Picking Low Hanging Fruits – Integrating Interdisciplinary Learning in Traditional Engineering Curricula by Interdisciplinary Project Courses

Andrea Dirsch-Weigand[1(✉)], Rebecca Pinkelman[2], Franziska D. Wehner[3], Joachim Vogt[3], and Manfred Hampe[2]

[1] Centre for Educational Development, Technische Universität Darmstadt, Darmstadt, Germany
dirsch-weigand@hda.tu-darmstadt.de
[2] Department of Mechanical Engineering, Technische Universität Darmstadt, Darmstadt, Germany
{pinkelman,hampe}@tvt.tu-darmstadt.de
[3] Department of Human Sciences, Technische Universität Darmstadt, Darmstadt, Germany
{wehner,vogt}@psychologie.tu-darmstadt.de

Abstract. Setting up integrated interdisciplinary study programs is complex and expensive. This case study presents specific interdisciplinary project courses of the Technische Universität Darmstadt as an alternative practice for integrating interdisciplinary learning in traditional engineering curricula. Relying on the experience from 22 project courses for first year students and 22 advanced design projects for master students, the authors exemplify that a sequence of interdisciplinary projects in the bachelor's and master's program leads to a systematical development of interdisciplinary competences: competence in interdisciplinary team work and problem solving in the bachelor's projects and actual interface expertise for interdisciplinary design tasks in the master's projects.

Keywords: Interdisciplinary learning · Problem-based learning · Project-oriented learning

1 Introduction and Motivation

Faced with the complex and multi-faceted challenges for smart societies, e.g. challenges of climate, energy, population, nutrition, water, health and safety, and the requirement for social, ecological and economical sustainability, the need for interdisciplinary engineering education is indisputable.

But setting up integrated interdisciplinary study programs such as Energy Science and Engineering or Computational Engineering is complex and expensive. Thielbeer measured the information costs of a new study program accreditation to be 131 work days (Thielbeer 2008, 4). This included self-documentation of the university's

M.E. Auer and K.-S. Kim (eds.), *Engineering Education for a Smart Society*,
Advances in Intelligent Systems and Computing 627, DOI 10.1007/978-3-319-60937-9_8

module-descriptions, examination regulations, qualification of lecturers, etc. and excluded all efforts for the implementation of the study program. Therefore, the Technische Universität Darmstadt took an additional approach to integrate interdisciplinarity to all departments of the university: Monodisciplinary project courses were extended into interdisciplinary project courses - a rewarding, uncomplicated and easy way to embed interdisciplinary learning in engineering education curricula.

Relying on five years of experience from 22 interdisciplinary project courses for first year students in 12 departments and 20 years of experience with 22 interdisciplinary advanced design projects for master students of thermal process engineering in a mechanical and process engineering department, we present the interdisciplinary project courses at the Technische Universität Darmstadt as an efficient alternative for integrating interdisciplinary learning in traditional engineering science curricula.

2 Objectives and Methods

In this paper, we exemplify project courses for interdisciplinary learning in the bachelor's as well as the master's program of the mechanical and process engineering studies at the Technische Universität Darmstadt. In the bachelor's project, we have analyzed the effect of project-based interdisciplinary learning on the self-reported development of a professional identity and the formation of professional competences including communication, intercultural and social skills as well as a cooperative mindset. The advantageous effects of interdisciplinary project teams are underpinned by a comparison of mono- and interdisciplinary project teams based on evaluation data of a project course with a total of 163 participants in 2012. For the master's project, we illustrate the impact of interdisciplinary learning on the development of professional interface competences and integrated technical knowledge. The case study is based on two project courses with a total of 119 participants in the years 2014 and 2015.

3 Results: Systematical Development of Interdisciplinary Competencies in Bachelor and Master Project Courses

According to the principles of evidence-based teaching and learning, the introduction of compulsory project courses as a specific form of active learning (Marra et al. 2014) in the mechanical and process engineering bachelor's program in 2007 was grounded on comprehensive experiences with project courses since 1998 and thorough empirical evaluations in 2006 (Möller-Holtkamp 2007).

In 2012, the monodisciplinary project courses for first year students became interdisciplinary with three objectives:

- On the one hand, the interdisciplinary study projects were to give mechanical and process engineering students from the very beginning a discipline-specific identity contrasting them with the profiles of other disciplines.
- On the other hand, the interdisciplinary study projects should support students in developing generic competences such as communication, team work, problem

solving and self-organization skills and in developing attitudes such as responsibility and appreciation of disciplinary diversity (Koch et al. 2017, 4).

