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THE USE OF CONCEPT MAPPING TO SUPPORT COLLABORATIVE ADVANCED DESIGN PROJECTS

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ABSTRACT

This paper describes the collaboration efforts of three departments of the faculty of mechanical engineering at Technische Universität Darmstadt (TUD), aimed at providing students of engineering design (ED) and industrial design (ID) with a common platform to work on. To this end, ED and ID students were provided with an opportunity to jointly practice collaborative advanced design projects, while acting as test subjects for the application of a networked, easy-to-learn, accessible software tool for knowledge modelling and data exchange. Projects were closely monitored to provide some insight into how the software-based, interdisciplinary collaboration works.

The aim was to determine, whether the visualization and modelling of the interconnected nature of the design process and product features increases process awareness in the participants. Thereby, a contribution to process improvement for industrial product design was intended.

Keywords: Interdisciplinary collaboration, networked structures, process documentation, project monitoring, concept maps, software

1 INTRODUCTION

Product design in an industrial environment is a complex process, in which actors, procedures and product features are intensely interconnected. As a result of this complexity, the process of inventing, designing and producing all but the simplest artefacts has evolved into a collaborative endeavour involving numerous participants with distinct areas of expertise. The need for efficient and effective communication and collaboration has increased accordingly.

Companies deal with this in different ways, e.g. by establishing more or less structured and formalized design processes, or by investing in human resources, organisational development or software tools. Engineering science offers many procedural models, methods and tools for controlling the complexity of the process. Among these are the prescriptive process models, according to e.g. Pahl and Beitz [1] or the Association of German Engineers' VDI guideline 2221 [2]. Furthermore, a huge number of methods and tools with discursive bias have been developed, in order to support frequently occurring activities in design, such as gathering requirements, generating solutions, evaluating and comparing concepts, searching for weak spots, etc. Examples are: Checklists, morphological boxes, and Failure Mode and Effects Analysis (FMEA).

In contrast, industrial designers take a less formal approach towards the design process, sometimes to the extent that they deny employing any fixed procedures or methods at all. Some examples of industrial design driven approaches are the "Offenbacher Ansatz" for description of aesthetic or rather "sensual" product properties by Fischer, Gros and Bürdek (compiled by Steffen [3]) or the systems theory-oriented methods developed by Jonas [4]. In a collaborative study with designers and engineers Peters [5] already pointed out, that jointly describing technical and aesthetical product attributes in networked structures leads to a better understanding for both engineers and industrial designers. But Peters' approach on networked product features with modelling and visualizing interconnections was only paper-based.

The following work is based on the hypothesis that a consistent computer-aided modelling and visualisation of the various interconnections in networked or netlike structures of product features and product development processes is feasible, can prevent misunderstanding and the often-resulting lack of collaboration between engineers and industrial designers. It is expected that process awareness can be increased and the corresponding need for iterations in the design process may be reduced.

Preliminary literature studies by the authors did not turn up theoretical foundations for the core topic, which may be due to several problems: nomenclature, language or simply looking in the wrong places (or –unlikely- absence of previous findings). Until this can be remedied, this paper is to be seen as an empirical study.

2 NETWORKED AND NETLIKE STRUCTURES

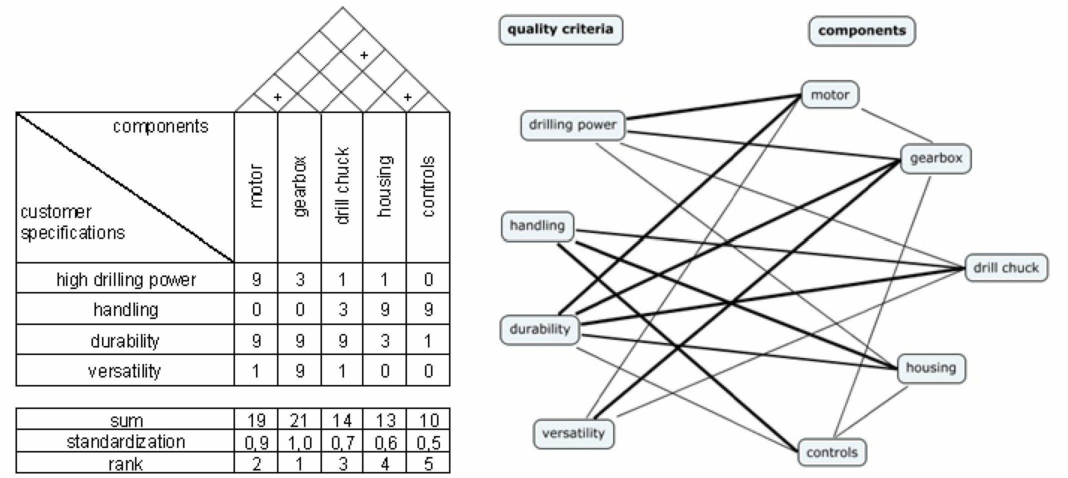
2.1 Handling interconnected structures in product development

