Engineering Education Review

ORIGINAL ARTICLE

Innovative engineering education for a better future

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ABSTRACT

The world is now changing almost continuously and very rapidly. Multifaceted challenges are facing humanity. Great minds have highlighted that you cannot solve problems on the same level of consciousness that created it. Better engineering is a basis to give our planet and our people the best possible perspective. It can ensure a safer, more fair, healthier, more efficient and peaceful future. To improve the world in a sustainable and an ethically responsible manner, future engineers need the best possible education. Students should learn to develop and apply better technologies, and universities have a responsibility to deliver them outstanding knowledge based on best possible methods. In the applied sciences know-how should not only be generated and transferred within academic circles but should be primarily used in real life. Theory has to be integrated with practice. In the classroom engineering students should be empowered to meet challenges in life, at the working place and beyond. This paper introduces a innovative approach in engineering education based on the cases of work-integrated study programs at the Hainan Bielefeld University of Applied Sciences in Hainan, China.

Key words: engineering education, work-integrated study program, empowerment, university-industry partnership

ENGINEERING EDUCATION FOR A BETTER FUTURE

There is an old saying that "Great minds think alike" and so it's probably no surprise that a 6th century BCE, Chinese thinker, Lao Tzu and one of the preeminent scientists of the 20th century, Albert Einstein, came to very similar conclusions about the best way to solve humanity's personal and collective problems. Lao Tzu said, "The key to growth is the introduction of higher dimensions of consciousness into our awareness."[1] Albert Einstein said, "No problem can be solved from the same level of consciousness that created it".[2] And so, as we look out at global problems in the 21st century and the world of Environmental Engineering Education, we need to think-about, dream-up and plan-for, new ways of educating, engaging, and empowering todays' engineering students.

The world is now changing almost continuously and very rapidly. The increasing speed of technological progress especially, is constantly producing new and revolutionary innovations such as Artificial intelligence, robotics, nanotechnologies, 3D-printing, blockchain and smart grids. In addition to technological change, the challenges of climate change, population growth and urbanization require innovative engineering and technology, better solutions and transfer, plus increasing engineering capacity and competence building. Given the speed of these changes, and the challenges faced by humanity, the engineering profession itself, also "needs to undergo transformative development worldwide to address the multifaceted challenges facing humanity".[3]

"For millennia, engineers have been recognized as individuals with the ability to find solutions for everyday problems".[4] Today, engineering has a central role in the

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United Nations 2030 Agenda for Sustainable Development (SD) adopted by the United Nations 2015.[5] Better engineering is a basis to give our planet and our people the best possible perspective. It can ensure a safer, more fair, healthier, more efficient and peaceful future.

"Engineering is a problem-solving profession".[6] Engineers have a creative mindset, are innovative, and seek improvement. Engineers actively contribute to the innovations in their companies and beyond. They influence practically everybody's daily life, everywhere, today and tomorrow. Engineering can lead to results that can change parts of the world forever. Currently we see this in the development of artificial intelligence (AI).

To improve the world in a sustainable and an ethically responsible manner, future engineers need the best possible education. Students should learn to develop and apply better technologies, and universities have a responsibility to deliver them outstanding knowledge based on best possible methods. Regarding the rapid technological evolution the learning outcome in "engineering education should follow suit, which will involve changes to both the content of education and the method of learning".[6] New educational approaches need to move away from the traditional teacher-driven system to a student-centered and problem-or work-based one, and from the technical knowledge focus to a much broader interdisciplinary approach to learning.[3] To define the strategy to develop engineering education at a university you firstly have to clarify who has an interest to do so. Basically, it is the global, regional or local society, the future employers of the students and the students themselves (See Figure 1).

Future employers would prefer to employ excellent educated talents who are highly motivated and loyal to secure their future competitiveness. In the best-case scenario, there would be no gap between the required skills and the available talent and all graduates would be productive and innovative for the company from Day 1. The students are interested in a future-orientated study program, an ideal preparation for their professional life, job security, career perspectives, and a suitable job environment. The society needs highly qualified experts with the required skills for the job market. It is crucial that graduates can be integrated into the job market as soon as possible so that they can contribute to social stability in their communities (avoidance of emigration). Later they can help to secure sustainable development in the region if they are able to work in an innovative environment like a high-tech zone, a science park, or a special business incubator.

