TEACHING CROSS-DISCIPLINARY COLLABORATION IN DESIGN PROJECTS WITH ENGINEERING AND MEDICAL STUDENTS

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ABSTRACT
In order to meet the med-tech community's high demand for innovation, the educational, cultural and communication gaps between medical doctors and design engineers need to be narrowed. Effective and efficient collaboration of members of the two disciplines is indispensable for successful exploitation of innovation in this area. While such cross-disciplinary collaboration is mostly learned on the job, students can already be made aware of the associated challenges in the academic environment. This requires teaching of cross-disciplinary communication, providing insight into the respective partner discipline and supporting the ability to work in culturally diverse project groups.
Here we present a case study of education in cross-disciplinary design based on a collaborative project between engineering and medical students. Several mixed teams are given a project assignment that is bound to produce cross-disciplinary communication challenges. The students are initially left to experience these to raise awareness of the negative effects on project performance if the challenges are not recognized and dealt with. Experienced medical doctors and engineers then coach the students in regular question and answer sessions, making them aware of the educational and cultural differences that produce the communication challenges in the first place.
We have seen high acceptance of this teaching approach among both student groups and have reached the main goal of raising awareness of the challenges associated with cross-disciplinary collaboration.

Keywords: Teaching, Cross-Disciplinary, Project work, Engineering, Design, Medical

1 INTRODUCTION

Cross-disciplinary and cross-cultural collaboration is ubiquitous in workplaces. Cross-disciplinary collaboration between engineers and medical doctors is indispensable for innovation in health care. The course outlined herein was developed to bring together engineering students and medical students to experience the rewards and challenges of such interdisciplinary work in a project based learning environment.
Future product developers must have the ability to work in interdisciplinary groups with a view to develop and validate innovative medical devices, as interdisciplinary collaboration allows for utilization of the most current knowledge and skills [1]. Motivated by real-life situations of miscommunications in interdisciplinary teams, this design course focusing on cross-disciplinary collaboration was created. Project based design courses are state of the art in education. Dym et.al [2] promotes project based learning (PBL) to enhance students' interest in engineering and to enhance their performance. Bell [3] describes PBL advantages as self-motivating, encouraging self-reflection and teaching to give constructive feedback. PBL is used for interdisciplinary teaching, e.g. to introduce mechanical engineers and product designers [4] as well as psychology students [5] to each other. The academic approach presented in this paper intends to go a step further and to acquaint engineers of different fields – mechanical, informatics or electrical engineering – with future medical doctors. In order to teach engineers- and physicians-to-be cross-disciplinary collaboration, the students need to develop a feeling for possible miscommunication and collaboration difficulties.
Therefore, one aspect of this educational approach is to create a perception for differences in mental models of different disciplines and to create an insight in misunderstandings that occur when mental models are compared between collaborators with the intention of sharing these models. Mental models

were introduced originally by psychologist Kenneth Craik [6] as instances of symbolization that are used to aid thinking, as a small-scale model of a person's external reality within its mind. Such a model includes the person's own possible actions and allows the person to try out various alternatives, decide for the best and react to future situations in advance. With utilization of past events, it allows dealing with the present and future. Mental models help to quickly understand new information and the sharing of mental models is an essential part of team communication [7]. This paper discusses the project work and the collaboration of the participants with a particular focus on the distribution of team roles and the sharing of mental models.

The goal of the cross-disciplinary design course is to educate students of different fields, cultures or communication patterns to work together in close connection. The intention is to teach them to be aware of the high possibility of creating misunderstandings and ways to avoid them with the concept of mental models. Furthermore, the students should be sensitized to situations that are created by preoccupation and prejudices, and introduced to possible ways to solve or simplify those.

2 COURSE DESCRIPTION

In this chapter, the setup of the course is described, the teaching goals are listed and the integration in the curriculum is shown. The students find requirements of the assessment and develop and build a prototype to complete their course.

2.1 Set-up

In order to teach cross-disciplinary cooperation, medical and engineering students are united in a supervised collaborative design project. After a general introduction to interdisciplinary communication and detailed background on the collaborative project, the engineering students receive tailored lectures on the anatomy and physiology of the relevant organ system. They then team up with medical students who have received a basic introduction to engineering methodology to collaborate on said project. In the process, they are coached both by engineering and medical faculty, receiving lectures customized to the project. The course ends with each team presenting their solution to a cross-disciplinary audience.

The main goal of this course is to demonstrate the differences in communication between the fields of medicine and engineering. Since such differences become the most evident during actual collaborative work, the course is based on a current project in physiology research that combines medicine and engineering. For the students, the specific aims of the course are to:

- Acquire a working understanding of the anatomy and physiology of the investigated system and knowledge of product development methods and project management
- Identify the engineering and medical challenges in the project and communicate them to the team members
- Develop and implement in mutual teamwork solution strategies for the identified challenges
- Present the found solutions to a cross-disciplinary audience

With 16 participants, four groups are created, equally divided between medical and engineering students. The course is intended for students from second year bachelor to first year master in medicine and from first year master on in engineering. Seven bachelor and one master student in medicine, as well as six master and two doctoral students in engineering were enrolled in the course that is rewarded with 4 ECTS points. The engineering students receive grades, while the doctoral students obtain attestations of course completion. The course comprises hours of lectures and two hours of tutor-supervised teamwork during 11 weeks. The students are graded on the final oral presentation (40%) in teams and on their individual performance during the semester (60%).