A common feature of many approaches for handling the complex and interconnected structure of design processes is to

- linearise them and
- re-iterate a number of sequential steps, if the outcome is unfavourable (iteration is a part of almost all major prescriptive process models).

As an example for linearisation, Quality Function Deployment (QFD) [6] may be considered. In figure 1, the interconnections implicitly given in the central “quality chart” matrix (left) are depicted on the right hand side. Strong correlations are expressed through thick lines and represent the “9” in QFD. Large parts of the QFD worksheet and process have been omitted for better readability, e.g. the weighting and competitor benchmarking.

The (fictitious) example below describes a power drill; the values chosen are of no relevance . Also, this is not to say that matrices should generally be transformed into graphs (although it is possible and sometimes helpful in determining areas of intense correlations between factors). The statement is rather, that through performing QFD, the connections are resolved and transformed into a linear ranking by summing up. This ranking acts as a basis for further decisions, e.g. about target cost or development budgets for individual components.



customer specifications \ components	motor	gearbox	drill chuck	housing	controls
high drilling power	9	3	1	1	0
handling	0	0	3	9	9
durability	9	9	9	3	1
versatility	1	9	1	0	0
sum	19	21	14	13	10
standardization	0,9	1,0	0,7	0,6	0,5
rank	2	1	3	4	5

Figure 1: QFD worksheet (excerpt, left) and graphical representation (cmap, right)

Prescriptive methods and process models are generally heuristic in the sense that they rely to some extent on the implicit knowledge and experience of the user. The influence of the user(s), with their skills and methods, on the outcome of design procedures is subject to ongoing research [7]. It has been acknowledged, however, that networked structures play a significant role in human cognition and „Design Problem Solving”.

In contrast to the discursive methods, a number of methods with an intuitive bias [1] are used in order to facilitate the production of original and innovative ideas. A prominent example is “brainstorming” in the form of a moderated group workshop, where people with different professional backgrounds are given a specific task and collect solution proposals by freely exchanging and building on one another's ideas. These methods make use of the properties of human cognition, namely the networked relations between concepts, which enable the participants to build up associations with previously suggested ideas and come up with ideas of their own as a result.

In product development, the utilization of methods or tools from these two categories is dictated by a central conflict of objectives. One the one hand, companies have to bring innovative new products to the market, on the other hand they have to minimise the risk of running into dead-ends or overlooking profitable variants and/or threats during product development. It is often felt that the outcome of the process (i.e. the product) profits from the free flow of ideas, unobstructed by restrictive process outlines or methods. To minimize development risk, a more restrictive process with fixed deliverables and success criteria is favourable.

The tendency towards linearisation is also mirrored in the formats used for documenting the design process. While visualizations in the form of nets are used in organisational planning (e.g. critical path analysis, petri nets, etc.), the documentation of actual product features in formal/abstract form relies largely on tools like spreadsheets or text files ("Powerpoint engineering"), until the product enters the stage of graphical representation in CAD-files.

To manage this kind of data, so-called engineering data management (EDM) or product data management (PDM) systems are a standard within the engineering domain of modern product development processes. They manage the engineering files and relevant processes, as well as the collaborative product development of the detail design phase, for which they were initially designed.

PDM systems distinguish between engineering objects that have to be managed (e.g. documents, drawings, CAD-files etc.) and the meta-data (e.g. identification, version, creation date, status, material, mass, quality, costs etc.) that describes them. Data is hierarchically structured, so that product structures, document structures, and project structures have to be built up, represented in trees. Workflows to process this data have to be defined in advance [8]. By experience, the initial training is very time-consuming, and use of these systems does not really support creativity.