- The third objective was to prepare students for the advanced design project in the master's program which has been interdisciplinary from its start in 1995.

Today, we can show that the sequence of interdisciplinary projects in the bachelor's and master's program leads to a systematical and gradual development of interdisciplinary competences, which are competence in interdisciplinary team work and problem solving in the bachelor's projects and actual interface expertise for interdisciplinary design tasks in the master's projects.

3.1 Definition of Interdisciplinary Competences

Interdisciplinary competences are a basic condition for interdisciplinary work in science and industry. Interdisciplinary work means cooperation of people from different disciplines (or even sometimes non-professionals) in order to reach a common goal or solution. Interdisciplinary cooperation can only be successful if co-workers define common goals, develop a common understanding of the problem(s) to solve, formulate common subjects, find a common language and agree on approaches, methods and individual contributions. The biggest challenges in interdisciplinary cooperation are consensus-building, finding a common language and managing group-dynamic processes that otherwise could lead to conflict or withdrawal of a group member (Defila and Di Giulio 2012, 4/5).

Therefore, the necessary interdisciplinary competences consist of specific techniques and methods on the one hand and adequate attitudes on the other hand. On the level of cognitive learning, these competences embed knowledge about and application of methods of consensus-building such as discussion, moderation and decision-making techniques and the ability to reformulate issues in a non-technical language and from a different point of view. On the level of affective learning, these competences include the awareness of the special interdisciplinary setting and its specific requirements and the valuing of mentalities and methods from other disciplines (Defila and Di Giulio 2012, 11/12).

The best way to teach and learn these competences is to offer learning environments where work in interdisciplinary teams can be experienced and reflected in practice. Interdisciplinary study projects implement exactly such settings. Technical, generic and interdisciplinary competences are equal learning objectives of this teaching and learning form.

From the work of Steinheider et al. (2009), we have a validated and reliable instrument to assess the awareness of interdisciplinary knowledge integration in project teams in academic and industrial settings. We adapted the proved instrument to assess the awareness of interdisciplinary knowledge integration in the project teams in our interdisciplinary projects for bachelor students.

The difference between interdisciplinary competences and interdisciplinary interface competences is that people with interdisciplinary interface competences are not only aware of the special requirements of team work in interdisciplinary project teams and know how to communicate, moderate and make sound decisions. In addition, they are able to structure, plan and coordinate their collaboration in a way that they take the maximum advantage of disciplinary diversity in their team. They, therefore, need additional advanced competences in project management and task design.

3.2 Acquisition of Interdisciplinary Competences in the Interdisciplinary Bachelor's Projects

The educational strategy behind the interdisciplinary study projects for bachelor and master students is the development of systemic and interdisciplinary problem-solving skills by active and practical learning from the very beginning.

Didactic Concept of Interdisciplinary Projects for Bachelor Students
The overall didactic concept of interdisciplinary study projects for bachelor students has been described in (Dirsch-Weigand et al. 2015; Pinkelman et al. 2015). Typically, first year students from engineering and natural sciences as well as from arts, social and human sciences form project teams of about 12 people to work on a complex set of tasks for one week. The task focuses on a real-life problem with societal relevance such as the global refugee problem, energy efficiency or urbanization. Interdisciplinary learning is ensured by a task assignment which forces students to make joint interdisciplinary decisions (Robertson and Franchini 2014). Since interdisciplinary problem solving is demanding for students in their first year, they are continuously supported by technical and team advisors. Technical advisors are academic staff from the participating departments and provide students with specialized feedback on the principle of "help for self-help". Team advisors are advanced students of pedagogy and psychology and have been trained and qualified intensively by the Centre for Educational Development. They enable students to engage in constructive and effective discussion, moderation, visualization, problem solving and conflict handling. At the help desk and in the expert interviews with professors, students can do further research for deeper technical information and discuss solutions.

A concrete example is the cooperation of the mechanical and process engineering department, the department of biology and the institutes of philosophy and political science in 2012 – one of five interdisciplinary bachelor projects in the mechanical and process engineering department since 2012.

