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IMPROVING ENGINEERING EDUCATION THROUGH DISTRIBUTED DEVELOPMENT PROJECTS

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ABSTRACT
Employers find that students are graduating from engineering programs without the necessary competence and know-how to be successful in industry, often lacking sufficient communication and collaboration skills imperative for developing new products. Modern product development, from development and design through to production, planning, and marketing is moving increasingly to the digital domain as a result of technological progress and increasing pressure to deliver more complex and more customized products in less time at the lowest cost. The engineers of tomorrow must be able to communicate and collaborate effectively and efficiently using technologies and software, such as Computer-Aided Design (CAD) or Engineering (CAE), Product Data Management (PDM) or Enterprise resource planning (ERP) tools.
In an effort to ensure that graduating students can successfully apply what they have learned in their engineering lectures to real-world engineering problems, the Lower Saxony Institutes of Technology (NTH) has sponsored a project “Computer-aided Product Development” that involves students in distributed development design projects that mirror what they will come across in industry. Engineering students from the Leibniz University of Hannover (Institut für Produktentwicklung und Gerätebau), the Technical University of Clausthal (Institut für Maschinenwesen), and the Technical University of Braunschweig (Institut für Konstruktionstechnik) work together on semester-long projects that require them to use engineering tools that are not often taught in typical engineering classes but crucial for product development in industry, exposing current shortcomings in the engineering curriculum. The project has been run twice, once with “closed” student groups at each site, each group responsible for a sub-assembly and communicating with students at other locations with regard to sub-assembly interfaces, and a second time with students from multiple locations making up “mixed” teams. Competence weaknesses have been identified, particularly in using PDM systems, and measures to improve the curriculum long term are being integrated into lectures. This paper will provide an analysis of the first projects as well as prospects for improving engineering education through distributed development projects.

Keywords: Distributed development, PDM, CAD

1 INTRODUCTION

In increasingly competitive global markets, companies looking for ways to shorten product development time have turned to distributed product development. The availability of collaboration software and other tools has made it easier for employees to work together and yet be distributed around the world [1]. This becomes a challenge to educate engineering students to be adequately prepared for development occurring mostly in the virtual realm. Employers find that students are lacking the desired competences upon graduation. In an effort to better prepare student for industry, collaboration between NTH schools examined methods and tools of Cross-Enterprise engineering (CEE) along with particular student competencies. The goal of the NTH Project is for students to gain experience in a distributed development environment of CEE while giving instructional staff an opportunity to analyze the methods and tools used by the students, allowing for better preparation for use in future courses and projects. Siemens Teamcenter PDM software was purchased in advance and integrated into the existing CAD environment. Scientific staffs at all locations were then trained in the application of the software. In addition, a communication environment based on Adobe Connect (available from the German Research Network (DFN)) was established, allowing for multi-site development.

2 DISTRIBUTED DEVELOPMENT

Cross-Enterprise Engineering comprises distributed, coordinated collaboration during product development [2]. Development tasks are typically carried out via email, videoconferencing, and other collaboration software. For successful implementation of distributed development, Enterprise Resource Planning (ERP) is typically used to allocate available resources in an enterprise (capital, equipment or personnel) as efficiently as possible and optimize business processes. Product data management (PDM) and product lifecycle management (PLM) tools are used together with CAD and CAE tools during the entire development process, from product definition through validation and manufacture.

Development may occur within one company at distributed locations or among various global companies, depending on the organization structure of the project and how development tasks are distributed. In a unit-specific model, teams are organized by product modules, with module A being designed at location A, Module B being designed at location B, with teams at all locations working together to be certain that all geometric and functional connections are considered. These interfaces are typically double-checked in the virtual realm, using the aforementioned computer modelling and simulation tools. With a subject-specific model, teams are made up engineers within the same discipline or specialization work together from different locations. In this way, a team could be working on the same module or sub-system of a product but spread across several locations. External companies are given development tasks when a company utilizes an outsourcing model.