In summary, PDM systems are not supposed to manage the highly fluctuating ideas, concepts and structures in an interdisciplinary project during conceptual design phase and are currently not able to support collaboration between engineering and industrial design on a product and/or process level.

2.2 Modelling and visualizing networked and netlike structures

As mentioned above, product development is based on a large amount of factual information concerning process and product, which is either directly represented or implicitly exists as a network. The goal of this project is to explicitly model and visualize these networks, using computer-aided tools, in order to support the product development process.

In general, networked structures may be graphically and semantically presented and represented through objects (dots, vertices, nodes, parts, concepts etc.) and relations between these objects. The relations and the objects can be both labelled (with numbers or text) or unlabelled. Additionally, they are often formatted by colour or shape, for example arrows in a relation or the shape of an element to express a special issue.

The number of allowed formats and restrictions is a good value for their degree of formalisation. On the one hand, highly formalised net-like structures are better computable (considering machine cognition). In this case, networked structures are used e.g. in mathematics and computer science (e.g. graph theory, semantic networks). On the other hand, a highly formalized structure leads to a bigger effort of learning and using always the correct syntax. Some examples are Ishikawa Diagrams, the Unified Modelling Language (UML) or the Structured Analysis and Design Technique (SADT). In the interdisciplinary collaboration of product development, we have to focus on networked structures primarily as a rapid and simple way to communicate and visualize different concepts (ideas, problems, issues etc.) without thinking about mathematically correct or even computable structures. Within this scope, networked structures are often referred to as “mapping techniques”. Some famous techniques are mind maps, spider maps, concept maps or knowledge maps. Eppler [9], for example, gives an overview about some of these structures.

In networked structures, the relations between elements are represented by an edge (displayed as line, curve, branch etc.) between the objects (net-type structure). But it is also possible to represent the relations between elements only by their distance or relative position to one another. This “positional type” is comparable to a net in which every element has an implicit relation to every other element, but the relations are not explicitly shown. Another special type of a net is the so-called tree structure. In this hierarchical structure, an element can be only connected to one superordinate element, whereas it can have several subordinate elements. Tree structures are well-known from product structures in CAD systems or data structures in computer science. All these three types are called netlike structures.

Every single type has its advantages and disadvantages. The positional type is useful to collect and sort elements (e.g. in a brainstorming) of an idea at its beginning, without being constrained to explicitly designate every relation to the other elements. To consolidate an idea, the net-type is more useful. Finally, the tree-type is best to build up a hierarchy and a give a fast and common access to the elements of an idea. Obviously, these three types are not transferable without human intervention.

Concept maps and mind maps are appropriate methods for structuring ideas and concepts in a flexible and efficient way for both novices and experts. Although both types of maps have some features in common, concept mapping is different from mind mapping [9]. One main difference relates to the kind of organisation of ideas. Whereas concept maps allow representing concepts both in a tree-type and net-type manner, the typical format of mind maps is the tree-type with one superordinate concept in the centre and the other concepts branching away from it. Hence, concept mapping is more flexible than mind mapping.

Concept mapping is a technique originally developed for cognitive psychology and didactics. It is used for modelling knowledge in a graphical representation. Many different definitions and methods for concept mapping exist. Some are more formalized (e.g. concept maps of Jüngst [10]), others less. A well-known concept mapping technique has been developed by Novak since the 1970s. Novak defines concept maps as “*… graphical tools for organising and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts.*” [11]. A lot of research work on using concept maps for didactic purposes has been done within the last years and their high value for learning and teaching is already accepted.

The Institute for Human and Machine Cognition (IHMC, http://cmap.ihmc.us) provides a freeware computer tool called CmapTools which allows to model concept maps. It includes a client/server structure and allows attaching documents to individual concepts and relations of a map. Documents can be managed both hierarchically within a tree-structure called "view window" and/or within the concept maps themselves. In addition, within the Cmap environment synchronous and asynchronous collaboration and communication are possible through a message board and chat functionality.

In summary, concept mapping and the CmapTools seem to hold some promise for supporting collaborative product development processes between engineering and industrial design. They provide the means of structuring product and process information in a far less formal way than existing engineering methods and tools, e.g. like PDM systems. Thus, they should accommodate engineering designers as well as industrial designers, facilitating project planning and collaboration while supporting a creative and intuitive mode of work.

