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Distributed Product Design in Educational Programs

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Abstract

In a collaborative setting between the Technical University Berlin and the University of Twente, a newly developed student project aims at distributed product design. In the course, four groups of ten students, with five students from each institute are given the assignment to develop a multidisciplinary product – in this case an electrical drive, autonomous scale model of a car.
The course aims at addressing the ability to effectively collaborate using virtual methods by gaining knowledge and skills on collaborative technology, managing information exchange, effective and efficient storage of information, handling CAD co-development, managing and documenting different versions and variants and documenting design rationale. Additional learning goals focus on the development of project problem solving skills in an intercultural and multi-domain engineering team and furthermore the development of trust and conflict management in distributed teams. At the same time, the course exposes the students to industrial PLM and teamwork software. In this, different fields of expertise are combined, within the teams where members have different mind-sets, different point of views and working methods. In short, the course uses the development of the multi-disciplinary product preparing real-world working conditions. By positioning the groups as competing design bureaus, students pro-actively aim for the best product possible, thus the project aim as providing realistic circumstances.

1. Introduction

In product development trajectories, the relations between the different stakeholders involved become more and more complex. This is caused by the increasing complexity of the products, the increasing complexity of the value chains and supply chains as well as by the vastly increasing opportunities offered by new technologies. Product developers must cope with all the aspects of the development cycle, while simultaneously maintaining an overview of that entire cycle. Within one company, this is already a considerable challenge, as different perspectives need to be integrated to do justice to the interest of the company. Here, many different design approaches are available to guide development cycles as Tomimaya summarizes [1]. Traditionally, such design methods may offer a blueprint or backbone for fairly conventional products – both in industry and education. However, their application in development cycles characterized by unfamiliar technology, new fields of application and uncharted perspectives leaves to be desired. This proposes challenges for industry, but certainly also in educational environments where students are trained to aggregate new knowledge – foremost on the new fields of expertise, while not having extensive experience with practice-oriented development cycles. Lünnemann [2] therefore places engineering activities in the center of attention and requests to consider process, organization and the tool in parallel during product design a creation process.

Moreover, current generations of students will work in industrial or academic environments that are characterized by not only the challenges mentioned, but additionally by the fact that individual companies hardly design and build an entire product anymore. Development cycles will, to an increasing extent, be distributed over different companies, each representing a sub-set of the perspectives and fields of

expertise involved. This not only means that development cycles will become development networks, but foremost that at any moment in a development cycle, teams will consist of people that do not have the opportunity to be actually working together in a physical team. Team members might not even know each other, yet they are expected to effectively and efficiently come up with appropriate solutions for their design problems. Current design methodologies barely pay attention to such aspects, nor do they present adequate approaches to deal with them. Based on that situation Larsson [3] figures out that in engineering education a focus to these industry oriented needs is required.

Also, many existing tools and techniques in product development often lack such co-operative characteristics [4]. Therefore, product developers are dependent on those methods, tools and approaches that currently allow for co-operation in decentral and dynamic development cycles. Mats Daniels et. al.[5] come up with positive experience and ask for more education at other universities aiming at teaching distributed development. Or as Dym reflects [7], "educators must look beyond the limits of their own institutions toward a global network for design education."

Following these advices, a co-operation between the Technical University Berlin (Germany) and the University of Twente (Enschede, The Netherlands) has been established. This publication presents this co-operation and reports on the findings.

2. Project context, scope and set-up

Both in Berlin and in Enschede a new project type course has been established, with the aim to bring together the participants of both universities in one development cycle. The extent of the course is 6ECTS per student (10% of an academic year), which is spent over a period of ten weeks. The bigger part of the participants to the course has been master's students in the field of Industrial Design Engineering, Mechanical Engineering as well as Computational Engineering Sciences. The course consists mainly of a design project, supported by a provision of background knowledge. At both locations, task advisors and tutors are available to help the participants. However, these advisors will purposefully refrain from steering the students in their working methods or choice of tools and techniques.