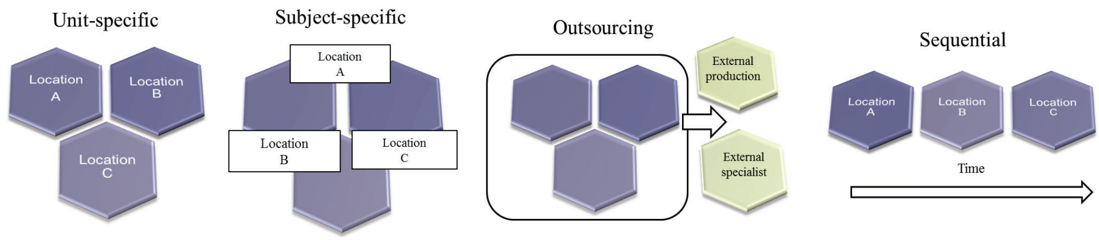

Figure 1. Development Organizational Model [3])

There are many challenges associated with distributed development. Regardless of organizational structure, communication is essential for successful product development [4]. Team members need to be working on the latest models and with the most up-to-date information relevant to their components or sub-systems. This information exchange is easier when teams are co-located rather than distributed around the world. Issues can be easily and quickly resolved when one knows exactly who to speak with and the communication can be done face-to-face. When colleagues are working from multiple locations that don't allow for personal meetings, there exist many challenges to communication, such as organizing meetings across different time zones, issues with language, and other cultural differences [2].

Challenges also exist with the integration of various CAD and CAE tools. This is especially true for development across multiple companies, with each possibly using a different CAD or CAE vendor. IT tools applied can vary as well, making the exchange of data amongst various locations difficult. While many tools exist to assist with communication and collaboration among distributed teams, learning these tools and acquiring skills is not always part of an engineering curriculum.

3 IMPLEMENTATION

The project "Computer-aided Product Development" was implemented over several stages:

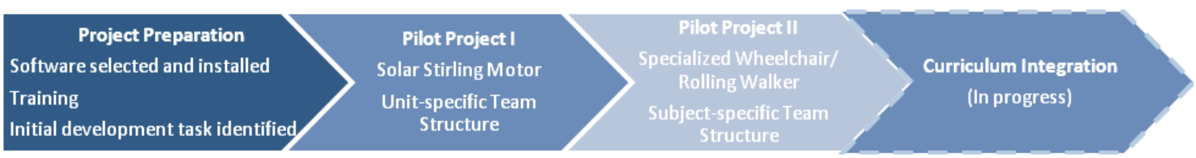

Figure 2. Project Sequence

3.1 Project Preparation

Starting in winter semester 2012, the first semester was used by the scientific/instructional staff to work out logistics for the project. Of highest importance was preparing the labs and infrastructure so that the development environment mirrored as closely as possible that found in industry. Engineers spend a significant part of the development process on design, with CAD and CAE software being essential tools. Three-dimensional modelling, product assembly models, and the ability to produce manufacturing drawings with Bill of Materials are relevant technical skills for students to acquire.

Creo 2.0 by Parametric Technology Corporation (PTC) was selected for solid modelling and assembly creation. However, additional modelling environments may also be used in the future to give students exposure to integration of several packages and exchange formats. Ansys (CAE software) was selected for finite element modelling, but further CAE tools are being considered based on availability within each of the participating institutes. To enable extensive documentation required of students to support design decisions and development planning, MS Office products were selected as every school had access.

Videoconferences between instructional staff as well as students were carried out using Adobe Connect through the German National Research and Education Network (DFN), which enabled document sharing and audio and video communication. The PDM software Teamcenter was hosted at the TU- Braunschweig and was accessed by teams in Hannover and Clausthal as well as Braunschweig. The software was chosen based on its popularity in Germany and its relative easiness to configure and use [5].

Also during this first semester, a development task for the first pilot project was agreed upon and defined by the three participating locations. Experience shows that students are more motivated when they perceive they are making a difference or have an impact with their work, and the development task was chosen for both semesters keeping this in mind. Simultaneously, a common engineering design methodology to implement was selected.