3 COLLABORATIVE ADVANCED DESIGN PROJECTS

3.1 The collaborative “Advanced Design Project” course

To support the hypothesis, we used the “Advanced Design Projects” at Technische Universität Darmstadt (TUD) as an empirical environment. The Advanced Design Project (ADP) is a curricular course at the end of the master program in mechanical and process engineering at TUD. It comprises an amount of approx. 80 working hours per student within a timeframe of minimum two weeks. These ADPs are offered at every department of mechanical engineering at TUD, so students can select an ADP according to their interest to attest their acquired knowledge within a special field of studies.

Teaching further knowledge in the field is not intended by the ADP. It should rather prepare students for their professional future in typical industrial projects. That is achieved by giving them complex, industry-like problem definitions, which have to be solved in a team of 4-8 students. Problems are only roughly verbalized and have to be detailed by the students by focusing on special issues and describing detailed project plans. Moreover, all projects contain a detailed report and a final presentation of the results at the end.

In winter term 2005/2006, DiK, IAD and pmd decided to develop a new kind of ADP extending the project idea across the three departments and considering interdisciplinary research questions in the product development process. To also consider aesthetic means, students of industrial design from Hochschule Darmstadt (h_da - University of Applied Sciences) were involved, too.

To mark the difference, this project was named "collaborative ADP (cADP) - Computer-aided development of products driven by ergonomics and aesthetics". Each team within these projects includes at least three students of mechanical engineering from TUD and one student of industrial design from h_da. Each of the three mechanical engineering students should cover a part of expert knowledge or “role” of the three involved departments. This way, the DiK student is responsible for product data technology-related issues, the IAD student for ergonomics and human factors and the pmd student for overall product development processes and methods.

Each cADP team works on a specific design task. The task is to develop a product on the conceptual and embodiment design level, using tools and methods specific to their respective roles. Given the already limited time-frame described above, a few restrictions on product complexity are established.

These restrictions are:

- restricted size: to allow full-scale rapid prototyping
- portability: the product had to be portable, to ensure ergonomically relevant user interaction
- electronics: no fully electronic products, to avoid "black box" engineering
- interaction: no (or very restricted) software-based functions, to avoid HMI-centric ergonomics
- innovation and aesthetics: obligatory, to motivate thinking "outside the box"

Project work starts with a formal kick-off meeting that has to be attended by everyone. Its goals are to initiate the teambuilding process (teams were pre-arranged by the supervisors), to give some formal and discipline-oriented introduction (including the rules outlined above) and to supervise the product selection process. Within the project, students are urged to plan, carry out and critically reflect on the design process. The use of computer-aided tools is mandatory. Therefore communication and data exchange have to be considered as well.

Up to now, cADP was performed three times. In the following sections we will describe project setup and results.

3.2 cADP put into practice

3.2.1 First cADP (Winter Term 2005/06)

Organisational Rules and Design Task Description

Because of the limited resources to be invested in the "first go", organisational rules were kept at a minimum. Only a thorough self-monitoring and conscious reflection about one's own and the team's overall actions were demanded. As a tool for communication, file exchange and process monitoring, a simple website with a "guestbook"-style interface (including file attachments) was set up, with the most recent postings of each team shown on top of the entries list. The use of Cmap in this first project was not mandatory, only the possibility of using Cmap was mentioned in combination with the task of establishing communication and data exchange schemes that seemed reasonable. The product and its field of application were almost entirely unrestricted, to accommodate the Industrial Design students' individual portfolio strategy.

Results and Observable Difficulties

From the product point of view, the results were largely convincing. All developed products, the "innovative trash bin" (integrated thrash-bag closing mechanism), "TransBoard" (a sporty daily-life trolley hybrid) and the "world-cup beer crate" (easy to transport and nice to sit on) showed a good combination of aesthetics and functionality, even the functional level of detail was comparable.

