

Design-build courses and student-centred-learning in biomedical engineering education

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ABSTRACT: The biomedical engineering 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 a new or revised curriculum has been demanded. For the capstone design-build course, taxonomies are used to formulate the learning outcomes and encourage a switch from a teacher-centred environment to student-centred learning. Design-build courses, as realised in the curriculum at Linköping University, Linköping, Sweden, starts with clinical settings engaging students to solve real world problems while working in a project team. To get a prosperous and successful work throughout the project cycle, project teams should be built on heterogeneous skill, age and gender, and harmonised using a team contract. Feedback of the group process is given throughout the design-build project, especially after completion. Assessment conforms to a student-centred-learning process as an integrative part of the course. With this set-up, learning becomes active and dynamic, giving the possibility to adapt project structures and ingredients to the particular needs and prerequisites of individuals in order to achieve the learning outcomes of the design-build course.

BACKGROUND

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 to encourage life-long learning. The biomedical engineering specialisation, performed at the Department of Biomedical Engineering, is part of the five-year Master programme in applied physics and electrical engineering at Linköping University in Linköping, Sweden. Extensive courses in mathematics and physics are found in the freshman and sophomore years, while focusing on BME dominates the last two years. The students participating in this programme have backgrounds in basically four disciplines, as follows:

- Applied physics and electrical engineering;
- Computer science and engineering;
- Information Technology (IT);
- Engineering biology.

However, students from mathematics, physics and the shorter bachelor programmes are also allowed to enter the BME programme. This means that students enter the programme with different skills and educational backgrounds.

The curriculum for the applied physics and electrical engineering programme was redesigned according to the CDIO Initiative (*Conceive – Design – Implement – Operate*) [1]. This involved all specialisations, 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, specifically the following:

- The Bologna process [2];
- EUR-ACE [3];
- The concept of *engineering for health* [4].

In 2004, the 12 standards for a CDIO programme were adopted, with seven of them being essential to a CDIO programme [1]. It has been manifested earlier that the BME domain has the potential for the generation of new learning strategies and outcomes [5]. The redesigned curriculum at Linköping University has, therefore, emphasised the standard context, syllabus outcome, and an introduction to engineering, design-build experience, integrated learning experiences and active learning.

The University's aims are to create a multi-professional education programme in biomedical engineering with multidisciplinary pedagogy and resources that support students not only to solve and apply their knowledge, but also to value and create new knowledge from that already existing and to foster tomorrow's engineers for health.

In this article, the authors describe their experiences in transforming the curriculum from a teacher-centred orientation to student-centred learning and the introduction of design-build courses.

THE EDUCATIONAL ENVIRONMENT AND THE BIOMEDICAL ENGINEERING CURRICULUM

The BME domain demands that students develop multi-disciplinary skills and knowledge and in order to strive towards life-long learning. Therefore, embracing pedagogical renewal as a part of a new or revised curriculum in biomedical engineering education has been demanded [5][6]. Traditional *teaching*, where the authorities or experts *teach* what they consider as being important or not, has to be revised by other learning strategies [7]. Already in 1956, Benjamin Bloom came up with a classification system, known as Bloom's taxonomy of the cognitive domain, trying to describe the intended behaviour of students in terms of learning objectives [8]. Six levels of intellectual skills were defined incorporating the acquisition and use of knowledge for the evaluation and judgement of the learned material.

The teaching model is too often focused on the knowledge level, furthermore, the assessment seldom goes beyond the application level. A decade later, the affective domain was described relating the emotional component of learning [9]. Both domains are important in the design of BME education and on teachers' efforts to meet the increased demands on BME students in the future.

Switching from a teacher-centred environment to student-centred learning is a great challenge, but also a possibility for BME. Student-centred learning is often recognised as a situation where the learning possibilities are relevant to the individual student and where students themselves determine the short-term goals. In such a learning process, the expert or teaching authority has to be replaced by mentorship and learning facilitators. The task for the teacher is, therefore, to create assignments and activities that require student input, but also to stimulate and motivate student to learn [10].

The redesign of the BME curriculum started in 1990 before the emergence of the CDIO Initiative with some of the BME courses. McMaster's University, the medical education programme at Linköping University and the engineering programme in Information Technology (IT), all practicing Problem-Based Learning (PBL), inspired this renewal. It was not compulsory, just an elective for those lecturers confident and interested in pedagogical issues and awareness. The BME specialisation and student-centred-learning (core PBL) is introduced as an integrative part during the third, fourth and fifth academic years. Problem-Based Learning (PBL), being a part of student-centred learning, was introduced to the following courses:

- TBMT01: Biomedical Signal Processing;
- TBMT02: Biomedical Imaging;
- TBMT36: Biomedical Optics;
- TBMI7: Medical Informatics;
- TBMI27: Classification and Decision Support;
- TBMT06: CDIO design-build course in Biomedical Engineering (later).

