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NEW METHODS FOR THE DESIGN OF SMART PRODUCTS: PROJECT BASED LEARNING WITH INDUSTRY

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ABSTRACT
In the last few years, IoT (Internet of Things) technology has been in full development. However, the market has not yet given rise to many concrete applications with high adoption since classic product oriented SMEs (Small to Medium-sized Enterprises) have difficulties with the integration of these IoT technologies in existing products. Simultaneously, our design education is shifting from knowledge based learning towards project based learning. Students need to be trained in the process of finding and applying new technologies rather than acquiring existing knowledge.
Both technological and educational shifts present opportunities for educators to expose design and engineering students to new design paradigms, while also involving local industry. Companies are also increasingly relying on external Research and Development (R&D) organizations, such as Universities, to support innovation [1]. Additionally, as stressed by Chen & Hsu [2], fostering creativity among students is viewed as an important skill for engineering students.
In order to achieve this, a new integrated design course has been presented to interdisciplinary teams of students with a background in industrial product design, electronics, and multimedia and information technology. In this course, we challenge them to come up with an idea and working prototype for a smart product.
In this paper we give an overview of the course and present its strengths and pitfalls. We found our approach to be successful, with design cases that lead to novel research, technologies and commercial products. We discuss the impact of our results for design education and suggest areas for further research.

Keywords: Smart products, project based learning, prototyping.

1 INTRODUCTION

Current educational strategies often fail to adequately prepare students for their professional career. Traditional educational settings with multiple weeks of classes followed by a written or oral exam are not representative for the environment engineers are confronted with in real life. Modern SMEs are looking for dynamic and independent employees with the ability to collaborate effectively. For many students, acquiring these skills is not an evident task. Consequently, allowing students to develop these skills during their education is essential to better prepare them for their professional career.
In this paper we present the findings from analyzing a one semester masters university course on designing smart products. The course brings together last year engineering students from different fields of study. The collaboration is possible because there is a close collaboration between the professors of the design and electronics faculties. The student groups are divided into cross disciplinary teams containing industrial product design, electronics and, multimedia and information technology students. Each team gets assigned a project case of their choosing. The set of cases originates from different sources within industry, academia, and non-profits and provides a broad context in which the students have to identify the added value opportunities. After analyzing these opportunities the most promising one is selected and a product concept is developed. The requirements of the selected concept have to be analyzed and the technical feasibility has to be confirmed. Once the

technical elements have been considered the students enter an iterative prototyping phase which leads to the final product. The groups have to create a product video and presentation which serves as a way to present their device to industry. Different qualitative and quantitative techniques are used to evaluate the effectiveness of the course. These include student assessment results, weekly personal feedback rounds, student interim presentations, group blog posts and final product papers.
In the following sections we first provide a more detailed description of the course. Subsequently, the results of our different assessment techniques are presented. These results are based on the course from the fall semester of 2016. During this semester 44 students participated divided into 13 teams. We conclude the paper with a discussion which evaluates the different findings and provides suggestions for further improving the course.

2 COURSE DESIGN

The design of a project based course is often founded on the epistemology of constructivism [4]. Constructivism builds upon the idea that knowledge cannot be transferred into someone's mind [5]. Knowledge is created (constructed) in the mind of the learner through a process of assimilation and accommodation. With the first process (assimilation) the learner fits new knowledge, resulting from new experiences, into his current mental framework. When new knowledge does not fit into the current mental framework, the learner can adapt his framework to fit the new knowledge. This process is called accommodation.
Multiple other epistemologies like constructionism and experiential learning are based on constructivism. Both of these theories stress the value of learning strategies like: project-based learning, inquiry-based learning, cooperative learning and active learning. Since the effectiveness of these strategies has been shown in literature [6], we use them as a basis for our course.
In the following sections we provide an overview of the course. First the goals of the course are presented, next we provide a more detailed description of the course structure and finally the different evaluation methods are explained..