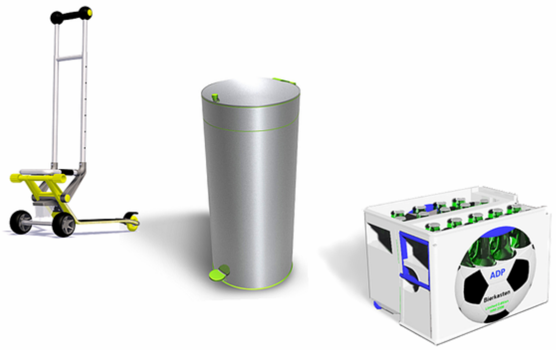


Figure2: Product results of the first cADP

The big downside, however, became apparent in process recapitulation, as the students basically performed none at all. Data exchange that did happen through the website was (by design) available only in reverse chronological order and (by decision) mostly uncommented and incoherently named. The only "standard" that every team came up with was the exchange of meeting minutes to document their progress, which proved too difficult to read to qualify as good process documentation. The worst problem, however, was the incompleteness of data due to an extensive, e-mail-based interchange. Furthermore, it seemed that no team member had really understood the concept behind process documentation and process orientation all too well, regardless of the thorough engineering design education most of them had gone through. Product documentation and presentation were brilliant, and students identified themselves very much with "their" product. But no-one was able to describe how the product had come into existence - it had "simply just happened", or so it seemed. Moreover the time limit of 80h/student was exceeded by a vast amount.

Aside from these formal problems, an effect on the products could be observed as well. In the case of the trash bin, the industrial designer started out with a number of sketches and a conceptual model in a CAS (Computer Aided Styling) software. The model already had the circular cross-section, as shown in figure 2. The engineering students then had some difficulty in devising the mechanism for closing the garbage bags automatically inside the trash bin, once they were filled. However, they failed to question, whether the trash can really had to be round. The mechanism for closing the garbage bags inside might have been totally different (and perhaps a lot simpler) with a square cross section.

An interview after the conclusion of the project revealed, that the designer had merely tackled the task in his normal fashion, by creating graphical representations of the item under consideration and had never meant for them to be definite solutions, but rather “thinking aids”. Since comparable 3D-CAD models are generally used in engineering after the concept is finished, the engineering students had assumed that the geometry was final, and went on to do the detail design. This misunderstanding is symptomatic for a lack of common understanding about the tools used and the state of the project.

3.2.2 Second cADP (Pre-summer Term 2006)

Organisational Rules and Design Task Description

The second iteration of cADP took place under slightly different circumstances than the first one. This time, engineering "manpower" was limited to only 4 mechanical engineering students, whereas there were three industrial design students participating. It was therefore decided to form only one team and to design one product, but in three different, market-oriented variants to ensure an adequate workload for the ID students as well. The product was pre-selected as an electronically-supported tape measure.

This time, the CmapTools client software along with the server environment was used as a tool for communication, collaboration and file exchange. Further methods or advice on how to use the tool were not given. It was considered a sufficiently self-explanatory tool not to require any specific introduction, since it usually takes only 15 minutes for a computer-literate person to learn the basic functions needed to operate it. After that, it was left to the students to figure out how best to apply it.

Results and Observable Difficulties

Comparable to the first cADP, the product and its documentation were again quite convincing; the three required tape measures were well-adjusted to their respective markets, both aesthetically and technically.

Figure 3: Product results of the second cADP

Additionally, the product and the development process had been documented much better this time. Though no instructions had been given how to use CmapTools within the project, it was excellently possible for the supervisors to monitor the process and the product’s progress by exploring the concept maps and the included discussion forums. CmapTools was found valuable not only for the support of the students’ product development process, but also for the supervisors’ project monitoring.

Nevertheless, using CmapTools for documenting the process and the product was considered time-consuming by the students. Reasons for this were:

- The ambition to perfectly organise data exchange on the concept map level as well as on the file-system level (CmapTools’ “view window”). Aside from just contextually linking files from within the appropriate concept maps, participants also tried to keep their folder structure in order, which resulted in a strongly increased administrative effort (Figure 4).
- The lack of adequate methods and rules on how to use CmapTools for product development.
- Some additional software performance, ergonomics and stability problems.

The written process documentation and process understanding in general had, as expected, suffered greatly from those deficits.

