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Cross-Disciplinary approaches – Indications of a Student Design Project

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Abstract: Cross-disciplinary approaches are adopted in technical product development for a number of reasons, including the improvement of the product quality and the reduction of time to market. However, the positive and negative effects of cross-disciplinary approaches such as cross-disciplinary teams or biomimetics are controversially discussed. In this work, we perform a case study with architecture and mechanical engineering students using biomimetics to gain insights to effects in a threefold cross-disciplinary project. The results indicate possibilities for improving cross-disciplinary team projects.

Keyword : cross-disciplinary team work, biomimetics, collaborative design

1 Introduction

Adopting a cross-disciplinary approach in technical product development is supposed to have a number of positive effects: a more profound problem understanding, higher quality of solutions and a shorter time to market are examples [1, 2]. A cross-disciplinary approach can be conducted in different ways. One approach is to set up cross-disciplinary product development teams in order to develop a product for a task related to both disciplines. An example is a product for HVACR (heating, ventilation, air conditioning and refrigeration): Both architects and engineers can contribute with their discipline-specific knowledge to the development. Another approach is to use information from different disciplines for inspiration. This is the case in biomimetics: The designer uses nature or results from biological research as inspiration for solving a technical task.

What are the effects if both these approaches are combined, i.e. a cross-disciplinary team uses information from another discipline? Understanding the effects of this combined constellation can give implications for supporting cross-disciplinary teams working on a cross-disciplinary project.

In this work, we explore the effects of cross-disciplinary approaches in a case study conducted with five cross-disciplinary teams consisting of 23 students of mechanical engineering and architecture collaborating in a biomimetic product development project. A particular focus lies on the comparison between the internal views of the participating students and the achieved outcome of the team work. To start with, this paper gives an introduction to literature on cross-disciplinary teams and biomimetics. Then, we describe the detailed proceeding of the case study. In the following section the internal views are presented. They are then compared to the outcome of the teamwork. In conclusion, this exploratory study shows positive and negative effects of cross-disciplinary approaches.

2 Literature survey: Cross-disciplinary approaches

This section gives an introduction to literature on cross-disciplinary teams and on biomimicry, an approach to use information from biology to develop technical products.

2.1 Cross-disciplinary teams

From an industrial perspective, working in teams aims at synergy effects and information exchange to enhance productivity. In this context, teams are defined as temporary work groups solving problems, developing solutions or fulfilling tasks within the framework of a superordinate target [3]. Cross-disciplinary-teams consist of individuals possessing knowledge from different disciplines. According to the above understanding that one goal of teams is to „exchange information", the individuals can contribute with their heterogeneous information achieving a higher productivity. However, research on diverse teams including cross-disciplinary teams has resulted in contradicting conclusions. Mannix and Neale[2] reviewed psychological research on diversity in teams and found that the negative effects prevail in the majority of research contributions. They propose theories such as the self-and social categorization approach. According to this theory individuals categorize others and have expectations based on this categorization. This increases the tendency to develop stereotypes about individuals belonging to a different "category" [2]. In contrast, conflicts and confrontation can also have positive effects. Stempfle and Badke-Schaub [4] state that cognitive confrontation is necessary for creativity. Kurtzberg [5] observed that diverse team develop a higher number of ideas even though the individual team members feel less creative.

2.1.1 Biomimetics – Using information from different disciplines

Engineers as well as architects are continuously searching for new solutions for their technical and design tasks in order to develop new, creative solutions. Nature offers a large repository of biological systems which can provide analogies or inspiration. Therefore, biomimetics are recommended as a creativity method [3]. Accordingly, Nachtigall [6] defines biomimicry as "learning from the design-, process- and development principles of nature". Still, applying biomimetics can pose a number of challenges due to the cross-disciplinary nature of the approach. Coming from different disciplines, mechanical engineers, architects and biologists use different models and terminologies [7]. This entails challenges for the search for biological inspirations and analogies as well as for their transfer to technical and design solutions. A number of researchers have focused on these challenges and developed approaches to support the biomimetic search and transfer: As to biomimetic search, databases of biological systems have been built [8-12]. Another research focus is on natural language analysis to map biological and technical terms [7, 13, 14]. The transfer of biological analogies to engineering and architecture is also addressed by Sartori et al. [8] using the SAPPhIRE approach to model both biological and technical systems. Other researchers propose development procedures specifically designed for biomimetics to facilitate the transfer [9, 10].