2.1 Goals

The goals associated with this course are twofold. On the one hand, we define a set of course learning objectives. The students are assessed based on whether they successfully achieve these learning goals by the end of the semester. On the other hand the course itself is evaluated with the aim to identify its strengths and shortcomings. The learning objectives for students are clearly defined before the start of the course and are shown in the following list:

1. Students interpret the case they are given and create a product concept within the context.
2. Students design a prototype based on the product concept.
3. Students implement the prototype.
4. Students acquire the necessary technical skills to implement their prototype.
5. Students evaluate their design and adapt if necessary.
6. Students evaluate their prototype and adapt if necessary.
7. Students collaborate during the different phases of the project and share expertise.
8. Students present their work to the public.
9. Students create a product video.
10. Students evaluate the marketability of their product and adapt if necessary.
11. Students evaluate the user experience of their product and adapt if necessary.
12. Students write a scientific paper describing their design process.
13. Students get the opportunity to be creative and implement innovative solutions.
14. Students apply existing technical knowledge during the design and implementation phases.

The level of quality for each of these goals is defined in the rubric assessment form. Since participating students are in the last year of their study program, most of the desired competencies are located on levels three to six of Bloom's taxonomy [7]. These levels provide a way to classify learning objectives based on their complexity. We assume the students have sufficient knowledge and comprehension of their respective fields of study. However, at the start of the semester, the students get an introduction to the tools and platforms they will be using during the project. For example, the electronics and, multimedia and information technology students get a short introduction on how to setup and program a Raspberry Pi microprocessor. They use this knowledge about the Raspberry Pi to analyze the trade-offs between using a microcontroller- versus microprocessor-platform.

Simultaneously, the industrial design students got an introduction to the Arduino microcontroller-platform and learned about how to use the processing programming environment.
These sessions also recapitulate prior knowledge and make sure all students start the project from an equal base level. During the rest of the course, participants mostly spend their time applying, analyzing, evaluating and creating, which are skills at the higher levels of Bloom's taxonomy.
Additional to the student learning goals, we collected data about the course to identify its strengths and shortcomings. In Table 1 there is an overview of the questions we aimed to answer.

Table 1. Research questions

Nr.	Question
1	Which parts of the course are experienced more or less challenging by the students?
2	How much time do the students spend on the course?
3	Which are valid indicators for end product quality measurable in earlier phases of the project?

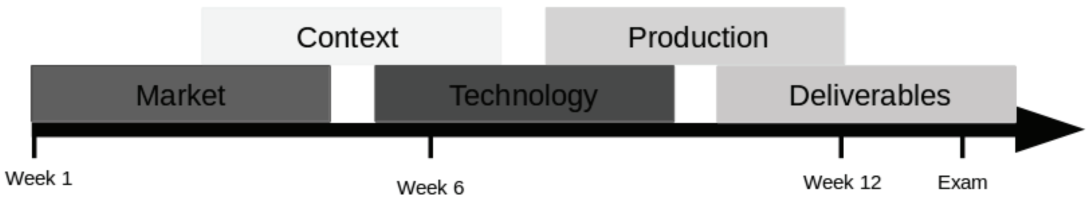

Figure 1. Course timeline: Students start by exploring the market with respect to their project case. Subsequently, the students create a concept of how they will position their product within this market. Once a definitive context is selected, the technological requirements are determined. With these requirements production of the prototype can start. In the final phase students deliver: a prototype, project video and paper

2.2 Structure

The course has five phases as shown in Figure 1. This structure has previously been tested within the context of the same course and was shown successful [11]. During the first phase students explore the market associated with their case. We expect them to answer the following questions: Are there products on the market solving this problem? What do these products do well/poorly? How can you differentiate from these products? In the next phase three product concepts have to be thought out based on their market research. These concepts have to be presented to the course supervisors who select the case which they feel has the most potential to turn into a successful product. During the technology phase students explore the technical requirements for their product. This allows them to construct a list of required components and estimate the product cost. At the end of the technology phase, students order the components required for their prototype. Once the deliveries have been made, the production phase starts. During this phase, most groups create multiple prototypes. The final phase is reserved for the creation of course deliverables like: a product video, presentation, research paper and public demo.
Even though the current course follows the same structure as presented in [11], it was executed in a different context. In [11], close collaboration between students of different fields of study was desired, however, collaboration remained superficial. In the course presented here, there is close collaboration since students of different fields of study participate in the same course. Additionally, in [11], limited attention was given to valid and transparent assessment. Consequently, significant attention was given to assessment during the course presented here.