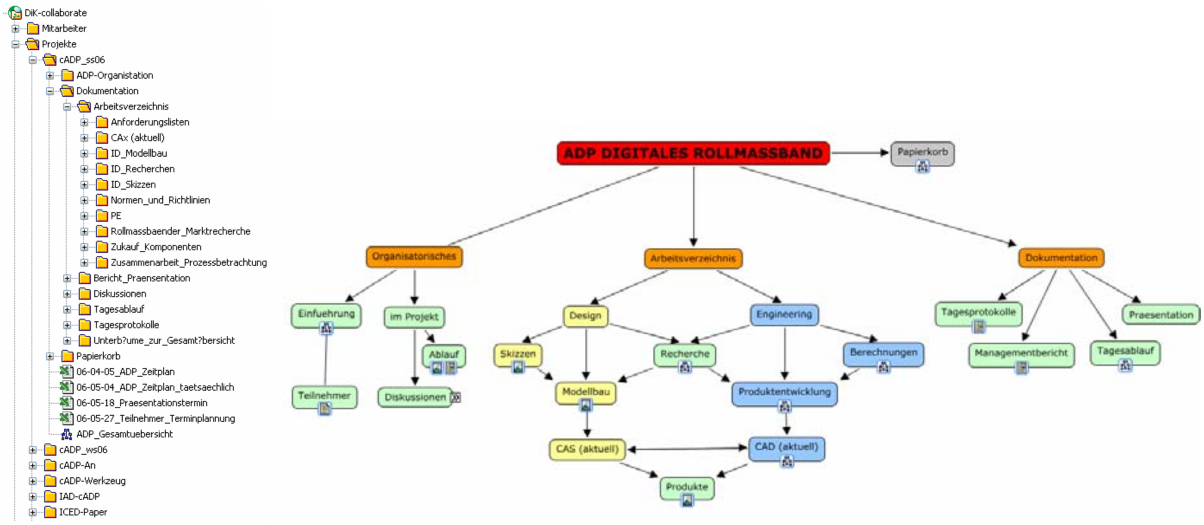


Figure 4. Files organised on both file-system (left) and concept map level (right)

3.2.3 Third cADP (Pre-winter term 2006/07)

Organisational Rules and Design Task Description

For the third cADP, three teams were recruited again. Each team consisted of three mechanical engineering students and one industrial design student. The product types were limited to a combined tool for either "kitchen and dining table", "workshop and workbench" and "office and desk". Because of the good results seen in the second ADP, CmapTools was used again. But this time a short (appr. 45 min) introduction to the usage possibilities of the CmapTools software was given, and some further rules and methods were added.

First of all, product and process data were to be managed from a central "!project_coordination"-cmap as a strategic level for project planning. Originating from this Cmap, operative Cmaps containing further product or process information were to be made accessible and results were to be connected to "!project_coordination" again. Additionally, within the strategic map, three milestones had been defined.

Furthermore, for modelling processes and product information a simple method (following basic concept mapping methodology) was introduced. This method contains five steps:

1. **Start collecting** relevant information in the form of different objects (concepts or pictures) both by using the team's creativity in a brainstorming session and by individually adding to it,
2. **Sort** the collected information by relatively positioning the elements to one another,
3. Name the main elements and start **connecting** in particular named relations between the elements,
4. Go on collecting and sorting during the whole process and
5. Finally **format and structure** the elements by the use of colours, text formats, etc.

For example, easily recognizable formats for responsibility (role or person), status (new, in progress, finished) or importance (low or high) of the objects were suggested. Adopting these organisational rules was recommended to the students rather than imposed on them.

Project monitoring was stepped up as well. Aside from saving results in CmapTools periodically, one team was randomly selected to be monitored closely during all their meetings. Additionally, all teams had to fill questionnaires and keep diaries on a regular basis. Details of this monitoring were taken care of by a student in the course of a master thesis.

Results and Observable Difficulties

Once again, the product side hardly gave any reason to complain. "Agnes", the desk lamp with an integrated tray that also serves as reflector for providing indirect lighting, "hammer+", a hammerscrewdriver with integrated ratchet for home use, and the “egg cup with integrated egg cutter” all proved to be convincing in most, if not all design aspects.

Figure 5: Product results of the third cADP

Methods and software tools were mostly used in an appropriate manner. All in all it seemed that students had thought intensely about "how" to do their development, questioning the rationale of the procedure, rather than predominantly thinking about "what" they should do in terms of applying established methods and tools.

Table 1 summarises cADP experiences, further results will be discussed in the following section.