3 Combined cross-disciplinary approach

In this work, we study a combined cross-disciplinary approach in product development involving three disciplines: A team consisting of individuals from two disciplines and a task focusing on these two disciplines for which information from a third discipline is required. The aim is to integrate information from the three disciplines to improve the development of a product. This threefold cross-disciplinary constellation discloses a number of questions:

- What are the effects of the cross-disciplinary team and how do they use information from the other discipline?
- What is the impact on the outcome of the project? What is the contribution of the three disciplines to the outcome?
- Which indications for a support of a project in this threefold constellation can be deduced?

We approach these questions with the case study described in the following section.

4 Case study: Cross-disciplinary student teams developing a biomimetic concept for a shell construction

In this case study, teams consisting of students of architecture and mechanical engineering develop a biomimetic concept for a shell construction. 23 students participate in 5 cross-disciplinary teams. The teams consist of four to six students of which one or two are mechanical engineering students. This team constellation is due to the task *developing a shell construction* which is considered mainly architectural but requires knowledge from mechanical engineering to ensure the technical functionality.

The students were guided and supervised jointly by members of the Institute of Shell Constructions from the Faculty of Architecture and the Institute of Product Development from the Faculty of Mechanical Engineering. Lectures focusing on shell construction, technical product development and biomimetics introduced the students to the project. In the first two weeks, the teams performed a literature research on biological systems which were used as inspiration for shell constructions. Then, within 7 weeks, they developed concepts for shell constructions addressing a chosen issue such as ventilation or lighting conditions. They tested and presented their concepts by models and prototypes. There was a mid-term presentation after four weeks and a final presentation after seven weeks.

To capture the internal view of the students, they filled out six questionnaires. The questionnaire at the beginning of the project was aimed at capturing the students' previous experiences and their expectations. During the project there were four questionnaires to record the development of the teams: before and after the literature presentation, at mid-term and before the final presentation. After the final presentation a last detailed questionnaire was used for a retrospective view on the project. To deepen the understanding gained from the questionnaires, semi-structured interviews with five of the students were conducted. For the interviews we chose two teams and interviewed one mechanical engineering student and one or two architecture students per team.

As to the outcome of the project, we regard the final presentation of the concepts. The focus lies on the contribution of each discipline to the outcome. The internal observations are compared to the outcome and discussed to analyse effects of the cross-disciplinary product development teams in combination with the use of information from another discipline. We conclude with the indications of the case study with regards to the questions presented in section°3.

5 Internal view of the students

We use the questionnaires and interviews with the participating students to analyse their internal view on the cross-disciplinary team work (section 5.1) and the biomimetic approach (section 5.2). In the following, due to limited space, we present only the most distinct results of the analysis of the questionnaires and additional insights gained in the interviews.

5.1 Cross-disciplinary team work

The results are divided into the topics: *team-performance* and its development during the project, *positive and negative aspects of the cross-disciplinary team constellation*, *tasks of the individual students* and the perceived *importance of the cross-disciplinary team constellation*.

5.1.1 Team-Performance

Figure 1 shows the students' evaluation of their team's performance and its development during the project. This evaluation was designed according to [15]. The students could evaluate on a scale between a *dysfunctional team* (0) to a *functional team* (4) to a *high performance team* (8). Figure 1 displays the average values per team. Since some students did not fill out all questionnaires, the number of students varied from 16 to 23.