That's why the development of engineering education should be the joint effort of many stakeholders like governments, academia, industry, engineering organizations and even civil society. Fostering partnerships between universities, companies, administrations, and governmental institutions are crucial for this. Universities are part of a local, regional and often global network. They are funded with public money, so they have the responsibility to meet big and small challenges of society and its stakeholders with excellent education, research and transfer. Students should be aware of this and be integrated in the societal networks of the universities to be able to contribute positively to them. Sometimes this is called the "third mission" of the university next to education and research.

INTEGRATING THEORY AND PRACTICE IN EDUCATION

Today academic knowledge is mostly published through the internet and high-ranked journals in a one-way transfer. But one-way communication from academia to the "outside world" is not enough to secure sustainable effects on science, society and politics.[7] Theory has to be applied. This is not a new insight. The famous German scientist Gottfried Wilhelm Leibniz wrote in his dissertation in the year 1666 that academic disciplines should unite "theoriam cum praxi" (theory with practice).[8]

In the applied sciences know-how should not only be generated and transferred within academic circles, but should be primarily used to improve the outside world. Therefore, the theoretical input has to be transferred into real life. Applied science aims to provide solutions to everyday challenges that everybody has to face, all around the world. Big challenges like climate change, deforestation or conserving the global fresh water supply; as well as specific problems like implementing safe working conditions in factories and offices. This understanding should be transferred to students, that every challenge is important and every question should be addressed. Teaching applied science should encourage and equip all students so they are ready, willing and able to use their knowledge, not only in their working environment, but also in taking political and social responsibility based on knowledge transfer, self-confidence, dialogue and cooperation.

As Kolmos has described, re-defining and modernizing engineering education needs both a top-down approach and a bottom-up approach.[6] Based on the university's mission and the development plan, the university board as the "educational leader" has to define the overall strategy for the future engineering education and implement it top-down. By promoting this strategy, the "usual tradition" of teacher-centered education will be changed by the lectures. Kolmos describes three

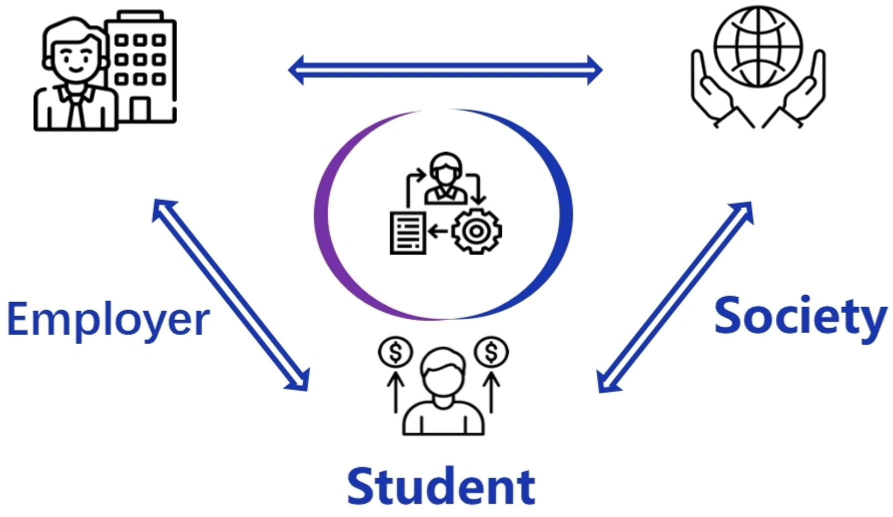

Figure 1. Main Stakeholders of Engineering Education.

different strategic options a university could follow to foster application knowledge (know-how, know-why) in engineering education: (1) The add-on strategy which adds more student-centered and active learning in the single lectures; (2) The integration strategy that integrates project-based modules and team learning in the lectures (project management, collaboration in labs) and uses real life projects done in so-called learning factories in existing courses; (3) The re-building strategy that restructures the whole education program by integrating all kinds of active learning, interdisciplinary project work and work-integration (internships) to educate both technical knowledge and competencies, and professional or employability competencies.[6]

