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Design-Build Experiences and Student-Centered-Learning in Biomedical Engineering Curricula

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ABSTRACT

The field of biomedical engineering (BME) is progressing rapidly into new areas, demanding the BME students to develop multidisciplinary skills, knowledge and a possibility for life-long learning. Changing the educational arena from teacher-centered to student-centered-learning is a challenge in the BME domain. CDIO (Conceive Design Implement Operate) design-build courses, starting at the freshman year, makes laboratory and research environment enhance student-centered-learning resulting in communicative skills and team-work. BME specialization, student-centered-learning and design-build experiences are introduced as an integrative part during the third and fourth academic year. Student-centered-learning is often recognized as a situation where the learning possibilities are relevant to the students and where the students themselves determine the short-term goals. The expert or authority teaching has to be replaced by mentorship and facilitators. This is recognized in design-build courses. BME cases without a known solution can be treated and solved through integrative thinking and problem identification. The cognitive tasks require the acquisition and synthesis of information. It prepares students to participate in research laboratories as undergraduates and it prepares them for time-constrained problem-solving in the real world. For research studies and developments in working life, skills including dynamic group processes and awareness of the affective domain are necessary.

BME education has three years experience of design-build courses from the freshman to the last academic year. Directives for the projects are based on clinical settings or demands engaging students to solve real world problems. Interaction with real customers or experts in the field encourages, stimulate and enhance all parts of the CDIO framework. To get a prosperous and successful work throughout the project cycle the project teams as we believe should be built on heterogeneous skill, age and gender, the affective domain all harmonized using a team contract. Project groups have also been enrolled with exchange students creating international groups. Feedback of the group process is given throughout the design-build project but especially after completion. Theoretical parts supplement the project and the group both in-depth but also to focus and harmonize the group towards the design-build project outcome. Experts working in the field validate and test the project. Assessment is conformant to a student-centered-learning process as an integrative part of the course. Development of assessment protocols and strategies as an integrative part of the learning process must be stimulated and emphasized.

INTRODUCTION

Biomedical engineering (BME) or Bioengineering is a domain, which progressively and rapidly finds new areas for research and development, demanding the BME students to develop multidisciplinary skills, knowledge and endeavour for life-long learning. The Biomedical Engineering specialization, performed at the department of Biomedical Engineering, is part of the five-year master programme in Applied Physics and Electrical Engineering programme at Linköping University, Sweden. Extensive courses in mathematics and physics are found in the freshman and sophomore years, while focusing on BME is dominant at the last two years. Redesigning the curriculum for the Applied Physics and Electrical Engineering programme, according to the CDIO initiative involved all specializations, including BME. The CDIO initiative has its focus on restoring, strengthening and "producing the next generation of engineers" [1]. This is well in accordance with the harmonisation process in higher education in Europe, the Bologna process [2] and EUR-ACE [3], but also the concept of "engineering for health" [4]. In 2004 the twelve standards for a CDIO programme were adopted with 7 of them being essential to a CDIO programme [1]. It has been manifested earlier that the BME domain has potential for new learning strategies and outcomes [5]. Our curriculum, as redesigned, has therefore emphasized the standard context, syllabus outcome, introduction to engineering, design-build experience, integrated learning experience and active learning.

Our aims are to create a multi-professional education programme in Biomedical Engineering with multidisciplinary pedagogy and resources supporting the students not only to solve and apply their knowledge but also to value and create new knowledge from already existing and to foster tomorrow's engineers for health.

EDUCATIONAL ENVIRONMENT in BIOMEDICAL ENGINEERING

Student centered learning

The BME domain demands the students to develop multidisciplinary skills and knowledge and to strive towards life-long learning. Therefore, embracing pedagogical renewal as a part of new or revised curricula in Biomedical Engineering education has been demanded [5], [6]. Traditional "teaching" where the authorities or experts "teach" what they think is important or is not, has to be revised by other learning strategies [7]. The BME student has to meet both the cognitive and the affective domains. Benjamin Bloom already in 1956 [8] came up with a classification system, known as Blooms taxonomy, trying to describe the intended behaviour of students in terms of learning objectives. Six levels of intellectual skills were defined incorporating acquisition and the use of knowledge for evaluation and judgment of the learned material. The teaching model is too often focused on the knowledge level and the assessment seldom goes beyond the application level. A decade later the affective domain [9] was described relating the emotional component of learning. Both will have a large impact on the design of BME education and on the teachers in their effort to meet future demands.