Examination and Learning Outcomes

In the traditional teacher or tutor-driven model, the teaching goals have been set according to lecturers' demands, which results in the strict predetermination of what the student should read in order to pass the examination. However, in student-centred learning, examination is part of the learning process itself and not separated from the rest of the course. If aims are crucial, then assessment and feedback should conform to these aims as an integrative part of the course. Therefore, the results of the teaching process should be described in terms of *learning outcomes* since *the description of outcomes (what a learner knows and can do as a result of a learning process) rather than the more traditional description of learning input (syllabus or course content)* makes the measurement of learning easier [11].

Therefore, in redesigning the BME curriculum, the courses are written according to learning outcomes and often defined in terms of knowledge, understanding, problem solving and skills regarding the following key aspects:

- Experiments;
- Mathematics;
- Design;
- Teamwork;
- Communication, etc.

This is also valid for the capstone design-build course where recognised taxonomies are used when formulating the learning outcomes [8][12].

DESIGN-BUILD COURSES

The CDIO design-build course results in communication skills and teamwork, and provides a laboratory and research environment that enhances student-centred learning [1]. It starts at the freshman year with a reduced version that gradually develops into a full-scale project model in the fourth year.

In the design-build course, students should establish engineering skills and get prepared for their future roles as professional engineers, especially within the BME domain. Therefore, after passing the course, students should be able to:

- Identify biomedical needs and suggest engineering solutions/actions;
- Analyse 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 and creative thinking, take initiatives and show good judgement;
- Document their work according to the LIPS model [13];
- Work in teams and take responsibility for the group and themselves;
- Communicate results within the committed time plan.

The project in the fourth academic year starts with just a short directive from which a full-scale design-build project emanates, capable of meeting the requirements of the customer. An example of a directive could be as follows:

> *To construct and analyse 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 interacts with tissue. They should also explain the choice of wavelength and bandwidth and recommend a set-up depending on the application site.*

A comprehensive list of requirements is then compiled and documented after negotiations with the customer. The available time and other resources are taken into consideration while deciding upon the requirements. All available resources (from intellectual properties to machines) are known right from the beginning, but adjustments may occur depending on the project's needs. Project steering follows the LIPS model and computer-aided project management is available on request [13]. Usually, five to eight persons constitute a project team, with a minimum of four persons in the case of an insufficient enrolment of students.

A variable team size demands that the project requirements can be scalable and adjusted accordingly. The team is assigned the same supervisor during the whole project in order to ensure competent and continuous help when needed and explicitly asked for by group members. The product outcome of the project is eventually assessed through a formal deliverance procedure where the requirements are tested rigorously by the customer.

The complete capstone design-build course consists of two parts, as follows:

- Firstly, a theoretical study is undertaken and then the project itself, the two parts comprising two and seven 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 second phase. A full semester is set aside for the complete module and the budget of the group is set to 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, tutors have selected team members. Until now, nine teams have been constituted: one comprising only females, one comprising only males using English as the team language (because of the participating exchange students) and seven mixed teams (males and females). In half of those mixed teams, females voluntarily enrolled as team leaders. The procedures of forming a team have not implied any negative issues; instead, it is rather regarded as positive both from the educators' and students' points of view, and have been found to be fruitful in relation to the learning outcomes.

In order to foster prosperous and successful work throughout the project cycle, it is believed that the project teams should be built on heterogeneous skills, educational backgrounds, age and gender, which should all be harmonised using a team contract. Despite this, teams consisting of only men or women have been constituted. The many degrees of freedom have not resulted in any discrepancy in terms of the performance and outcomes of the projects. The team members have always managed to perform according to the project's requirements. Somehow, the skills of the team always exceeded the sum of the individual skills.

The enrolment of exchange students in the design-course has introduced even more possibilities. Forming project groups with English as the only operative language has been tested and yielded excellent results. None of the students had English as their native language, but reported positively that this introduced a great possibility to improve their linguistic skills; it also sharpened project work since communication was important to make the goals understandable for all the participants involved. As a consequence, at the final demonstration and presentation of the project, where all groups are present, the performance and evaluation are performed in English, thereby giving all students further opportunities to gain communication experience in a setting that resembles an international forum.