In this study project, 506 students in 48 project teams developed integrated concepts in order to halt desertification. The concepts had to be based on an innovative fiber fleece, which enabled the application of appropriate plant seeds or cuttings and supported the germination and establishment of plantations. Ideally, the fleece should allow a profitable cultivation of crops, which had to be proven by a rudimentary business plan. At the same time, production and application of the product should be sustainable and authorized by the political participation of the concerned people. Due to this product, soil degradation should be halted, and the spread of agriculturally unusable and barren land should be prevented permanently.

In the first step, students chose a country where to apply the innovative "FloraPad". In this phase, students of political science held a position of professional leadership, whereas in the following investigation of ecological and climatic restrictions of the chosen region, the biology students could hold this position. Definitions of technical, chemical and biological capacities for the product and a first set of feasible product concepts were joint work of both mechanical and process engineers and biologists. The subsequent decision of which concept was to be refined and finalized was done conjointly by all disciplines in plenary, but philosophical criticism had a special importance because reflections on ethical, political, social, economic and ecological implications were part of the design rational. The students worked step by step collaboratively and switched from individual work to team work and vice versa. The 506 students were continuously supported by 36 technical advisors and 29 team advisors. Around fifty professors and industrial experts were available in expert interviews or as jury members for half a day. At the end of the week, all 48 student teams were successful to present a concept of "FloraPad".

Effective Acquisition of Interdisciplinary Competences

Due to the different number of students in engineering and other studies, not all project teams in the 2012 project were interdisciplinary. Therefore, project evaluation data allowed for a comparison of mono- and interdisciplinary teams with N = 163 students after inconsistent responders were excluded (e.g. pure engineering teams reporting

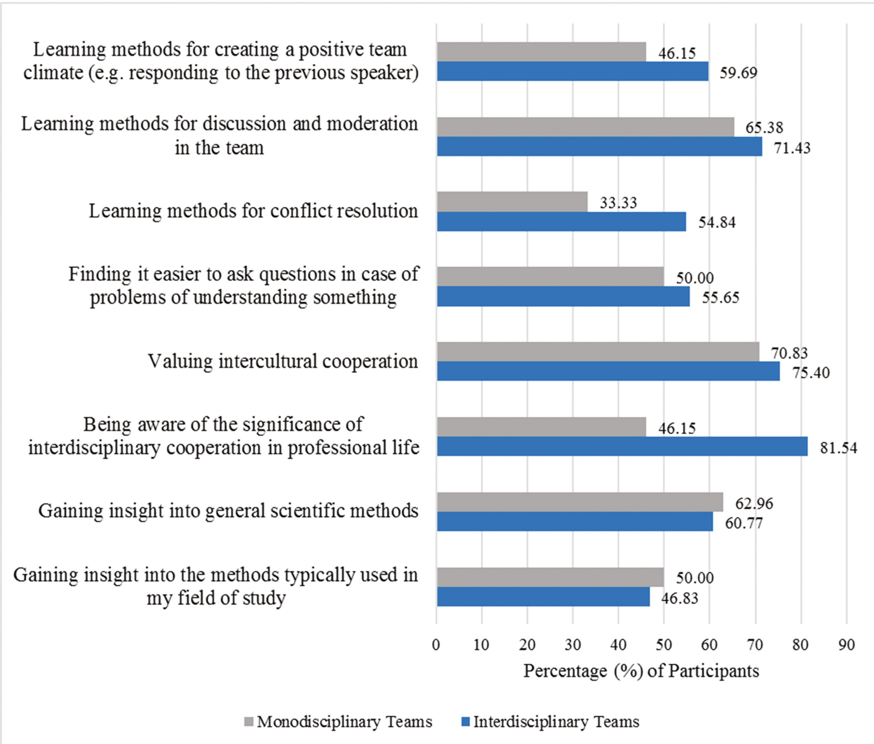

Fig. 1. Percentage of students agreeing to different learning experiences in the project (ratings lower than 2.5 on a 1–5 scale from 1 = agree to 5 = disagree)

themselves to be interdisciplinary). Of those, 135 students had been in interdisciplinary and 28 in monodisciplinary teams. Figure 1 shows percentages of students from inter- and monodisciplinary teams who agreed that they had certain learning experiences through the project (i.e. who gave ratings of 1 or 2 on a scale from 1 agree to 5 disagree).