Table 1: Overview of cADP progression

	cADP 1 ("free product")	cADP 2 ("strict product")	cADP 3 ("guided")
Team Composition	3 teams (3-4 engineering, 1 industrial design)	1 team (4 engineering, 3 industrial design)	3 teams (3 engineering, 1 industrial design)
Product Definition	No product or market limitation within complexity limits	Product and markets fully pre-defined	Product / market categories pre-defined, complexity limits
Data Management Software	Guestbook-style website, no introduction	CMAP tools client/server, no introduction	CMAP tools client/server, introduction and usage suggestions
Process Monitoring	Self-monitored	Self-monitored	Self-monitored externally monitored

4 USE AND BENEFITS OF CONCEPT MAPPING IN COLLABORATIVE ADP

In interpreting the project results, it has to be kept in mind that the total number of processes conducted during the three terms is quite small. Moreover, the participants were students with little experience in project work, though well-educated in the methods and tools of their respective disciplines. Since direct comparisons between design processes that do utilise concept mapping and the ones that do not are not possible (and the sample size is not sufficient to present statistical conclusions), the following findings have to be marked as preliminary.

The application of concept mapping software during the project serves two purposes:

- Facilitate coordination and collaboration of the team members.
- Serve as a monitoring tool for the project supervisors.

With regard to the first item, several benefits of using CmapTools present themselves. For the team members, it provided a quick and simple way for structuring the design process. During the third cADP, teams were given a rough outline of the process in the form of milestones. By applying a concept mapping approach, the teams first collected the activities which had to take place in between the milestones, then sorted them into the appropriate phases and finally plotted a connecting timeline. Furthermore, the project plan was only as detailed as necessary to reach the successive milestones. It was revisited several times during the project and detailed further, with the consequence that, on the whole, team members were well aware of the progress made and the state of the project at any given time.

Besides structuring the design process, CmapTools also served to organise product features on different levels of abstraction. The most beneficial feature is probably the possibility to link nodes across different maps and even to embed some maps into others (“nested node”). Thus, maps were dedicated to one purpose, e.g. collecting requirements, but the individual objects within one map were also linked to related information in other maps. For instance, requirements in one map were linked to assessment criteria for selecting variants in another map. In consequence, the assessment criteria and their weighting could be traced back to the original requirements in a matter of seconds by just following an existing link, without the need to consult further documentation and e.g. browse a text file or table. In case further documentation is needed (for example a spreadsheet for automatic computation of weighting ratios in an assessment method), the file can be attached to a node in the map and is directly accessible through it.

Misunderstandings comparable to that presented in section 3.2.1 did not occur in the projects supported by concept mapping. The overwhelming majority of participants, both engineering and industrial design students, rated concept mapping as very beneficial to the project in terms of supporting coordination and collaboration. From the supervisors' point of view, the value of applying CmapTools lies mainly in the possibility of monitoring the progress of the project. It has been found that one can achieve a very good overview by simply examining the main map and following the links to the most recently added or changed concepts. In some instances, Cmaps have supplanted other means of project documentation, like e.g. minutes of team meetings.

In the third iteration of cADP, process monitoring by studying the students' own documentation was supplemented by an external monitoring. It consisted of a number of monitoring methods, summarized in table 2.

Table 2: Monitoring methods

	Monitoring methods						
	indirect						direct
Time of application	Participant data	Process insight	Role identification	Milestone questionnaire	Project diary	Feedback meeting	Non-participating observation
cADP kick-off	X	X	X				
milestones				X			X
individual work					X		
group meetings							X
cADP completion		X	X	X		X	X

After establishing the individual preconditions through collecting participants' data, questionnaires were used at the beginning and the end of the project, in which participants characterized their perception and understanding of their role within the team. At regular intervals during the milestone presentations, students were asked about the state of the project, their satisfaction with their own performance and that of the team, and many more aspects. All team members were asked to keep diaries, detailing, among other information, the amount of time used on different tasks and their communications outside of CmapTools. Students of one team, which was under closer observation, were also observed during team meetings, with activities and behaviour were recorded on paper. This way, a huge amount of information was gathered, the evaluation of which is not yet completed at this point in time.

However, one particular monitoring activity shall be presented as an indicator of which influence the projects might have had on the participants' understanding of the interconnectedness of the design process and their roles within it. In a procedure internally named the "process insight" test, students were asked to depict their understanding of the connections between aspects of the design task, again using CmapTools. A range of ten concepts was provided, all to be connected using five different relations. Concepts and relations are given in table 3.