2.2 Course Assignment

A modified Krogh bicycle ergometer for measuring the power output of the quadriceps muscle group [8] (Figure 1) is used in current exercise physiology research at the collaborating institute of physiology. After they received tailored lectures about the other discipline, the students receive a brief introduction into their assignment and the purpose and use of the modified Krogh bicycle ergometer.

The subject sits on the pink wood plate wearing a customized boot connected to a flywheel, which is moved by motion of the lower leg of the subject.

The assignment of this course is to build an improved system to measure the power output of the quadriceps muscle group. Therefore in a first step, the participants need to find and describe the requirements of this system, and define possibilities to enhance the system. The second step requires the students to develop different possible concepts for their device and to decide on one. In the following steps, the prototype is build and tested iteratively by the students to a final state where it will be presented.

Figure 1. Modified Krogh bicycle ergometer to measure quadriceps power output

2.3 Results

This chapter covers the results presented by the teams, starting with the defined needs and the different approaches resulting in the presented prototypes, while some special solutions and findings of the teams are reviewed.

2.3.1 Requirements

The teams found certain requirements, which can be summarized as follows:

- More comfortable seat for the patient/subject, because experiments last up to 8h
- Adjustable seat
- Comfortable attachment of the foot
- Improved isolation of the quadriceps muscle group
- Possibility to change force on the muscle
- Possibility to analyze the force and frequency of the motion

2.3.2 Final Prototypes

Team 1 designed a mechanical device (Figure 2a), with a wire rope hoist connected to a bucket filled with weights, allowing an increase of force on the fly by adding weights during the experiment. They used a bicycle computer to track the frequency of the leg extension.

Figure 2 a,b,c and d. Final prototypes of teams 1,2,3 and 4

Team 2 designed a mechanical solution, too, but with a rack of weights, which are held down by a constant force spring (Figure 2b). The measurement is made with an infrared distance sensor and analyzed by computer. They also designed and built a seat adjustment feature and validated the isolated stress on the quadriceps with by EMG (electromyography).

Team 3 built a seat from an air mattress filled with Styrofoam to replicate a vacuum mattress (Figure 2c). Their force is generated by an electric linear motor and connected to the foot of the subject by a wire rope hoist and a lever. The programming and analysis is made by computer as well.
Team 4 bought a used leg-extension machine and planned to install a force sensor in the gear chain. (Fig. 2d) They initiated a detailed research on the requirements and found a machine with the needed requirements to be available to buy and went to test it. This finding was displayed in the final presentation.

3 KEY-FINDINGS

In this section, two significant findings are introduced. First, the evolution of team roles in cross-disciplinary teams is discussed with two examples, and secondly, a teaching approach in which a game called Pictionary is adjusted to be an educational exercise showing the students differences in the understanding of terms throughout different disciplines.

3.1 Distribution of Roles

A particular finding is the change in distribution of team roles as found out through observation and in the interviews afterwards. The idea of collaboration is unclear in the beginning, without experience in cross-disciplinary work, and can be developed on its own, or triggered by the educators. This is presented in two examples: In one group, the engineers had problems organizing a workshop for the assembly of their concept, due to language difficulties in communication with workshop personnel. The search took certain weeks for the group and raised frustration in the team, until one medical team member voiced his frustration about the situation to teaching staff. When asked if he tried to find a workshop himself, he realized that this did not occur to him in this project. Motivated by the educator, he adapted his role and organized a workshop for the assembly. This group delivered one of the most advanced prototypes in the final presentation.
Another participant reports in her interview that the medical students of her team doubted in the beginning whether they would be able to support the engineers in the development of the desired device. In the progress, the medical students supported the development with several ideas, most of the time very simple and a lot easier to realize compared to the engineers' ideas, and gained confidence as the project progressed. This shows that some participants come into this project with a preconception of roles and knowledge, but it is possible to help remove those in cross-disciplinary project work with steady support.

3.2 Pictionary

One specific teaching method produced extraordinary positive feedback. To demonstrate to the students the variety of mental models in different disciplines, the game Pictionary was adjusted and used in one of the lectures. There are two groups needed for the exercise. One person of the first team is given a term that has to be explained to the rest of the team by drawing and without talking. The teammates have to guess the word. The faster they guess it right, the better. In this specific case, teams were set up for each term in a specific manner as shown in Table 1.