3.2 Pilot Project I

A development task was defined in cooperation between the three institutions at the beginning of the semester, with the goal being a working prototype at the end of the semester. To kick-off the initial pilot project, a meeting was held at the Hannover location, giving the students an opportunity to meet once at the beginning to discuss the development task face-to-face. During this meeting, the students were given an overview of the task at hand, instruction on using the collaboration software and forum available for communications during the semester and decided jointly on the rules and timing regularity of such communications. In addition, they were instructed to document each of these communications so that supervisors at each location were able to stay informed as well. Given that a prototype was to be built, the students also used this initial meeting to discuss project planning and timing so that enough time was allocated for part orders and manufacturing and build issues. Design reviews were scheduled also during this initial meeting.

The pilot project involved the development of a solar Stirling engine. It was decided to organize the teams using a unit-specific group structure, such that each location was responsible for a sub-assembly of components of the Stirling Motor. This distribution of tasks can be seen visually in Figure 4.

The mirror unit and its components were designed and processed in Hannover, the development of the Stirling engine and control electronics was carried out in Clausthal, and Braunschweig had the tasks of system integration and transport solutions. In terms of distributed development, the main focus in this first project was on the clear definition and clear documentation of the interfaces of the system between the individual sites.

Bachelor and Master Mechanical Engineering students were involved in this pilot project, and the students followed the German guideline for engineering design (VDI 2221) within product development, starting with identifying and clarifying their respective tasks and collecting requirements that resulted in a specification document. A functional decomposition was considered for the entire product by the group as a whole and then decomposed further by each location into sub-functions. The student worked several weeks on generating concepts for each sub-system and presented these ideas in monthly design reviews, also conducted simultaneously over the three locations via a web conference. Students refined their designs using CAD and other computational software and shared files, initially using Dropbox and eventually through Teamcenter PDM.

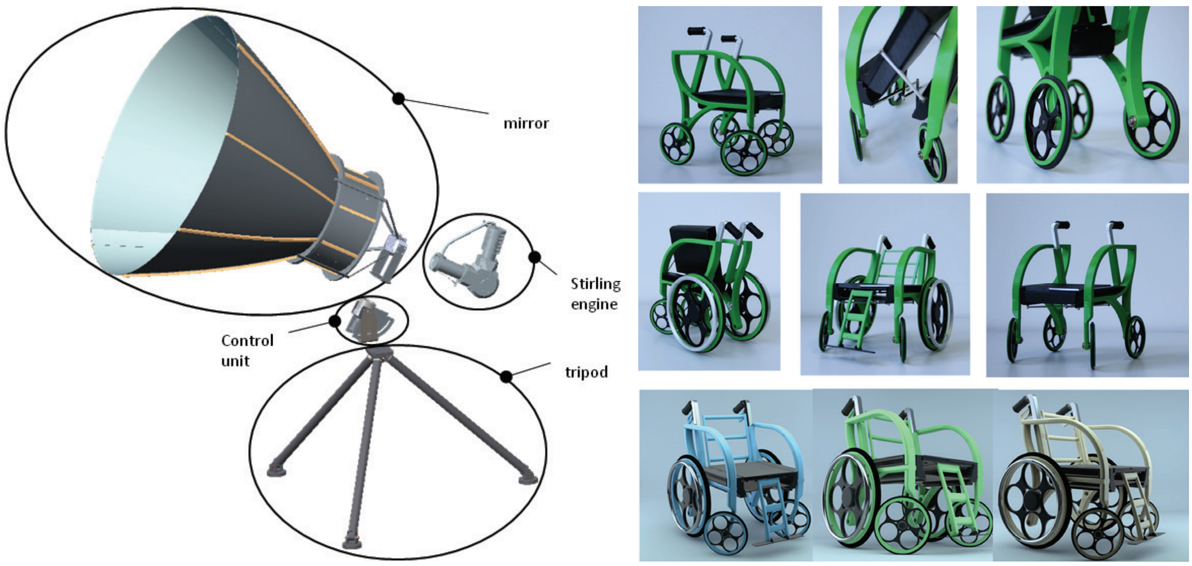

Figure 3. Pilot Project I Solar Stirling Motor and pilot project II Specialized Wheelchair