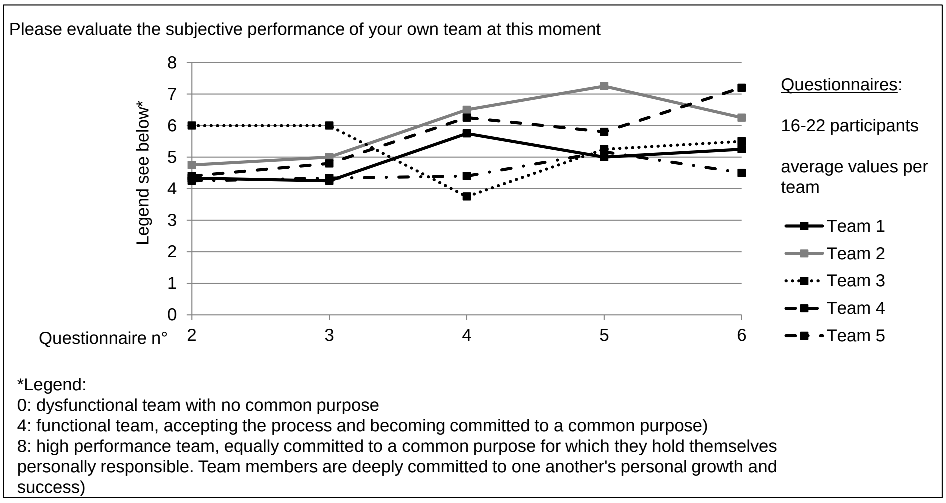

Figure 1 Questionnaires: development of the team performance

The first time the students evaluated their team's performance was in the second questionnaire before the presentation of the literature search (week 2).The other questionnaires were filled out after the presentation of the literature search (week 3), at mid-term (week 6), before the final presentation (week 9) and after the final presentation (week 10). The axis in Figure 1 is therefore not proportional to the elapsed time. It can be noted that the average value per team varies from 3,75 to 7,25 throughout the whole project. It has to be added that the minimum evaluation by one student in one questionnaire is 2 (not displayed in Figure 1). Still, it can be concluded that in general all teams considered their team functional or more. As to the development during the project, all teams except team 3 evaluated their team's performance higher at the end of the project than at the start. Team 3 evaluated their team's performance highest at the beginning of the project in comparison with the other teams and lowest at mid-term. Towards the end of the project their evaluation of their team's performance increased.

5.1.2 Positive and negative aspects of the cross-disciplinary team constellation

In the questionnaires the students were asked for positive aspects in their team (*What contributes to the success of your team?*) and for negative aspects (*What causes difficulties in your team?*). The students could choose six options per question and suggest additional observations. Figure 2 shows the students' expectations at the start of the project (questionnaire 1) and their view at the end of the project, i.e. after the final presentation (questionnaire 6).

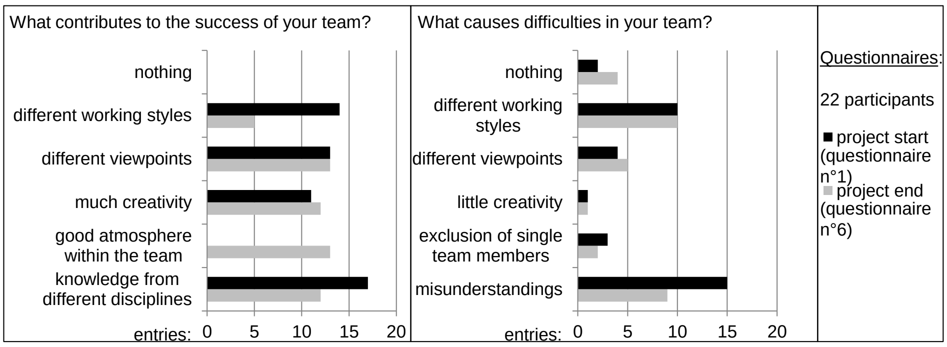

Figure 2 Questionnaires: positive and negative aspects of the team work

As to the positive aspects, no student chose the option *nothing contributes to the success of the team*. Both at the start and at the end of the project, more than 10 students chose "different viewpoints" and "much creativity" as positive aspects. This positive view was sustained by a student in the interview stating that he gained awareness of the other discipline's viewpoint which caused him to leave his common patterns of thought.