The students work on the development of a mechatronic scale model of a race car. Here, the key element is the integration and interplay between the mechanical and electronical system, thus stressing the importance of adequate co-operation as well as methodic approach e.g. for testing. At the end of the project, each group has to present and test a physical prototype in a physical meeting. Obviously, any decentralized prepared parts of the prototype can only be assembled during that final meeting. However, bringing together control software and physical parts that have been produced at different locations can be done in an earlier stage.

Overall, the project was positioned as a regular development cycle, in which each team acts as an 'independent engineering company', being fully responsible for the approach, results and outcomes, project management and the way in which the results are presented. In total, four groups of ten students participated – each group consisted of five participants from Berlin and five from Twente.

2.1. Background provided

The project "Global Product Development" is established to help students build skills in virtual collaboration through practical experience. During the first part of the project, in the form of different lectures, students receive information about the causes and effects of virtual collaboration, project management in virtual teams and methodologies to co-develop virtual products in a CAD system. Additionally workshops were organized in a partly voluntary concept for the students, where they participated upon previous knowledge. Such workshops encompass topics like virtual collaboration methodologies, introduction to CAD/PLM, introduction to electronic prototyping platforms and systematic product development of mechatronic systems. Furthermore a simple choice of documentation e.g. for Arduino programming was provided in the collaboration platform.

For the participating student, the project is a challenging combination of actually developing the mechatronic project and explicitly investing in purposeful means of collaboration while understanding the possibilities, challenges and limitations of decentralised product development teams.

2.2. Didactic approach and learning goals

The way in which the project is set-up and attended to by the task advisors required quite a specific approach. After all, the students may have previously been exposed to linear or 'waterfall' development methods that have been presented as the appropriate blueprints. However, here, the students should consciously and purposefully develop, use, evaluate and reflect on the working methods in decentral projects based on initial input from the task advisors. Therefore, the project has carefully been established in such a way that no pre-defined checklists, procedures, rules, etc. have been made available to the teams. Moreover, the task advisors have explicitly been instructed not do any problem solving for or on behalf of the teams. Most academic staff involved, therefore, had to intentionally refrain from facilitating the students in the way they are used to. So, staff often had to decide to not answer specific questions, to not give hints and to not prevent potential 'less-structured situations'. This obviously presented challenging situations for both students and staff, but lead to a better alignment with the learning goals. After all, these learning goals (see table 1 below) are only partially addressing the development of the mechatronic product, but foremost focus on project problem solving skills and the development of trust and conflict management in virtual teams. This focus on problem solving skills has been underlined by project reviews organized in a peer-review format. In that format two groups of students

present and discuss their progress while supervisors on purpose do not interfere and answer rather in counter questions.

Furthermore the number of students per group has been intentionally set quite high with ten in order to position students in a situation with the need of organizational matter.

Table 1. Summary of learning goals

Learning goals
Teamwork, organization and softskills:
Understanding distributed teamwork
Coordinating team communication,
Organizing groups
Problem solving skills, conflict management,
Working in a cross-domain team
Project management
Presentation skills
Design and construction:
Using existing parts from a given library
Designing required parts in CAD environment
Choosing sensors guiding the vehicle
Dimensioning the electrics and circuits
Designing Autonomous driving software with Arduino
Setting up a structure in PDM
Linking relevant documentation in a PDM
Building a prototype

3. Course of the project

The overall task of the project was to design and build an autonomously steered and electrically driven scale model of a race car. Constraints and requirements such as aesthetic aspects e.g. an overall width, an overall height of 80 mm, and a scale of 1:30 compared to an actual race car were given to the students. A budget limit of 100€ per car, or needs to use certain tool environments constitute and complete the task description. Before the start of the project at both universities short introduction to the project, organizational details and an enrolment to the groups took place. During the kick-off, the four groups of both universities are randomly combined in the teams. All teams are given the exact same assignment, so there are no control-groups, nor any pre-established approaches per team.

3.1. Kick-off

The project started with a kick-off, in which the students physically met in Enschede for one day. Although this might immediately seem to violate some aims of the course, this first day was mainly used to introduce the organisational issues in the project to the students and to ensure that all technical conditions for the project were met. Moreover, staff wanted to ensure that all students were indeed prepared for the project. This was also relevant because the students were from different educational programmes, so even students from the same university might not know each other.