EMPOWERMENT EDUCATION IN THE CLASSROOM

The bottom-up approach in engineering education should be based on the empowerment of the student in the classroom. In conventional lectures, the teacher defines what is to be taught and the methods to be used.[9] This also corresponds to a strongly deductive teaching style, which Felder *et al.* describe as the prevailing method where teaching starts with principles and "fundamentals" and only later proceeds to applications.[10] This approach of lectures is traditionally based on the idea that the lecturer knows everything, while the students know nothing (deficit orientation). The lecturer defines the particular set of what students need to learn and how these learning needs can be met. Students do not have any active role during this process. The lecturer becomes the central point, around whom the entire process revolves. In applied sciences, this method cannot be regarded as state-of-the-art. The success of communication (teaching) depends on the listener not on the speaker. Because of this, effective teaching requires a change of the lecturer's role from being a mere sender of knowledge to a coach, then to a motivator, and finally, to a mentor.

Participatory training methods are based on an empowerment-orientated approach. They promote learner-centered development through training and learning. Participatory training methods help learners by enabling them to develop knowledge, skills and attitudes individually and to share perceptions so that they can actively contribute to renewal and improvement.[11] They aim to increase the potential of the learner (potential orientation). Empowerment teaching thus boosts the confidence of learners which then impacts on the motivation of learners.[12]

In practice, active application of participatory teaching methods also implies a change of perspective for the lecturer as the seats are arranged in a semi-circle or circle to create a closer contact between participants and the lecturer.[13] Regarding training materials, diverse tools and other materials such as white board, moderator box and contents, sheets of A0 paper (flipcharts), notebooks, projector and screen, *etc.* can be used. Besides this, lecturers should use materials such as photos from incidence in practice or/and video clips to visualize the theoretical inputs.[14] This will help students to remember the detailed information, more than by just listening to the trainers, or reading documents or books.[15] Additionally, posters, related statistical data, and charts can contribute to a better understanding.[14] Most important, however, are the lecturer's attitudes and mindsets of intelligence and abilities: studies have shown that an open, non-fixed belief about intelligence may influence students 'performances in exams,[16] their persistency in college and students' motivation.[16,17]

Moreover, lecturers' attitudes and mindsets may also convey and facilitate a sense of belonging to engineering applied sciences[18,19] as this may be an important factor to further pursue this field academically or professionally.[20,21]

If participatory training methods are applied during the teaching programs the lecturer can motivate and mentor the learners' initiative and encourage them to contribute more at work, for example, by looking for difficulties and problems and working out how to improve the situation themselves. Participatory teaching methods promote learner-centered development through learning and practicing. Therefore, teaching should be multi-sectoral, interactive and focused on group work. Participatory teaching is learner-centered as it recognizes, evaluates and seeks to build on the existing knowledge of the learners.

In addition, the lecturer should explain the "big picture" of the lecture, the framework and the rules he expects to be followed in the course of the lectures. It must be kept in mind that learning is set within a frame which might incorporate cultural differences between the teacher and the learner. Culture is changing.[22] The students from today don't have the same attitudes as students in the "good old days", when the professors did their own studies.

After formal aspects of the training course have been defined by the lecturer, the participants should be asked to introduce themselves, sharing briefly their experiences and expectations of the content of the lecture. The aim of this first short introductory sequence is to overcome students' hesitancy to speak. During the whole training course, it is imperative to welcome questions as this gives the students the chance to participate and actively contribute to the learning success of their fellow students.

After the introduction it is necessary to quickly "break the ice" between lecturer and students! New students have a lot of intrinsic motivation and interests. If possible, the creation of an emotional bond based on trust and sympathy should start from the beginning. A "warm-up phase" has to be regarded as important as communication has a social dimension and is therefore the result of the interactive behavior between the lecturer and the learners (based on their culture and experiences). In the process of an active know-how transfer, two levels of teaching are present. On the content level the objective information is emitted but on the process, and relationship level sympathies, emotions, expectations and fears are transferred in the way people speak to each other. Communicative relationships–like the ones between lecturer and student–are influenced predominantly by emotional feelings and only to a much lower extent by rationality.[23]