Switching from teacher-centered environment to student-centered-learning is a great challenge but also a possibility for BME. Student-centered-learning is often recognized as a situation where the learning possibilities are relevant to the individual students and where the students themselves determine the short-term goals. In such a learning process the expert or authority teaching has to be replaced by mentorship and learning facilitators. The task for the teacher is to create assignments and activities that require student input but also to stimulate and motivate the student to learn [10]. A criticism, often mentioned against student-centered-learning, is the shortcoming of students in realizing how the learning objectives can be used to reach the important learning outcomes since they lack a priori knowledge.

Biomedical engineering curricula

The redesign of the BME curriculum was ahead of the CDIO initiative and started in 1990 with some of the courses. McMaster's university, the medical education program at Linköping University and the engineering program in Information technology, all practising Problem Based Learning, inspired this. It was not compulsory, just elective for those lecturers confident and interested in pedagogical issues and awareness. The students participating in our programme have their background in basically four disciplines: Applied Physics and Electrical Engineering, Computer Science and Engineering, Information Technology and Engineering Biology. But also students from Mathematics, Physics and the shorter Bachelor programmes are allowed to enter the BME master programme. This means students actually come into the programme with different skills and educational background. BME specialization and student-centered-learning (core PBL) is introduced as an integrative part during the third, fourth and fifth academic year. Problem based learning being a part of student centered learning was introduced to the modules of TBMT01 Biomedical Signal Processing, TBMT02 Biomedical Imaging, TBMT36 Biomedical Optics, TBMI7 Medical Informatics, TBMI27 Classification and Decision Support making and later into TBMT06 CDIO – project course in Biomedical Engineering.

Learning outcomes

It is well known that examination has an effect on the learning processes and this is likely to be found in the measurement model of assessment [12] with a dominating summative examination. In student centered learning examination is part of the learning process itself and not separated from the rest of the course. Traditionally, aims and goals have been set by what the student should read on behalf of the lecturers demand, teacher or tutor driven model. In problem based learning the aims are crucial, and assessment and feedback are conformant as an integrative part of the courses, with both formative and summative examinations. Therefore the learning process should be described in terms of “Learning outcomes” to better apply to the process. It is often described in statements of what students should know, understand or being able to perform after passing a course or a module. This is often described in terms of knowledge and understanding, problem solving, skills according to: experiments, mathematics, design, teamwork, communication, etc. The is also valid for the capstone design-build course and with taxonomies as a base for the formulations [8], [12].

Design-build courses

The CDIO design-build course, starting at the freshman year, makes laboratory and research environment enhance student-centred-learning resulting in communicative skills and teamwork.

In the design-build course the student should be able to mirror and establish engineering skills in a professional manner and in accordance with industry rules, especially within the biomedical engineering domain.

After passing the course the student should be able to:

- *Identify biomedical needs and suggest engineering solutions/actions.*
- *Analyze and structure problems into sub domains, in relation to their pre-knowledge and to create new knowledge.*
- *Generate new knowledge and transform knowledge from other scientific and engineering fields into the field of biomedical engineering.*
- *Demonstrate solutions to identified needs and solutions.*
- *Apply critical thinking and judgement.*
- *Develop initiative and creative thinking.*
- *Document the work according to the LIPS-model [11].*
- *Work in teams and take responsibility for the group and themselves.*
- *Communicate results within the committed time plan.*

The project starts with just a short directive, from which a full-scale design-build project emanates, capable to meet the requirements of the customer. An example of a directive is the following:

To construct and analyze a wearable biomedical optical sensor system able to record spatial and temporal blood volume changes within the micro vascular bed. The team should be able to demonstrate physiological events in relation to changes in optical properties as light interact with tissue. They should also specify the choice in selection of wavelength and bandwidth and recommend a setup depending on the application site.

A comprehensive list of requirements is compiled and documented after negotiations with the customer. Available time and resources are taken into consideration while deciding upon the requirements. All resources (from people to machines) are known right from the beginning. Project steering follows the LIPS-model and computer-aided project management is available at request. Usually, five to eight persons constitute a project team, with a minimum of four persons in case of insufficient enrolment of students. The variable team size demands that the project requirements can be adjusted accordingly. The team is assigned the same supervisor during the whole project.

The complete capstone design-build course consists out of two parts: First a theoretical deepening and then the project itself, the two comprising 2 and 6 credit points respectively. More specifically, the theoretical part together with the specification of the project requirements concludes the first phase of the course. Design, implementation, documentation and evaluation define the project's second phase. A full semester is set aside for the complete module and the economy of the group is a total of 200 hours per student.

Lessons learned

Team formation: The participating students comprise a heterogeneous group with different backgrounds and skills. Different strategies for constituting the project teams have been tested. Traditionally, students themselves have selected their members or joined a team because of the directives given; alternatively the tutors have selected team members. To get a prosperous and successful work throughout the project cycle the project teams, as we believe, should be built on heterogeneous skill, age and gender and with the affective domain all harmonized using a team contract. Nevertheless teams consisting of only men or women have been constituted. Despite the many degrees of freedom in constituting the team no discrepancy has been noticed in terms of the performance and outcome of the projects. The procedures of forming a team have not implied any negative issues; instead it is rather regarded as positive both from our and the students' point of view.