During the kick-off, the students were presented with the design brief, which can be summarised as "Develop and create a prototype of a scale model of a formula-one car, which can autonomously follow a track with obstacles. For building the prototype, 3D printing facilities, standard Lego-parts, an Arduino board and a limited budget are available. It goes without saying that the exact geometry of the track and the appearance of the obstacles were not yet communicated to the students. Next to introducing the content of the assignments, the students were helped to install and configure some software related to the project. This basically consisted of Siemens Teamcenter and Siemens NX11. Some of the team members had some prior knowledge of NX, for some other students it was completely new. With Teamcenter, the students could connect to a configured Teamcenter server provided by the TUB. Teamcenter was introduced as the main platform for collaboration in the group. So, on the first day of the project, the students were confronted with the fairly steep Teamcenter learning curve – forcing them to really think about how to work together, how to collaborate and how to share data. Other ways of sharing data were not precluded, but some of the deliverables were formulated in terms of the Teamcenter environment. In a specific session during the kick-off, the student teams are challenged to establish their own preferred ways of communication – both offline and online.

3.2. Project Work

As all students had prior experience with project work in limited time-frames, all four groups energetically started to address the design brief. However, compared to other projects, the teams visibly, purposefully and consciously paid much more explicit attention to their working methods, the organisation of the team and the project management. On purpose, the staff involved did not prescribe nor intervened with any of such aspects. Most groups devised a kind of organisational structure, with not only assigned experts in the different fields of expertise involved, but also responsible team members for communication and management. The way in which this was done ranged from 'fairly organic' to 'strictly hierarchical'. Additionally, the teams knowingly addressed information storage and exchange. Based on informal surveys, all groups indicated to have benefited from explicitly addressing these topics, although they all also indicated to have been overshooting the mark in spending excessive time and efforts on organisational matters. Most groups reported that discussions on organisational matters were quite instrumental in team-building and habituation, to such an extent that the actual content of the project work suffered less from incongruences in the teams. At the same time, the more formally organised teams reported on a stifling effect of focusing on and maintaining the organisational agreements.

With respect to the integration of the different fields of expertise involved, two groups chose a 'departmental' approach, where individuals represented the fields of expertise. The two other groups relied more on a 'work

breakdown' approach, thus assigning tasks and responsibilities accordingly to team members.

During the project, all teams had to initiate, organise and host a milestone meeting, thus discussing progress with the staff in a formal manner. In most cases this presented the teams with additional challenges in their communication approaches – given the meanwhile ingrained modus operandi for the team members. Due to this, the milestones became a rather obligatory addition to the informal communication channels the teams set up with staff members.

In all communication with staff members, the teams clearly showed a tendency to provoke statements that would secure their approach and achievements in the project. In this, all teams indicated that this intent was infused by the combined responsibility for project result and project organisation.

Compared to other, non-distributed projects, staff observed a much lower tendency to deviate from agreed-upon working methods and means of communication or information exchange. Hardly any ad hoc or opportunistic subterfuges became more than one-off attempts to solve immediate issues. All groups reported that this was not the result of the high quality of their initial agreements or the convenience of using the Teamcenter installation. Rather, it was reported to be a consequence of responsibility, respect and actively precluding confusion in the team. Paradoxically, the teams felt restricted in their impulses to revert to 'quick-and-dirty' solutions, while feeling strengthened by relying on clearly structured and agreed-upon approaches.

During the project, the teams experienced quite some struggles and harsh discussions on the actual design work. This especially was the case for the teams with the 'departmental' approach, where individuals tended to defend their perspectives, solutions and ideas. Here, quite quickly the need for formal communication in the decentral teams incited the differences of opinion. The fact that in the different phases of the project various fields of expertise where leading did certainly not mitigate this effect. Here, the only real distinction between the local parts of the team and the entire team became visible: quite often, disagreements were settled, or solutions were sought 'locally', before exchange of ideas in the entire team could have been endangered.

3.3. Product test and presentation

Fig. 1. One of the teams fine-tuning their car.