2.3 Assessment

Assessing project based learning (PBL) is often a challenge [3]. Traditional testing techniques like oral or written exams are not applicable within the context of PBL. To validly assess PBL many data has to be collected. This data is used during the course to paint a picture of students accomplishment. During the course described, various formative and summative assessment techniques have been used.

2.3.1 Formative assessment

Starting from the first group session, each group has an informal conversation about their progress and future work with at least two of the course supervisors [8]. This conversation is repeated every week enabling the course supervisors to maintain an accurate image of the progress and challenges of each group . When problems within a group are observed, immediate feedback is provided to put students back on the right track. To ensure students have a solid product concept, they have to give a mandatory presentation in front of a jury consisting of all project supervisors. Three concepts are presented ordered by the students preference. This preference is considered during the final concept selection since it increases student ownership which motivates them when creating their product [10].
Each group is required to document their progress on the course blog [9]. No specific guidelines are provided for how and when post should be made. Since students have this flexibility, they are able to structure and time their progress reports as they seem fit. The blog data can be analyzed, identifying how students go through the design process and provide feedback when necessary.

2.3.2 Summative assessment

Even though formative assessment is more valuable for the growth of the students [13], summative assessment is required to assign a grade at the end of the semester. Scoring a PBL course has various challenges: How do we score students according to the same standard when they are working on different projects? How can we differentiate the performance of students within the same group? Which deliverables do we assess to have an accurate valuation of the entire learning process?
To assess the course deliverables, namely the public presentation, product video, product demo and scientific paper, an assessment rubric was used [12]. All course supervisors where responsible for providing a grade based on the student rubric. These grades were averaged leading to the final score for each group. To take intra group differences into account, students filled out a peer evaluation form. Based on the results, certain group members score was reduced or increased.

3 SMART PRODUCT CASES

The course resulted in a diverse set of products. Some had a more social focus, others were more business oriented and some were research related. The processes to go from project case to product are diverse and have their respective strengths and weaknesses. In this section we give an overview of three noteworthy products developed during the course.

3.1 Matti

In this case, the students were asked to create an interactive gaming mat. This mat can be used by physiotherapists to provide interactive exercises to their patients. Mats like these have been used before but have some limitations. For example, they have predefined zones where the patient can stand to register a touch, are often less robust and have limited pressure sensitivity. Matti solves these problems by integrating a 15x15 pressure sensitive Velostat grid and led matrix into a soft foam packaging. Combining the sensor array and led matrix with data processing software allows the physiotherapist to fully configure pressure sensitive zones on the mat. Additionally, the pressure sensors can be used to analyze the balance and movement of the patient.

3.2 Robot gripper

Most robot grippers are designed to pick up rigid objects however, a lot of real world objects are deformable. If these deformable objects are picked up by a rigid robot gripper they might deform and brake, imagine picking up a strawberry with metal pliers. This case required the students to design and build a robot gripper for picking up soft objects.
The designed gripper uses flexible 3D-printed fingers which bend around the object during the gripping process. The fingers also contain flex sensors which measure the finger deformation. This deformation can be used as feedback to the gripper control module to estimate the applied force.

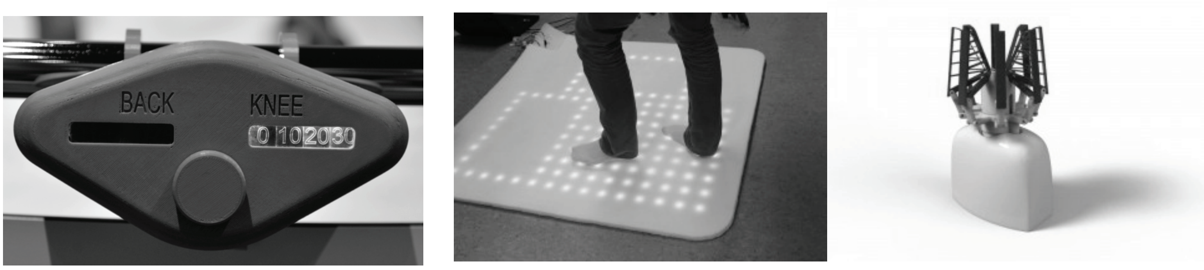

Figure 2. From left to right: BEND: intelligent hospital bed system. Robot gripper: a force-sensitive robot gripper for soft objects. MATTI: The Interactive gaming mat

