboratories in teaching. The incorporation of laboratories in general is a key aspect of the engineer's' education. Using them remotely offers new opportunities in terms of accessibility and didactical embedding. Central steps have been made during the TeachING-LearnING.EU project but there is a lot left to investigate so that the potential of virtual learning environments is used to its full capacity.

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