Table 3: Concepts and relations for detailing process insight

Concepts	Product	Engineering	Human
	Design	Production	Mechanics
	Planning	Ergonomics	Aesthetics
	Culture		
Relations	changes	influences	decides
	uses	follows	

This procedure was performed at the beginning of the kick-off meeting, even before the exact nature of the project and the task had been disclosed, and repeated after the project results had been presented. The resulting graphs were compared, in order to determine how the perception of the connections between the concepts had changed. An example is given in figure 6. It could be observed that the graphs usually showed an increased number of connections after the completion of the product. In a few cases, even a qualitative shift could be observed, in the sense that other concepts became the centre of the graph. However, without additional work and a larger number of participants, preferably with good design experience, no further conclusions can be drawn at this point.

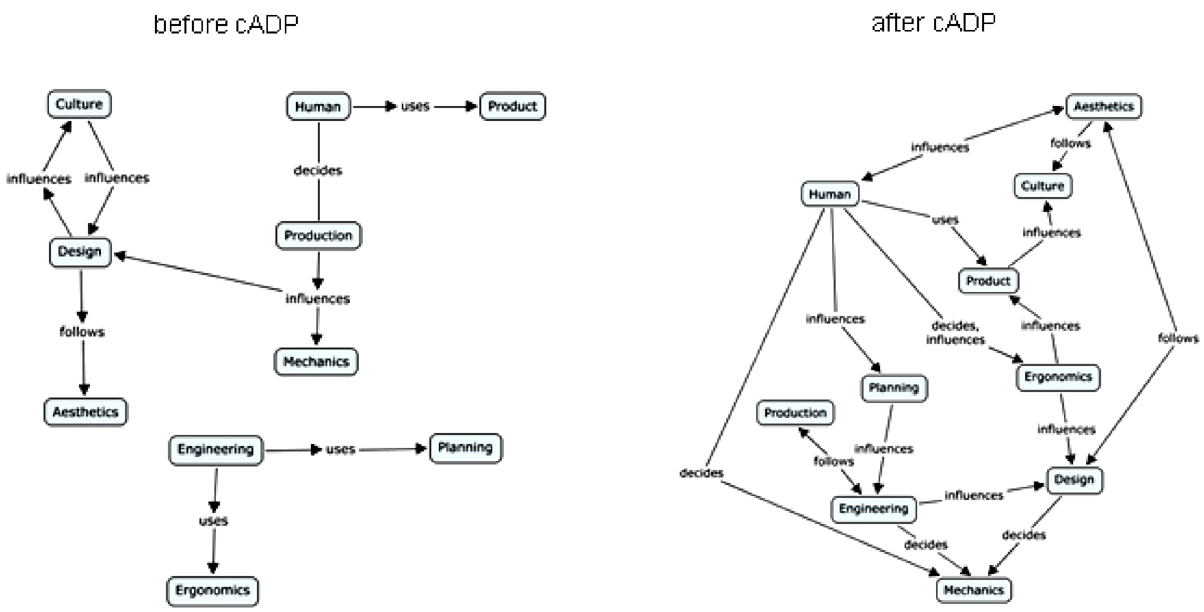


Figure 6: Comparison of "process insight" concepts maps

5 CONCLUSION

The CmapTools software has proven to be a suitable tool to monitor and document collaborative product design. It shows great potential in both visualising and supporting the product design process, without being specifically adjusted to these tasks. It also facilitates ad-hoc collaboration while providing concept map integrity, and even the still rather basic file system functions are immensely helpful thanks to their integration into the concept map. With virtually no learning curve for computer-literate users, it provides easy access to its data regardless of the designers' origins or affiliations.

cADP, on the other hand, has shown a steady improvement across its three iterations, difficulties from under-regulation (esp. cAPD 1, free product) as well as over-regulation (esp. cADP 2, given product) have been encountered on both product and process side. Up to now, the moderately restricted, milestone-guided cADP 3 has shown most promise, with adequate rules in place for product, process and software support. Some of the more ambitious goals of the supervisors could not be met (particularly the recurrent lack of process understanding is to be noted), but one must also be aware that high standards within a short time frame are difficult to meet when they're out of the usual, "applied methodology" focus of engineering design education.

An increasing amount of external project monitoring therefore appears to be a good idea, rather than only relying on students' own insights and usually lacking documentation. Along with the seemingly "automatic" documentation of the development process in a concept map it should allow to identify some interesting parameters.

All in all, results warrant further work in this interesting environment. Aside from continuing the monitored cADPs, the still recurrent deficiencies of the CmapTools software suggest that the development of a product design-specific concept mapping tool might also prove to be of interest.

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