At the start of the project, no student expected a "good atmosphere" as a positive aspect in a cross-disciplinary team. At the end of the project this option was chosen 13 times which represents more than half of the students. They now perceived the good atmosphere as a factor in their team work even though they had not expected it.

At the start of the project the majority of the students (17) expected *knowledge from different disciplines* to be a positive aspect. At the end of the project the number of students choosing this option had declined to 12. This decline might be explained by statements from the interviews. In the interviews, three students stated that the technical ideas from the mechanical engineering students could not be pursued as far as they had wanted because of a lack of time. According to these three students the main contribution of the mechanical engineering students was their knowledge about systematic approaches in product development. On the other hand, they considered the architecture students more pragmatic, but less systematic.

Different working styles were expected to be a positive aspect by 14 students at the start of the project. At the end of the project solely five students chose that option.

With regards to negative effects, at the most five students chose *nothing*, *different viewpoints*, *little creativity* and *exclusion of single team members*.

Different working styles as a negative aspect was chosen by ten students at the start as well as at the end of the project. This view is sustained by two of the architecture students in the interviews. In their opinion, the architecture students were prepared to work more than the mechanical engineering students. One of them stated that "*architects accept iterations due to significant concept changes if the result can be improved*". The other one stated that "*when a model had to be finished, it was the architecture students who stayed and worked*".

Misunderstandings were expected at the start of the project by a majority of 15 students. At the end of the project the number of students choosing that option had declined to 9.

5.1.3 Tasks of the individual participants within the team

Figure 3 shows the students' expectation about their individual tasks at the start of the project (questionnaire 1) and their view after the final presentation at the end of the project (questionnaire 6). The students could choose several options in the questionnaires. The answers of architecture and mechanical engineering students are shown separately to allow for a comparison.

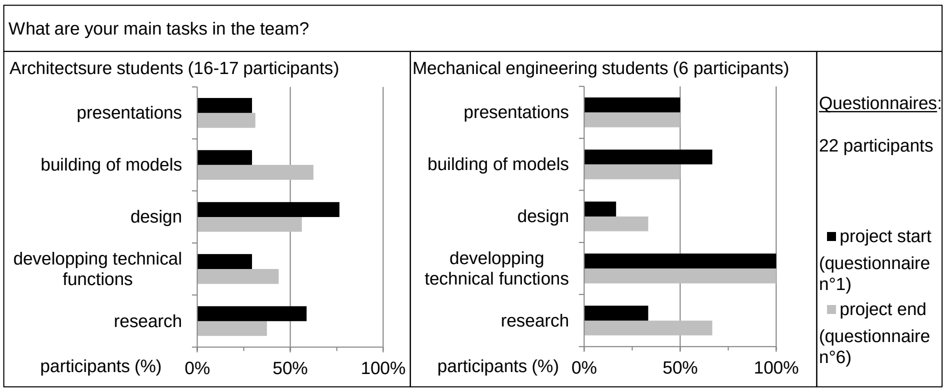

Figure 3 Questionnaires: Tasks of the individual students within the team

At the start of the project more than 50 % of the architecture students chose *research* and *design* as their main tasks. The other tasks were chosen by about 25 % of the architecture students. At the end of the project, the rating of the task *building of models* had changed most: More than 60 % of the architecture students chose this option. In the interviews, one architecture students stated that he had expected the mechanical engineering students to be technical "tinkerers" who build a lot of models and prototypes, but was proved to be wrong during the project.

As to the mechanical engineering students, all of them chose *developing technical functions* to be one of their main tasks at the start and at the end of the project. Apparently, they felt this was their main responsibility, possibly because there were only one or two mechanical engineering students per team.

5.1.4 Importance of the cross-disciplinary team constellation

Figure 4 shows the degree of confirmation of two statements comparing the importance of the cross-disciplinary team constellation to the option to carry out the project with students from one of the disciplines. These statements were part of the questionnaire at the end of the project after the final presentation (questionnaire 6). The students could choose six options on a scale between one (not true) and six (very true). The options one to three therefore express declining disagreement with the statement, the options four to six show increasing agreement with the statement.