3.3 Pilot Project II

The second pilot project utilized the same software as the initial pilot project. Documents were uploaded only to Teamcenter and followed a work flow process during pilot project II, being accepted as official documents only after two out of three supervisors had approved of the documents. Rather than having the teams broken into component groups by location, the teams were instead mixed, with students from two schools working on the same system. The development task for the second project was to design a specialized wheelchair or rolling walker, with each team designing for a different use case. The development task was presented as an open-ended design task, allowing students to creatively identify specific use cases during the kick-off meeting held in Clausthal for the second pilot project. Weekly meetings and design reviews were again used to ensure timely project completion.

4 OUTCOME (ANALYSIS)

To better analyze the outcomes of these initial pilot programs and to provide focus for the integration of material into future courses, a total of seven competencies were identified: the ability to work in a team, to use the prescribed design methodology, project management as well as personal time management, CAD skills, communication and the use of collaboration software and tools. These competencies were deemed by the respective Institutes as the outcome of good education and important for future engineers. Each student was individually evaluated by the instructional staff for these skills on a scale from 6 (student is lacking skills and needs training) to 1 (shown competency with skills). The result is shown in Figure 5.

There is a striking variation in results across all competencies that can be partly attributed to the distinct difference in the education levels of the participants. The difference can be explained by individual strengths and weaknesses as well as by the academic progress of the students, since Bachelor and Master students participated together. The outcomes from the initial projects show both strengths and weaknesses in our current respective curriculums. A strength of all students involved is the ability to solve technical problems, but when working in distributed groups, team building and communication made this task more difficult. These difficulties raised awareness in the students that these skills would be of great advantage when leaving University. These two pilot projects also revealed the enormous amount of time necessary to work in distributed development teams. Some of this additional time could be attributed to organizing the projects in such a way that the students were able to finish a prototype of the design by the end of the semester. This required additional time of the supervisors at each location as well, which could be partly due to the complexity of the collaboration tools being used. Before the start of the pilot projects, none of the students had any experience using Teamcenter.