Project Disposition

Directives for the projects are based on clinical settings or demand engaging students to solve realistic problems. The purpose of this selection is to reinforce both the *conceive* and *design* properties of the CDIO Initiative, making them easier to perform, more understandable and trustworthy for students. Interaction with real customers or experts in the field, validating and testing the project results, encourages, stimulates and enhances all parts of the CDIO framework.

Design-Build Assessment

Assessment is conformant to a student-centred learning process as an integrative part of the courses. Throughout the design-build course, the team members themselves and the tutors provide continuous feedback and evaluations of the group process. At the end of the course, students reflect upon their experiences and document them thoroughly in order to visualise them and gain awareness about their learning process; at the same time, tutors receive feedback. The project deliverables, according to the project LIPS model, throughout the design-build project are important since they act as a formative feedback and assessment [13]. With this set-up, learning becomes active and dynamic, giving the possibility to adapt project structures and ingredients to the particular needs and prerequisites of the individual in order to successfully reach the design-build course learning outcomes. The development of assessment protocols and strategies as an integrative part of the learning process has thus been stimulated and emphasised in these courses.

Product Outcomes

In order to pass the design-build course, students do not have to be successful in delivering a functioning prototype or product, rather they have to follow the design-build process in order to gain their own knowledge. In all of the course's teams, learning process and product goals have coincided and both have been delivered as outcomes. However, the learning outcome of the product delivery has a large impact on assessing engineering solutions and skills in the BME domain. The final presentation of the project, as part of the product delivery, encourages students to communicate their knowledge and skills in a realistic and professional environment.

General Outcomes for Students and Teachers

While the course is ongoing, students change their educational perspective by progressing from an instructional environment to learning behaviour. Tutoring from a given project disposition, teachers need to rely on students' capacity to take responsibility for their own learning. This means that students need to make sensible use of the available learning opportunities (eg 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, tutors observe this educational change and can, to an even greater extent, contribute to and enhance the learning process.

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

Students tended to spend much more time on the CDIO courses compared to other, more *traditional* courses, according to the feedback given at the end. This may have a negative impact on other courses and modules that receive less student attention. Some of the reflective comments given by students when explaining their prioritisation included that it was highly motivating to work in a team, be encouraged to test their knowledge and foster new skills by working with technology in practice, etc. This finding has to be handled and evaluated when the course and curriculum are designed, and the learning environment created.

A final remark needs to be made about the tutor-student relationship. Tutors get to learn and gain insight into their students' learning during a design-build course; that is an inevitable fact due to the long duration of the course and the close interaction between tutors and students. The projects demand personal development, since students may be unprepared for the responsibility that follows with the assignment of different project roles. The role of the project leader is particularly crucial for the project, the course and the learning outcomes of individual students. Despite the fact that leadership-learning outcomes are present within the CDIO framework, the BME design-build course and the project model poorly support this. In practice, a more implicit assessment of leadership is performed through the project's performance and implementation, rather than on leadership learning outcomes. However, the supervisor continuously monitors leadership, and finally feedback is given from the tutor and the team as part of the follow-up process.

Attention must be given to all situations regarding intrapersonal conflicts and interpersonal thoughts that may arise, endangering the learning process and the project. Hence, tutors have to be aware of dynamic group processes.

CONCLUDING REMARKS

Student-centred-learning has been successfully implemented and evaluated in engineering education. Problem-Based Learning (PBL), as part of student-centred-learning, is the educational approach that realises a uniquely suited breeding ground to challenge and develop BME education and its domain. Engineering sciences can learn from PBL development in the medical sciences, but they have to create their own strategies, learning outcomes and learning objectives. BME cases can be treated and applied, as in the design-build courses described above, through integrative thinking and problem solving strategies that distinguish BME experts from their single-discipline peers.

The cognitive tasks identified in the BME field require the acquisition and synthesis of information. Project models and learning environment, such as design-build courses, prepare students for work and participation in research laboratories, and prepare them for time-constrained problem solving in the real world, including research studies. The development of assessment protocols and strategies as an integrative part of the learning process must be stimulated and emphasised. 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 an awareness of the affective domain are necessary.

This educational approach is well suited to the demands of a rapidly changing BME field that needs experts who can change and grow through life-long learning. Rearranging pedagogical viewpoints and progressively involving design-build course environments make the BME curriculum more conformant to CDIO Standards. This supports the syllabus, and provides scaffolding for engineering skills and outcomes. In summary, after 15 years of work experience with student-centred learning, processes that could be described using the term *multi-professional PBL*, students are observed as having more confidence and abilities to value information and facts, and are able to create knowledge from available resources.

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