As can be seen in Figure 4, the confirmation of the first statement (importance of cross-disciplinary team constellation) was high. The majority of both architecture and mechanical engineering students chose between four and six (very true) points.

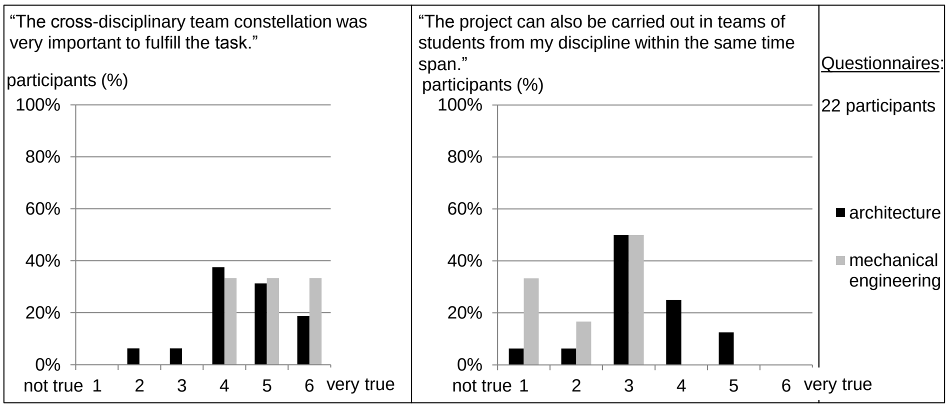

Figure 4 Questionnaires: Importance of the cross-disciplinary team constellation

With regards to the second statement, the result differs for the two disciplines: The mechanical engineering students all rather disagreed with the statement and chose between one (not true) and three points. The majority of the architecture students chose between three and five points. This shows their tendency to see less importance in the collaboration with the mechanical engineering students.

5.2 Biomimetics

Figure 5 shows the evaluation of the students with regards to the influence of biomimetics on creativity and the importance of biomimetics for the task. This evaluation was part of the questionnaire at the end of the project after the final presentation (questionnaire 6).

As to the question "did you develop more creative ideas because of biomimetics?", students could choose on a scale between one (no more creative ideas) and six (much more creative ideas). About 60 % of the students choose five or six showing that the majority of the students believed to have more creative ideas due to biomimetics. This view was confirmed by four of the five interviewed students. One of the students stated that biomimetics had helped to disengage from existing solutions and to defer the feasibility of ideas. According to him, both fostered the development of more creative ideas.

To evaluate the statement *"working with biological documents and models was very important to fulfil the task"* students could choose on a scale similar to those in section 5.1.4. About 20 % of the students evaluated this statement with two, three, four and five points respectively. This shows a moderate disagreement to a moderate agreement with the statement. Accordingly, in the interview one student stated that since the literature research on biological systems had been separated from the development of concepts they had not pursued ideas from that phase later in the project.

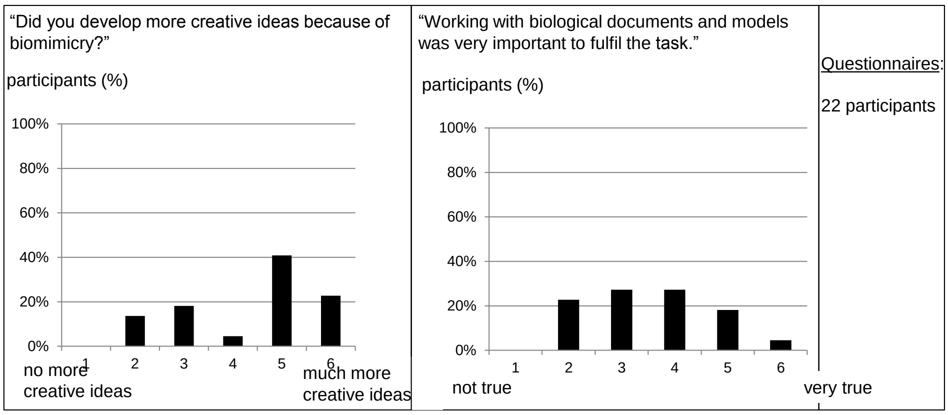

Figure 5 Questionnaires: Biomimetics – creativity and importance

To sum up, a majority of the students were of the opinion that biomimetics triggered their creativity. On the other hand, almost half of the students did not think it was essential to fulfil the task. A possible reason for this is that they did not pursue a biomimetic idea until the end of the project, but solely used biology as an inspiration at the start of the project.