Lecturers and students should understand each other on the content level and on the relationship level. That is why during this phase the lecturer should evaluate potential barriers like shyness, restraint and poor language skills in order to further adapt the course or to offer individual support if needed. In this process the role of the lecturer as a team leader with social competences and emotional and social intelligence is crucial for the success of his lectures. The lecturer should try to encourage the students' willingness and abilities. Moreover, consoling or comforting struggling students is not helpful but tends to demotivate students as Rattan *et al.*[17] have found regarding students' math abilities. Instead, an open mind of the students' ability to grow and develop may essentially make a difference. Though a main aim of the lecturer should be to motivate the students to talk and listen—it is their task to be the best listener in class. Student's acknowledgments of the learning progress should be given and contributions in classroom should be valued. In this way students will feel optimistic about their abilities to learn, enhance creativity and decision-making skills which keep the intrinsic motivation high and leads to a better learning effort.

The learning and experiencing process within the classroom should enable students to develop their potentials, knowledge, skills and attitudes. Central are methods which are often labelled as "active learning" as they engage students in the learning process, by "actively processing and applying information in a variety of ways"[24] and thereby prompting students to "think about what they are doing".[25] This may include many different teaching methods such as collaborative learning in small groups, cooperative learning between individuals and longer phases of problem-based learning,[25] which have been found to positively influence student performance in general and in science, technology, engineering and mathematics in particular. Freeman *et al.*[26] studied the impact of active learning on student performance and found that average exam scores improved by 6% while students in classes with active learning were less likely to fail. The teaching methods have to be outlined and explained to the students comprehensively. Time should be given to the students as they probably do not know the new teaching methods that will be applied during the course.

The course has to be designed by distributing learning in intervals, there has to be enough time for discussions and repetitions. For the long-term learning effect, it is essential that students have the opportunity to learn from their own experiences by guessing, trying, and speculating on new ideas and techniques.

In the theoretical inputs sessions, participants should share their own ideas and experiences. When learners get used to speaking out loud, they gain self-confidence to contribute more.[14] The lecturer leads by setting the framework and planning the learning process. He acts as a moderator when the students provide their own ideas, knowledge and techniques. He helps the learners to understand the content of the lectures leading Q & A sections and discussions.[11]

Keeping in mind different learning styles[27] as well teaching styles especially in engineering education,[10] lecturers use different approaches to engage the students and enhance the active pursuit of new knowledge. It is also important to acknowledge Felder *et al*.[10] assessment, that most engineering students prefer visual, sensing and active learning styles, whereas most engineering education is auditory, abstract and passive. A different teaching approach, as it is advocated here, may therefore enhance student performance and students' motivation. Theoretical input sessions should be systematic, scientific, updated, and realistic. The systemization of knowledge and techniques helps participants better obtain new knowledge and skills. The scientific features are illustrated by up-to-date achievements, can become persuasive evidence to the students. Students are free to contribute to the achievement of the group and ask questions to get a better understanding of the practical relevance of the theoretical input. The lecturer should play the role of a motivator and a mentor when facilitating and supporting participants' knowledge development.[28] Participants can exchange experiences, share reactions and observations, reflect upon implications and consequences, and discuss theoretical input with responsible people in practice. Subsequently students can develop practical and conceptual understanding.[9]

A main goal of the teacher should be that the students are eager to come to class and learn as they have been inspired by the transmitted new ideas and learning processes. Due to the possibility to contribute to class in a two-way-learning-process (which increased their acting competence) a trust and belief in their competencies is enhanced more and more which contributes to an increasing self-efficacy and self-esteem. This can also impact on students' self-belief in their own intelligence and abilities – studies have shown that students' fixed growth mindsets (fixed abilities and intelligence) are predictors of their academic performance.[29]

Planned distractions like participating in sports events, field trips or excursions to cultural sites or even touristic places will foster the group cohesion and support the creation of a student network, which is especially important if students in the courses come from different regions or countries. Extracurricular activities help to overcome barriers between the lecturer and the students and among the students themselves. Enjoying free time together brings collective positive experiences into the classroom. The aim is to create "happy moments" (and many photos by the learners) to show the learners that lecturers can be good company. The learners sometimes will remember these happy moments for the rest of their lives.