Recently, exchange students have been participating in the design-course introducing even more possibilities. Forming project groups with English as the only operative language has been tested and turned out working excellent. None of the students had English as their native language but reported positively that this included a great possibility to improve their linguistic skills but also sharpened the project work since communication was rather important to make the goals understandable for all participants. As a consequence, at the final demonstration and presentation of the project, were all groups are present, the performance and evaluation are prescribed to English since this gives further possibilities to gain communication experience in a setting that resembles an international forum.

Project disposition: Directives for the projects are based on clinical settings or demands engaging students to solve real problems. The purpose of this selection is to reinforce both the "conceive" and the design [CDIO] properties, makings them easier to perform, more understandable and trustworthy for the student. Interaction with real customers or experts in the field encourages, stimulate and enhance all parts of the CDIO framework. Experts working in the field validate and test the project.

Design-build assessment: Assessment is conformant to a student-centered-learning process as an integrative part of the courses. Evaluation and feedback, both oral and written, of the group process is given throughout the design-build course but especially after completion. The project deliverances according to the project model [11] throughout the design-build project are important since they act as a formative feedback and assessment. With this setup the project becomes dynamic, giving the possibility to adapt the project structures and ingredients to the particular needs and prerequisites of the individual in order to successfully reach the design-build course learning outcomes. Development of assessment protocols and strategies as an integrative part of the learning process must therefore be stimulated and emphasized in design-build projects.

General outcomes for students and teachers: While the course is ongoing, students change their educational viewpoint going from an instructional to a learning environment. Given the project disposition, the teachers need to rely on students' capacity to take responsibility of their own learning. This means that students need to make sensible use of the available learning opportunities (e.g. formulate personal learning goals, find the ways of achieving those goals, evaluate their own performance etc) as facilitated by the course tutors. In the same process the tutors observe this educational change and can to an even greater extent contribute to the learning environment.

This student focus also incorporates the affective domain and how students feel about themselves. The practical use of theoretical knowledge (especially in physics, electronics and computer technology) as outcome from earlier studies has in many cases surprised the students themselves in a positive, self-confidence boosting, manner. The majority of the team members report that the "newly" discovered communicational skills and the feeling of belonging to and acting in a professional group, where everybody is depending on each other, were highly inspiring and developing on a personal level.

Furthermore, students tend to spend much more time on the CDIO courses compared to other, "traditional" courses according to the feedback given at the end. This may have a negative impact on other courses and modules, receiving less student attention. Highly motivating to work in a team, putting the student knowledge to the test, developing new skills by working with technology in practice etc are some of the comments given by the students themselves when explaining their prioritization. This finding has to be handled when the course is designed and the learning environment created.

A final remark needs to be made about the student-teacher relationship. Teachers (tutors, supervisors) get to learn their students during a design-build course; that's an inevitable fact. The projects demand personal development, since the responsibility that follows with the assignment of the different project roles (especially the one of the project leader) may find the students unprepared and elicit inter- and intrapersonal friction and thoughts respectively, that need to be addressed and solved within the group or with personal discussions with the tutor. The role of the project leader in design-build courses has to be given more attention since there are no specific learning outcomes visible for this role although very important for the project and thus the course outcome.

CONCLUDING REMARKS

Student-centered-Learning has been successfully tested in engineering education. Most success has been gained in courses including application of general knowledge. Problem-based learning as part of student-centered-learning is the educational approach or scaffolding-learning environment, a uniquely suited breeding ground to challenge and develop BME education and domain. Nevertheless engineering science can learn from the PBL development in medical science, but has to create its own strategies, learning outcomes and learning objectives. BME cases can be treated through integrative thinking and problem solving strategies that distinguish the BME experts from their single-discipline peers. The cognitive tasks require the acquisition and synthesis of information. It prepares students for work and participation in research laboratories and it prepares them for time-constrained problem solving in the real world, including research studies. Development of assessment protocols and strategies as an integrative part of the learning process must be stimulated and emphasized. BME teachers/educators/facilitators have to reflect and change their performance in order to avoid violating the learning process. Skills in dynamic group processes and awareness of the affective domain are necessary. This educational approach is well suited to the demands of a rapidly changing field that needs experts who can change and grow through lifelong learning. After more than ten years of working experience with student-centered learning processes that could be described using the term “multi-professional PBL”, we see students with more confidence and ability to value information and facts and to create knowledge from available resources.

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