As can be seen from Fig. 1, a slightly higher percentage of students from monodisciplinary teams agreed that they had achieved insights into specialist methods and common scientific methods through the project. A higher percentage of students from interdisciplinary teams, however, reported that the projects had inspired them to value interdisciplinary and intercultural team work. Additionally, a higher percentage of students from interdisciplinary teams agreed that they had acquired team work and communication competences (e.g. asking questions etc.). The acquisition of these interdisciplinary team work and methodical competences builds the foundation for the advanced design project in the master's program. Moreover, a higher percentage of students from interdisciplinary teams (78.03%) agreed that they had seen themselves in the team as a competent representative of their field of study compared to monodisciplinary teams (66.67%), suggesting that the interdisciplinary team work supported students' identification with their field of study.

Furthermore, the students' responses in interdisciplinary teams supported our assumption that the project provided appropriate conditions for successful interdisciplinary cooperation. Figure 2 shows the percentage of students from interdisciplinary teams who agreed to several items referring to the interdisciplinary collaboration in their team. As can be seen in Fig. 2, the great majority of students in interdisciplinary teams agreed that they had shared objectives and goals with their teammates and that they had developed a shared understanding of the project. Even more, most students agreed that they had been able to communicate well within the team.

Whilst we chose the results presented here to illustrate the successful implementation of interdisciplinary first year projects in mechanical and process engineering, similar results have also been found for other projects involving students from other engineering disciplines such as electrical engineering.

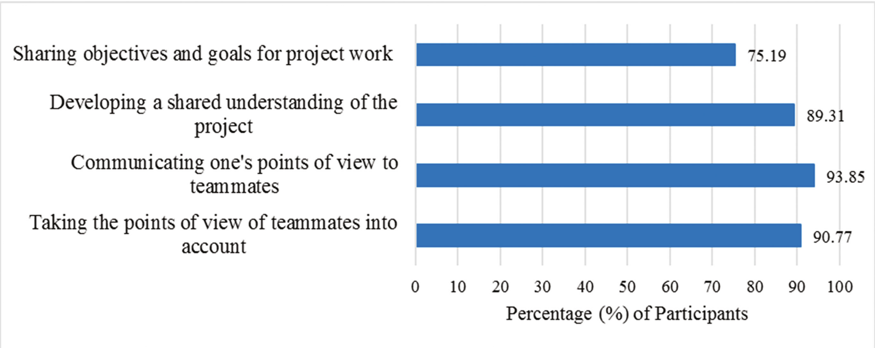

Fig. 2. Percentage of students in interdisciplinary teams agreeing to items assessing successful interdisciplinary cooperation (ratings lower than 2.5 on a 1–5 scale from 1 = agree to 5 = disagree); items adapted from (Steinheider et al. 2009).

3.3 Acquisition of Interdisciplinary Competences in the Interdisciplinary Master's Projects

Didactic Concept of Interdisciplinary Projects for Master Students

The overarching didactic approach to the master's projects is an Advanced Design Project (ADP) with two main learning objectives: the development of professional skills through team work and design skills through application. The teams are diverse and interdisciplinary including students from chemistry, mechanical and process engineering from TU Darmstadt, and students from chemical engineering from a university of applied science (Fachhochschule in German) in 2014 and additionally, American chemical engineering students in 2015. ADP is a bridge between typical course design projects and "real" industrial design projects. The project topic (typically a chemical plant) is developed with and supported by an industrial partner with real plant data. For example, in 2014, the project was the design of a bioethanol plant and in 2015, a sulfuric acid plant.

ADP is a two week, intensive project design course. Due to this nature and the scope required to design an entire new chemical process, ADP is taught as structured design with little room for variation and creativity in the plant design. The overall plant design is segmented into major tasks, and tutors develop specific tasks and goals (daily and project) that the groups must do and meet, e.g., on the first two days, they must complete a mass balance of the entire plant, usually with a given method, e.g., the Nagiev method for the mass balance. All groups are composed of approximately 5–7 students and are interdisciplinary with differing degrees of diversity (in regards to disciplines). Since there are only approximately five tutors for 60–70 students broken into 10 groups, groups are encouraged to talk with and collaborate among each other (especially for troubleshooting).

Effective Acquisition of Interdisciplinary Interface Competences

Development of the original assessment for 2014 is detailed in (Anders et al. 2014). Shortly, it assessed team competence, including students' ability to contribute to a group project, communicate well within the group, resolve conflicts, and plan, schedule, and assess the group's progress, and design competence, specifically their ability to find and evaluate different solutions, use of criteria to critically evaluate their progress and design, aptitude in carefully defining the problem, breaking complex problems down, and using networks and flowcharts to keep track of design variables. In 2015, open-ended questions about team and design competence were also included along with daily reflection questions. The closed-ended questions were assessed three times at the beginning, middle, and end of the two-week course. The 12 questions (6 – team and 6 – design) were compiled for both years and compared.