3.3 BEND

This group got the assignment to design an intelligent hospital bed system to help nurses and doctors and at the same time provide more comfort to patients. The BEND project created a smart hospital bed add-on allowing nurses to accurately set bed angles for patients which require specific sitting conditions. The product has two angle measuring modules and one control module. The angle modules are placed on the angling parts of the bed, the control module is placed at its foot side. A simple LED based display shows the nurse when the bed is in the correct angle range. Additionally, the control module uses the wifi network to send its data to a central server which stores and processed the data. The server also provides a web interface so nurses can get an overview of the status of the different beds. The angle modules contain a full 3-axis accelerometer and gyroscope. This data can be used to perform more advanced patient analysis. Systems like sleep tracking and out of bed detection could be possible with the same system.

Table 2. Blogposts for each group in each week of the semester

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Case 1	0	0	0	1	0	0	0	0	0	0	0	0	3	4	0	0	2	0	0
Case 2	0	0	0	0	0	0	0	0	1	0	0	2	0	1	2	1	2	0	0
Case 3	0	0	0	0	0	0	0	1	2	0	1	2	1	1	0	0	4	0	0
Case 4	0	0	0	0	0	0	0	2	11	0	0	0	0	0	0	0	19	0	0
Case 5	0	0	0	0	0	0	2	5	0	0	3	4	0	0	0	0	1	0	0
Case 6	0	0	0	0	0	0	0	9	2	2	0	2	4	0	0	14	2	0	0
Case 7	0	0	0	0	1	2	2	2	1	1	1	1	3	0	0	1	1	0	0
Case 8	0	0	0	0	0	0	1	7	0	0	0	0	2	0	0	0	12	0	0
Case 9	0	0	0	0	0	0	0	4	7	0	2	0	0	1	1	6	12	0	0
Case 10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	11	1	1	0	0
Case 11	0	0	0	0	0	0	0	4	3	2	2	0	0	0	0	17	10	0	0
Case 12	0	0	0	0	0	0	0	11	5	2	1	3	0	0	0	0	9	0	0
Total	0	0	0	1	1	2	5	45	32	7	10	14	13	8	14	40	75	0	0

4 RESULTS AND DISCUSSION

Looking at students evolution, the products they delivered at the end of the semester, and the positive feedback of external partners we are convinced the course better prepares them for their professional career. All students at least meet the minimum passing requirements for the course. Additionally, no problems were observed during the semester, collaboration went well and all groups showed dedication to their project. As described in the previous section, this resulted in an impressive set of product prototypes.

Plenty of feedback was provided to the students during the semester. The weekly discussions between groups and course supervisors was effective at keeping students on the right track. It facilitates early problem identification and resolution. However, the discussions are mostly ad-hoc consequently, the progress and problems are not documented. This lack of evidence makes it difficult to compare the evolution of the different project groups. In the future, short reports of the group interviews should be recorded to enable a more in depth analysis of the project evolutions and group dynamics.

When we analyze the student blog some interesting patterns arise. Firstly, most groups do not regularly post their progress this can be seen in Table 2. A clear increase in post frequency is observed right before the concept and final presentations. Since no guidelines were provided for when posts should be made this is somewhat expected. In the future more strict rules should be defined to facilitate a more accurate documentation of the design and development process. Secondly, no significant correlation was observed between either number of blog posts or regularly of the posts and the final group score.

The value in cross disciplinary collaboration is clearly visible in the final product prototypes. The industrial design students have a strong positive influence on the usability and design of the final product. The electronics and multimedia-ict students provide the required technical knowhow to create a fully functioning product. Without cross disciplinary collaboration groups would only be able to deliver a partially functioning prototype [11].

Collaboration with external partners, either from industry, non-profits or academia, usually has a positive impact on students' performance. The partners provide additional information and material to expedite the development process. However, in some cases disagreement between the parties (students, external partners and/or course supervisors) results in a loss of confidence within the student groups which usually leads to a delay in the design process. In the future, a more close communication between supervisors and external partners is required to ensure clear communication towards the students.

In general, the course succeeds in creating an environment wherein students can develop their higher cognitive abilities. Furthermore, by mimicking a real world cross disciplinary business environment, students train the skills many SMEs expect from future employees. The environment results in almost effortless collaboration and well refined product prototypes. In the future we aim to better document the individual development processes of the different groups to identify common problems and strengths.

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