All four teams worked towards the deadline of the project: on the last day, the teams physically met in Berlin. By design, the programme started with a session that allowed the teams to bring together the separate modules/parts, sensors, actuators, electronics, and software of the prototypes – mostly for the first time. Some teams indeed brought together the modules that had been prototyped at the different locations. Some other teams actually attempted to build two prototypes at both locations simultaneously – thus discovering interesting dissimilarities when comparing them. Next, all teams presented their products to all their peers and staff members. Additionally, they reflected on the organisational matters, co-operative strategies and decision making in the project. The presentations included a Q&A session with peers and staff. These presentations were based on reports that each team had to hand in before the deadline. The reports underpinned both the design decisions of the groups as well as their project management considerations.

Fig. 2. Group presentation.

During the project, the students evenly divided their attention over the project work and the effective and efficient

organisation of that work. However, during the last meeting in Berlin, focus was foremost on the performance of the end-product. So, any time available during this day was immediately spent on fine-tuning the cars, and especially on adjusting sensors and car-behaviour to the track. This track was only shown to the students on this last day, so expectations had to be adjusted and the first sensor data on the reading of the track-marking were only available then. Obviously, this stressed the relevance of adequately integrating hard- and software in this project, thus emphasising the importance of an effective project architecture. As all groups made such architecture an inherent part of their communication approach and project management, no structural problems were encountered.

This certainly does not mean that all cars smoothly accomplished lap after lap on the track. As it is often the case for design, reality-checks brought nuance to self-evident theories and truths. In other words, although students were prepared for accommodating unexpected phenomena in and around the track, the scope of the envisaged adaptations was not always fit to indeed meet the conditions of the prepared track. Consequently, all groups struggled to demonstrate the real performance of their cars, e.g. in figures 3 below only one car remains on the track, whereas the other one does not properly recognize the marking.
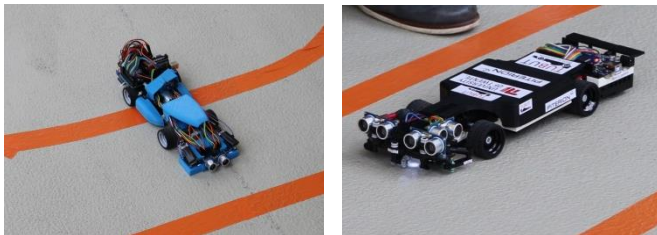

Fig. 3. Race cars on the track.

During the presentations, the students were already questioned on the balance between the actual project work and the (pre-) conditions of working together in a distributed team. Obviously, students formed an opinion on this during the project, and were certainly prepared to answer questions on this topic. However, perhaps also due to the less-than-perfect performances of the cars, even during the race, the students in and amongst the teams continued to fundamentally reflect on optimising project content against project organisation.

3.4. Assessment of the groups' results

After the final meeting in Berlin, the cars, final reports, presentation material as well as authoring data such as CAD models of all teams were collected and have been graded. As was communicated to the students on beforehand, the grading was based on the milestone meetings, the report, the presentation and the prototype including design models such as CAD or software code. The grading was based on team performance, i.e. each student in a team would receive the same grade. Table 1 gives a simplified overview of the assessment criteria; between these aspects, weighing factors

were applied. In this, the final report had the highest factor (40%), followed by the presentation (30%). The milestones and the prototype each contributed 15% of the grade. For each of the aspects, the rows mentioned in Table 2, each also had a weighed contribution to the grade for the respective column.

Table 2. Overview of assessment criteria.

Milestone	Report	Presentation	Prototype
Enthusiasm	Research	Enthusiasm	Professionalism
Composition /structure	Problem solving	Composition /structure	Objectives
Communication	Composition /structure	Communication	Reflection criteria
Visual aids	Approach	Discussion	Aesthetics
Project planning	Visual aids		CAD model
	Enthusiasm		Teamcenter
	Teamwork		3D printing
	Reflection		Budget

Given the amount of assessment criteria, expectations were that teams would quite easily be able to compensate an unsatisfactory grade by the many other grades. This obviously would easily lead to fairly 'average' grades, damping any extreme grades for sub-aspects. Using thresholds might have been useful to single out real shortcomings, but that would have increased the risk that one detail would be overrepresented in combination with the weighing factors. Moreover, in design, some assessments will remain subjective by definition, thus also complicating the use of thresholds. For this reason, a scoring system has been applied that later on was converted in the actual grading.