6 Comparison of the internal views with the outcomes of the project

For the final presentation, all teams prepared a presentation to show their final concept and its development. In addition they presented physical models of their preliminary and their final concept. We analysed this outcome of the project to assess the contribution of the three disciplines architecture, mechanical engineering and biology to the final concepts. Table 1 shows a short description of the final concepts and the contribution of the three disciplines. As can be taken from Table 1, all final concepts are predominantly architectural concepts as required by the task given to the student teams. In addition, all final concepts include elements from mechanical engineering. Either they are necessary elements to actuate the developed concepts (paraffin cylinders, electro-magnets, hydraulic cylinders) or additional elements to save or produce energy (water pumping systems, wind turbines). The third discipline, biology, on the other hand, is not directly visible in the final concepts, but the teams claim to have used biological systems as inspiration. Hill distinguishes between four different degrees of abstraction for biomimetics, of which using a biological principle as an inspiration is the most abstract one [9]. It can be concluded that in this case-study biology was abstracted to a high degree to serve as an inspiration.

In comparison with the internal views, the outcomes confirm the evaluation of the students to a high degree. As to the cross-disciplinary collaboration of architecture and engineering students, the final concepts confirm that both disciplines contributed and that the architectural part dominates. With regards to biomimetics, biology served as an inspiration, but the teams detached themselves from the biological systems when developing their concepts.

Table 1 Final concepts of the teams

team	final concept	architecture	mech. eng.	biology
1	Cooling and shading system for a building	window blinds adaptable to different conditions during day and night	water pumping system cooled during night-time in the window blinds through the building	the wings of beetles served as an inspiration for the folding of the window blinds
2	Shading system between the window panes	ring elements connected via paraffin cylinders; they twist due to heat and change the shading conditions	actuation of the elements via paraffin cylinders changing their length due to heat	hairs of the old man cactus served as an inspiration to provide shading with thin elements that can be twisted to enhance their opacity
3	Cooling a building and producing energy	façade leading the wind through the building (adaptive to the wind direction)	wind turbines for the energy production	the den of the prairie dog served as an inspiration to use wind
4	Shading system between the window panes	(un) folding elements to shade parts of the window	electro-magnetic actuation of the window panes	butterflies served as an inspiration to vary the geometry of elements
5	Shading system for a building	(un) folding elements that are installed in front of the windows	actuation of the elements via hydraulic cylinders	mimosa serves as an inspiration for the folding mechanism

7 Conclusion, discussion and outlook

This work can provide a few starting points for further research. It cannot provide generally valid answers because of the limited number of teams and participants and the number of additional influences characteristic for such a case study. In the following, the indications of this work with regards to the questions of section 3 are presented:

- What are the effects of the cross-disciplinary team and of the use of information from the other discipline?

As to the cross-disciplinary team, the positive aspects prevailed, as the students affirmed a positive influence of different knowledge and viewpoints. The main negative aspect was differing *working styles*. With regards to biomimetics, the teams perceived a positive effect on creativity but did not unanimously perceive a high importance for the project.

- What is the impact on the outcome of the project? What is the contribution of the three disciplines to the outcome?

Both architecture and mechanical engineering contributed to the outcome. Biological systems were not transferred or copied but abstracted and served as an inspiration.

- Which indications for a support of a project in this threefold constellation can be deduced?

To support the cross-disciplinary team work, this case-study indicates that a support of the teams to understand the working styles of the other discipline can be beneficial. In this case study teams used biomimetics on a highly abstract level. This is not necessarily negative, but if a more direct use of biomimetics is requested, measures for support can be beneficial. Possibilities are the inclusion of biologists or providing more support for the transfer of biological systems to architecture and mechanical engineering.

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