By creating a positive and challenging atmosphere the lecturers should guide the students through the exams. Lastly, after the exams, all students should be asked to (anonymously) evaluate the course. Student evaluation of teaching (SET) is an acknowledged instrument of evaluating teaching effectiveness in institutions of higher education worldwide.[30] It can give valuable insights into students' reception to further refine and develop the lectures.[31] Giving meaningful feedback is also a strong motivation for students' participation in teaching evaluations thus accepting students' opinions and feedback may also strengthen the relationship between lecturers and students.[32]

Overall, it is the final and most important task for the lecturer to encourage the students to be proud of themselves. In order to strengthen the emotional bond and build a trustful and long-lasting future relationship, the class and staff of the institution which supported the course could jointly celebrate the end of a course or a semester. This will close the whole education process in an appropriate way.

FOSTERING EMPLOYABILITY: WORK-INTEGRATED STUDY PROGRAMS

Following the theory of Edgar Dale's "cone of experiences", people remember much more by field trips, demonstrations and own experiences than by verbal or visual symbols (reading or listening).[33] So, the aim of work-integrated studying is firstly to learn with all senses, to develop skills and attitudes, and to understand processes and relations. Learning is often not done with the head alone, but with the hands (touching), the heart (emotions), the skin (heat, coldness) and sometimes with the whole body (very strenuous work), and of course mostly in teams. Secondly, the students get to know why their study program is very relevant in practice, why she or he is important for industry and beyond. Practical work can allow future engineers to gain and apply valuable knowledge through structured, supervised, hand-on experiences.[34] The students learn what they will be able to do in the future. This can be an immense driver for their motivation to finish their program as successfully as possible.

Universities of applied science in Germany, for example, are responsible for educating around 70% of all engineers. Since their foundation in 1971 they have been working very closely together with companies and other state-owned and private organizations. These collaborations have been very successful. Today there are more than 200 universities of applied sciences in Germany being a strong pillar for the development of the national economy.

One of them, the Bielefeld University of Applied Sciences and Arts has developed a work-integrated study model based on alternating phases of theoretical and practical education. The theoretical parts are taught in lectures, seminars, exercises on campus, while the practical parts are taught in collaborating companies and other institutions. The joint aim is to train innovative, multidisciplinary and practically experienced talents in line with the needs of economic, social and environmental development. Students should gain fundamental and comprehensive expertise in theory and practice and be proficient in essential procedures. Rich work experience should be combined with high academic standards to develop high-quality engineering talents with excellent employment prospects. This practice-integrated model has been adapted by the Hainan Bielefeld University of Applied Sciences on Hainan Island in China.

During their internship phases, students must be given space to realize self-effectiveness and competence and to develop future skills. They should understand that the details can be seen in the workplace by staff involved directly and not by the management board. Their mentors in practice should foster their acting competence. They should encourage teamwork and demand students' contribution by actively asking questions, sharing experiences and observations, reflecting on implications and consequences and leading the discussion with people in industry. To sum this up, students must test themselves in order to become future engineers, decision-makers and team players. The mentor should set the goals and rules, provide orientation and lead the practical learning process! Most importantly they have to create a positive learning atmosphere with the aspiration in mind—yes, we apply! In many cases the companies will employ the students after the exam, because they simply do a "good job" during the internships.

CASE STUDY: THE WORK-INTEGRATED STUDY PROGRAM DIGITAL TECHNOLOGY OF HAINAN BIELEFELD UNIVERSITY OF APPLIED SCIENCES

The first semester is an "onboarding" semester. The focus here is to integrate the students who are coming from many different regions in China into the university and its processes. The first steps involve empowering the students to use their knowledge and creativity, the improvement of their self-organization and team-work, plus the improvement of their language skills as the focus of study programs. The students learn what it means to study engineering and are informed about their career perspectives by the professors and guest lecturers from companies. They are introduced into scientific writing and project work. Furthermore, they have to improve their English skills and start to learn German. In the second and third semester the students learn the necessary fundamental knowledge of their study program: mathematics, foundations of computer science, algorithms and data structures, object-oriented programming, data bases, data security, foundation of business administration and other classes. After a three-month long third semester, the students do their first internship for two months in companies and get the opportunity to apply their knowledge. Of course, at the beginning, the employer has to invest time and efforts in the engineering talents. But, the more they learn in practice the better they know how to apply their knowledge to support the company.