Analyses of the two projects have shown that teams with higher professional qualities produce higher quality design work. These professional qualities are interdisciplinary interfaces competences: the ability to work cohesively in an interdisciplinary group and design a plant that requires the knowledge and skill of different disciplines. The more diverse the group was (in terms of discipline), the higher were also their overall competences in interdisciplinary team work and design skills. Specifically, in 2014, students self-reported their team roles every day. Two of the groups reported more than one leader (for one day) compared to other groups and also had lower competences and final project scores. This indicates that the team was not effectively working together as evidenced also by their lower assessed team and design competences, which in turn affected their final project score.

At the end of the two-week course, 81.18% of students assessed themselves higher than 3.5 (on a 1–5 scale, with 5 being the most competent) for team competence. Overall, they perceived themselves to be competent in their ability for individual contribution, team work, communication, and conflict resolution (Fig. 3). Interestingly, half way through the course, students assessed themselves lower in all six team competence questions but most especially in conflict management (data not shown). This indicates, that there were conflicts within the team, but they were able to resolve them and communicate better by the end of the course.

Due to the structured design process in this course as described above, there is little room for creativity and variants in design. This can be seen in the answers to the question whether or not they had developed different solutions (12.16%), which in turn had a large effect on the average design. It is also interesting to note that over the course, students reported that they were able to integrate different perspectives into the design process.

Here, we are able to show that based on the foundation of first year interdisciplinary project courses master students have a high competence in interdisciplinary team work at the start of the course (Fig. 3, Avg. Team (pre) 74.34%) and further develop this competence through ADP (Fig. 3, Avg. Team (post) 81.18%).

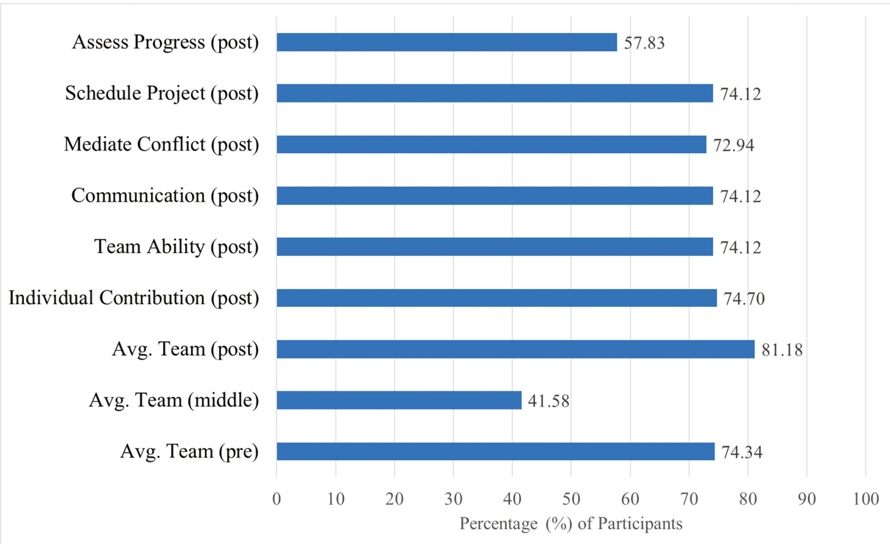

Fig. 3. Percentage of students assessing themselves higher than 3.5 (on a 1–5 scale with 5 being the most competent) for team competence pre, middle, and post, and the six core questions for team competence at the end of the course (post)

4 Conclusion

We have demonstrated that the combination of interdisciplinary project courses in the bachelor's and master's program of mechanical and process engineering at the Technische Universität Darmstadt leads to a gradual development of interdisciplinary competences.

An intensive advancement and testing phase for interdisciplinary project courses in all departments of the Technische Universität Darmstadt was developed by the university and funded by the national program “Quality Pact for Teaching”. The result is a portfolio of five different types of interdisciplinary study projects that now can replace the existing monodisciplinary study projects. In most cases, interdisciplinary project courses are not introduced as a complete new module in a study program but as an equivalent for an existing project course module. This keeps administrative costs low compared to more than a year of redesign and reaccreditation that would be necessary for a completely integrated interdisciplinary study program.