3.5. Evaluation on learning goals and teaching methods

Where the assessment day in Berlin was wrapped up with an informal event to formally close the project, the students were subsequently asked individually both orally and in formal questionnaires on their individual learning curve, feedback towards learning goals and achieved project results. These results were handed back to the students in a detailed written statement together with remarks on their grades. With respect to a formal scientific approach the oral survey might be supported by an independent party and standardized for the entire group.

Most students indicated that the 'lack of information' was experienced as a flaw in the course. This addressed for example templates on the organisation of the project, but also the fact that the layout of the test-track was only available on the day of the test. In well-nigh all examples, the remarks were expected or even evoked explicitly. In other words, the staff would have been able to provide much more organizational information, but that would have immediately counteracted the main learning goal of the project: how can one organize a decentral development cycle. Therefore, these remarks stress the students' demands for explicit information and guidelines, but also indicate that students need to build

confidence in situations characterised by uncertainty, volatility and dynamics.

In the evaluation, it was evident that the students appreciate the opportunity to work in an international co-operation. They perceived the project as being very relevant for their professional future. More important, however, the students made explicit that actually experiencing and living through (or 'surviving' as one student formulated it) a full development cycle in a distributed development team bring an experience and a way of looking at product development that cannot be understood from sheer theoretical treatises. With this, the vast majority of the students agreed that although the process could be quite cumbersome at times, the advantages of gaining the practical and organizational expertise and experience of working in a distributed team has been a valuable addition to their education.

Students were not corrected in their decisions, for example when it comes to organizational matter. Like that students are confronted with the results of their decisions and requested to support the positive and negative consequences. Meaning students are in this way supported in their learning goal "problem solving skills". Underlining this aspect from staff position it was not necessary to moderate on difficult situations within the teams, they learned to solve things by themselves.

All groups successfully developed a car and are proud and positive on their work. Next to engineering insight, which some students on purpose avoided where other extended it personally, all stated that they learned on communication, teamwork and international collaboration. Like that the stuff considers the course setting and learning goals as presented to the students and the assessment criteria as relevant for engineers.

4. Concluding remarks

Education in engineering often focusses on using typical tool environments or teaching classical methods. Whereas the day-to-day challenges of engineers such as widely spread teams, taking over responsibility, constraints from tools, organizational conditions are not considered in education and thus young professionals facing these circumstances for the first time on the job. Here an alternative way of education demonstrated first concepts, where students as well as industrial peers positively quoted the real-life experience.

The realistic tool environment setting including "problems" in handling it, going together with an adequate support not delivering solutions at the first place but back students is considered a positive outcome. The competitive aspect of the race creates a motivating atmosphere for students. Compared with the learning goals especially of collaboration and practical experience, the report creation might be replaced an even higher focus on design models. This matches the outcomes of [9] where a combination of engineering design courses should be taught across geographically dispersed, culturally diverse, international networks.

As other authors [6, 8,10] conclude as well such a doing based approach focusing on international collaboration results in an overall motivated and committed student attitude and with that appropriate learning results. [7] remarks in his distributed educational courses that students act better in documentation. Within the Berlin-Enschede course we observed that same as in classical local course approaches generally students tend at documenting what is requested for course completion only. However, documents serving the collaboration are well frequented.

Compared to the Anglo-American university system the continental European teaching is public and in general independent from industry. However [7] recommends for international teaching aspects a strong problem based approach, meaning he suggest an industrial show case. Further student education projects might shift the focus even further towards researching and testing aspects in order to support the confidence on students' creative problem solving skills and independence in finding solutions. This can be done for example when the staff presents more of the required input optionally as well as placing the task description rather as a problem statement in a way that might be found in industry as well, meaning that constraints, options and boundaries need to be reworked during the meeting.

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