During the following semesters, students expand their theoretical knowledge on campus in classrooms, in exercises and in special teaching support facilities like laboratories or (virtual) learning factories. Courses deal with topics like business process modeling and (information technology) IT systems, data mining, machine learning, AI, speech and image recognition, web technologies *etc.* Elective modules are change management, diagnosis and predictive maintenance, industrial control technologies, marketing and technical sales, sensors and actuators among others.

To increase the employability of the students based on the demand of industry and administration lecturers with special expertise from practice are employed. They enrich the theoretical knowledge of the students with their applied knowledge, especially in elective modules. This is a win-win situation for both sides: The students learn about the relevance of their knowledge in future jobs, and the lectures from the companies have the opportunity to get to know students who might be future employees.

The more theoretical, but application orientated education alternates with the internships of the students in practice. A work-integrated study program means the academic year is divided into four parts: the education on campus starts middle of August and ends in November, the internship follows from December until the end of January, the students are back on campus from end of February until middle of May, and learn in the companies again until middle of July. Finally, Bachelor theses will be written companies and supervised by both, the university professor and the expert from practice.

UNIVERSITY-INDUSTRY PARTNERSHIP: TRIPARTITE AGREEMENT WITH THE STUDENT

To better cultivate talents for enterprises and realize the work-integrated studying model, a tripartite internship agreement between the university, the enterprise and the students should be formulated. The agreement is necessary to define the rights and obligations of each party. It should be signed by legal or authorized representatives of the University and the enterprise and the student. The term of the agreement should be medium or long term to secure a reliable strategic cooperation in the interest of all participants.

The obligation of the university is to organize interviews with students for internships, work out specific internship plans and timetables with the enterprise. During the internship, the university will appoint a person responsible for supervising and supporting the student, give her or him guidance, and inspect the internship situation. Furthermore, the university has to establish management methods and feedback mechanisms for students in enterprises, motivate them and secure the transparency of information.

The enterprise will appoint a professional tutor to guide the practice process. He is responsible for formulating the internship plan and guiding the content of the internship, as well as carrying out an evaluation and assessment of the student's internship. The tutor must have a bachelor's degree or higher. He has to guarantee that students will be provided with specific hands-on practice related to their study program and may participate in company projects. The enterprise should provide an appropriate subsistence allowance for the student during the internship.

Students are strictly required to follow the rules governing the internship phase and must not violate the Student Code of Conduct or the company's rules. During the internship phase, students might attend classes or have self-study as required by the university. They have to submit a certificate or internship report on their activities. Besides, they have the obligation to keep trade secrets and confidential matters related to intellectual property rights of the enterprise. This kind of agreement can assure the engineering students can be included in the personal development of the companies. When they have graduated the students should be highly employable. They know their employer, they have seen different sections of it and worked in different projects. They have been empowered, theoretically and practically. So from the first day as an employee, they are able to meet the challenges in the work place, be self-responsible and competent as qualified professionals.

CONCLUSION

In applied sciences like engineering, theory and practice should be developed in harmony. This means that the education at the universities should be as innovative as the practice in companies and other institutions. As the philosopher Leipniz said it is a necessity to unite "theoriam cum praxi". Universities should teach the students both with an integrated strategy from the beginning. This is more efficient than a sequential procedure learning theory first, and years later practice. The empowerment of the "next generation of engineers" should be the paramount aim of engineering education to secure a sustainable development and a better future for everybody. This could motivate young talents to study engineering. They are having an excellent reason to do so. They are empowered to become "Engineering Superheroes" ready for the "#MissionTomorrow".

DECLARATION

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Author contributions
Jürgen Kretschmann developed the concept for the manuscript, reviewed the literature, formulated research questions, collected data, conducted analyses and interpreted the data. The author read and approved the final manuscript.

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The author has no conflicts of interest to declare.

Data availability statement
Data used to support the findings of this study are available from the corresponding author upon request.

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