With concern to the implementation, even for large project courses with up to 700 students, the additional efforts for the coordination of different disciplines amount to an average of six additional meetings of professors and/or scientific staff to elaborate the task design. During the project courses, the support of students is delegated to scientific and student tutors in order to relieve the professors. Thus, professors and external specialists can concentrate on expert advice.

Therefore, we see in this model a rewarding, effective and efficient way to incorporate interdisciplinary learning in engineering science curricula.

Next steps include the extension of, specifically, the interdisciplinary advanced design projects to the entire mechanical and process engineering department and other engineering science departments such as electrical engineering, civil engineering and computer science.

Acknowledgement. The introduction of interdisciplinary study projects to all departments of Technische Universität Darmstadt is co-funded by the joint programme “Quality Pact for Teaching” of the German Federal Government and the Länder in the context of the KIVA project (Competence development through interdisciplinary cooperation from the very outset; project funding reference number 01PL16048).

References

Anders, B., Pinkelman, R.J., Hampe, M.J., Kelava, A.: Development, assessment, and comparison of social, technical, and general (professional) competencies in a university engineering advanced design project - a case study. In: Musekamp, F., Spöttl, G. (eds.) Competence in Higher Education and the Working Environment. National and International Approaches for Assessing Engineering Competence, pp. 217–238. Peter Lang, Frankfurt am Main, Bern, Bruxelles, New York, Oxford, Warszawa, Wien (2014)

Defila, R., Di Giulio, A.: Vorbereitung auf interdisziplinäres Arbeiten – Anspruch, Erfahrungen, Konsequenzen. In: Berendt, B., Szczyrba, B., Fleischmann, A. et al. (eds.) Neues Handbuch Hochschullehre, E 1.3, pp. 1–20. DUZ Verlags- und Medienhaus, Berlin (2012)

Dirsch-Weigand, A., Koch, F.D., Pinkelman, B., Awolin, M., Vogt, J., Hampe, M.: Looking beyond one's own nose right from the start: interdisciplinary study projects for first year engineering students. In: Proceedings of 2015 International Conference on Interactive Collaborative Learning (ICL), Florence, Italy, 20–24 September 2015 (2015). http://www.weef2015.eu/Proceedings_WEEF2015/proceedings/papers/Contribution1221.pdf. Accessed 14 Mar 2017

Koch, F.D., Dirsch-Weigand, A., Awolin, M., Pinkelman, R.J., Hampe, M.J.: Motivating first year university students by interdisciplinary study projects. Eur. J. Eng. Educ. **42**(1), 17–31 (2017). doi:10.1080/03043797.2016.1193126

Mara, R.M., Jonassen, D.H., Palmer, B., Luft, S.: Why problem-based learning works: theoretical foundations. J. Excellence Coll. Teach. **25**(3–4), 221–238 (2014)

Möller-Holtkamp, S.: Fachintegrierte Förderung von Teamkompetenz. Evaluationsstudie über eine Projektveranstaltung zu Studienbeginn im Fachbereich Maschinenbau an der Technischen Universität Darmstadt. Logos Verlag, Berlin (2007)

Pinkelman, R., Awolin, M., Hampe, M.J.: Adaption and evolution of a first year design project week course - from Germany to the United States to Mongolia. In: Proceedings of the 122nd ASEE Annual Conference and Exposition 2015, Seattle, USA, 14–17 June 2015 (2015). http://www.asee.org/public/conferences/56/papers/12509/download. Accessed 14 Mar 2017

Robertson, B., Franchini, B.: Effective task design for the TBL classroom. J. Excellence Coll. Teach. **25**(3–4), 275–302 (2014)

Steinheider, B., Bayerl, P.S., Menold, N., Bromme, R.: Entwicklung und Validierung einer Skala zur Erfassung von Wissensintegrationsproblemen in interdisziplinären Projektteams (WIP). Zeitschrift für Arbeits- und Organisationspsychologie **5**(3), 121–130 (2009)

Thielbeer, M.: Messung der Informationskosten der Akkreditierung von Studiengängen mithilfe des Standardkosten-Modells. Abschlussbericht – Anonymisierte Kurzfassung. CHE Centrum für Hochschulentwicklung, Bertelsmann Stiftung und Thielbeer Consulting (2008). http://www.che.de/downloads/Veranstaltungen/CHE_Vortrag_2008QM2_che_thielbeer_PK213.pdf. Accessed 14 Mar 2017