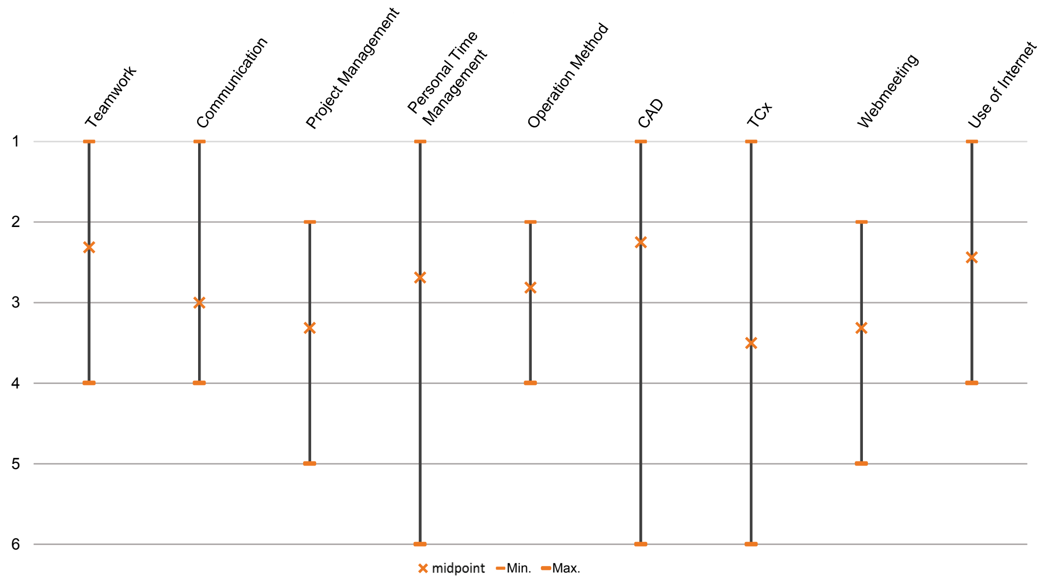

Figure 4. Student Skill Analysis

The evaluation shows that while most of our students are comfortable with CAD, a course that has long been a part of the curriculum, many students struggled with the use of Teamcenter (TCX). Since using CAD software caused problems only in individual cases, it may be assumed that the use of computer -aided development tools generally does not constitute a challenge for students and TCX, due to the unfamiliarity with the students and the complexity, is an exception here. Communication between the sites was a significant challenge at the start of the initial pilot project. The students were not only inexperienced with the video conference and collaboration software, but they were also relatively inexperienced in working in teams, as teamwork is not a typical component of previous classes. However, this communication improved throughout the duration of the project. Students became out of necessity group speakers and meetings were organized in advance and carried out with a specific goal in mind. It has been shown that students work together albeit it reluctantly with strangers. Students hold a belief that the project will take longer to finish with teamwork rather than finishing it alone. Another concern is that grading could be adversely affected. These fears are especially prevalent when there is great disparity of knowledge among the stakeholders. At this point, an early and significant intervention by the supervising staff is essential in order both to alleviate these concerns and also to compensate for deficits as early as possible to prevent the risk of frustration. Cultural diversity within the groups created an additional challenge with communication. Non-native German speakers may be more hesitant to join in or may lag behind in the discussion during video conferences.

Also varied was the ability of student project planning and to manage their time and to stay on task to finish a prototype build by the end of the semester. About two -thirds of the students demonstrated good to very good ability to manage time, whereas the remaining students were not able to plan their own work or to adhere to self-set goals. In the future, this can be remedies with closer supervision by the instructional staff with relatively little effort during the early stages of projects. Although the theoretical foundations for these competencies are in place in the curriculum, the students are learning to apply this theory to practice.

5 INTEGRATION INTO CURRICULUM

Overall, it became clear following these two pilot projects that additional skills need to be taught as part of the curriculum to allow for students to work in the future in CEE distributed teams.

It was decided to integrate what was learned from the first semester earlier than planned into an advanced lecture in CAD at TU-Braunschweig. As part of this integration, 40 students worked in small groups on a development task using the PDM software Teamcenter. The students were given an introduction to the software and were given the task to modify a Quadcopter for reduced weight and improved safety technical aspects, an example result is shown in Figure 6.

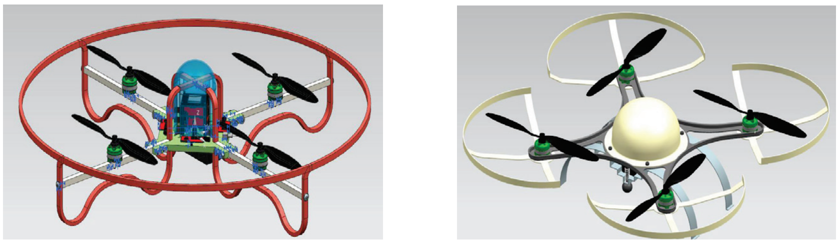

Figure 5. Lecture Integration in CAD Labour

To close the knowledge gaps identified during the course of these projects, two lecture modules were created jointly, compiling the basics of CEE as well as technical aspects of the development environment. These lecture modules will be integrated into the CAD course in Braunschweig and CAE lectures in Clausthal and Hannover. Module contents include an explanation of distributed development in conjunction with the motivation and need for its use and demonstrate technologies needed to handle the design projects. These modules are, however, not enough to address the identified shortcomings in the area of soft skills. These skills are best acquired through practical experience on behalf of the students, which can be achieved only with additional time and organization that is not available with the existing lecture structure. One possible solution would be to further develop the group project currently integrated into the lecture at TU-Braunschweig by allowing students from all three schools to work together to complete a similarly-sized development task within a semester. A more comprehensive solution would be to create a NTH Masters program in product development, which allows for conditions for CEE to be better fulfilled. The geographical proximity of the three universities of NTH offers opportunities for practical application of distributed development**.** Furthermore, a new degree program offers more flexibility to integrate soft skills into the curriculum.

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