Table 1. Terms to be drawn, drawing and guessing teams

Term:	Drawing:	Guessing:
Pressure	Engineering	Medical
Cancer	Medical	Engineering
Stress	Engineering	Engineering
Infection	Medical	Medical
Filter	Engineering	Together
System	Medical	Together

The groups with drawers and guessers of different disciplines are called cross-disciplinary and those with guessers and drawers of the same discipline interdisciplinary in this paper. This educational exercise shows that there are differences in mental models in different disciplines. As seen in the first example, pressure (Figure 1b) is drawn by an engineering student as a square with different force-arrows. The medical students had difficulties guessing the term. When asked to improve the drawing, a medical student drew the picture shown in Figure 1a, which represents a human with a blood

pressure meter. Interviews after the course show that the students kept this lesson in mind. They used this insight in their further communication. Team 4 noticed in discussions that the medical students of the team use different words for the same part of the device than the engineering students. This group therefore determined new words with agreed-on definitions,
It was not possible to show significant differences between the cross-disciplinary groups and the interdisciplinary groups because this would require the students to draw and guess the same term in different team-constellations. Nevertheless, the interviews show that the students saw the differences in mental models and adapted their communication as intended by the tutors.

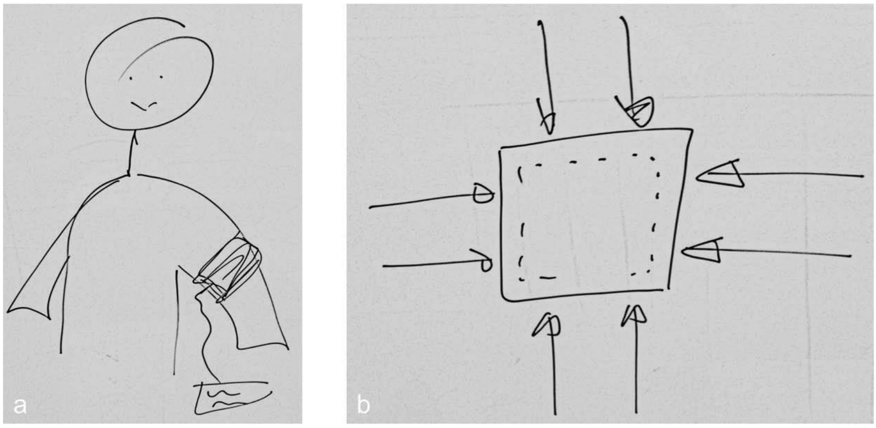

Figure 3. Different visualizations of mental models of pressure by: (a) medical students and (b) engineering students

4 CONCLUSION AND OUTLOOK

To teach future engineers and physicians to collaborate, communicational, cultural and educational differences need to be shown in order to raise awareness and teach how to avoid problems in a multidisciplinary design project.
The education project presented here received positive feedback from the students. The concept of teaching medical and engineering students together allows for a tight connection between the disciplines. The group composition of two medical students and two engineering students was well suited for the purpose of the course. One student left the course early due to a medical condition, leaving one group with only one medical student. This resulted in an unbalanced approach to the tasks.
The intense examination of the accomplished work in order to prepare the final oral presentation pushes certain reflection of collaboration and intensifies the cooperation. The students discussed the different aspects of their work, and were asked to present their experience of cross-disciplinary interaction during their project. The presentations show the different approaches and reflect the growing together as a group. This could be noticed by the use of technical terms of the ancillary discipline and the unified style of presentation. The audience consisted of members of different disciplines, from engineers without medical knowledge to doctors without technical knowledge.
The combination of lecture, project work and discussion meetings supported the teams with important knowledge in the beginning and encouraged collaboration with a mutual goal. The Question and Answer sessions with experienced experts of both disciplines allowed observation of differences in the teams. They also allow the tutor to recognize teams that are stuck on a problem which they cannot solve on their own and to get involved and sustain the team as early as possible.
In order to develop a sense for cross-disciplinary collaboration, one has to be aware of possible issues of communication. As explained in the section Pictionary, this exercise which requires only little time demonstrates impressively different mental models of identical terms. It can be easily adapted to other cross-disciplinary constellations, but the used terms need to be chosen with care, the ideal terms being abstract ones such as "system".
Another important learning is the relevance of a real design problem and the possibility to build a system in reality. As seen in other design projects, the motivation is higher and the groups have the possibility to do their own need finding and to question the task by themselves. The possibility of building and validating their concepts in reality increases the risk of frustration, but boost the feeling

of accomplishment if the goal is achieved in the end. The design task has to be chosen very considerately. With the task described in this paper, the medical students are able to provide knowledge in the beginning, but as the needed development and construction is very labour-intensive and demands a fair amount of the engineering skills, some said they sometimes felt unneeded. Therefore, the task should be changed to a different technical system, which should be designed and built early and can be developed in several iterations giving the medical students the task and possibility to validate and evaluate the designed device and apply their knowledge. In summary, the presented educational approach can help students to connect and collaborate in a cross-disciplinary team and teach methods and awareness for their further education and future work life.

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