Abstract – Research in the challenging field of industrial engineering and engineering management often needs the expertise from more than one discipline. Various disciplinary competences have to be combined to answer research questions and to solve specific (engineering) problems at the interfaces of different professional disciplines. The disciplines being part of the research and problem solving process have to be consequently integrated to form an efficiently performing interdisciplinary consortium. Current research states that this interdisciplinary integration process has to include various dimensions. This paper introduces three sets of interdisciplinary integration methods. Together they cover all of the dimensions explained before and lead to an enhanced interdisciplinary integration. Having just implemented a set of integration methods, measurement methods are adjusted to evaluate and optimize them continually.

Keywords – Interdisciplinary integration, Knowledge Management, Terminology, Virtual and physical cross linkage

I. MOTIVATION AND PROBLEM STATEMENT

The challenging area of industrial engineering proves just as demanding as the management of engineering processes, as all their different facets need to be considered: Problem analysis, design of tailor-made solutions, creation of products out of these solutions and converting them into profit [1]. The complexity of the problems to be solved and research questions to be answered has constantly increased over the years [2].

Not only does the complexity of the problems increase, but more and more problems originate from the interfaces between professional disciplines which traditionally may have been perceived as investigating completely different research subjects [3]. For these problems an isolated disciplinary search for solutions can no longer suffice [4, 5]. They have to be tackled by interdisciplinary consortia, where every discipline has to be integrated into an interdisciplinary research process. Various disciplines need to jointly work together on the same problem, each one contributing and integrating their special knowledge and experience. This leads to another increase in the complexity of the process of finding solutions, especially when research disciplines not only cooperate with other but also with partners from the business world. Because of this fact, the needed cooperation structure has to be effectively managed to ensure a good performance of the consortium [7]. This management includes the integration of all participating disciplines. Experiences in our three research subjects, i.e. various interdisciplinary research consortia, show that this holds not only for consortia comprising disciplines from the field of engineering.

I. The Cluster of Excellence (CoE) “Integrative Production Technology for High-Wage countries” at RWTH Aachen University was initiated by the German Research Foundation (DFG)1 and the German Council of Science and Humanities (WR)2 as part of the German excellence initiative3. It is devoted to the resolution of the polylemma of production and serves (together with II.) as an example for a rather local interdisciplinary consortium [8]. Many engineering scientists jointly investigate ways to solve the tradeoff between scale and scope and between plan and value oriented production [9]. In this consortium the different sub-disciplines in the engineering context and their differences become apparent.

II. The Cluster of Excellence (CoE) “Tailor-Made Fuels from Biomass” at RWTH Aachen University adopts an interdisciplinary approach towards research of new, biomass-based synthetic fuels, in order to verify their potential, with regard to modern combustion technologies, while simultaneously reducing the dependence on fossil fuels [10]. The long-term goal is to determine the optimal combination of fuel components based on renewable materials and their production processes [11].

III. In the funding priority “Innovative Capability in the Context of Demographic Change” of the research and development (R&D) program “Working – Learning – Developing Skills. Potential for Innovation in a Modern Working Environment” of the German Federal Ministry of Education and Research (BMBF) several cooperative projects investigate the opportunities due to demographic change especially in the working environment. These projects mostly offer a larger variety of different scientific disciplines than the CoEs, and the applying practice poses an incremental partner in the consortia. Moreover, the cooperative project partners are scattered all over Germany [12]. Hence, this research subject serves as an example for a more distributed interdisciplinary consortium.

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1 http://www.dfg.de/en/index.jsp
2 http://www.wissenschaftsrat.de/en/home.html
3 The excellence initiative was started in 2005 by the government and federal states. It is divided into three funding lines: graduate schools, clusters of excellence and future concepts for top-level research. In 2012 its second funding period started.
The management of such research consortia has to integrate the different disciplines into the consortium to realize its interdisciplinary potential [3]. However, often enough such consortia hardly evolve further than to a collection of different disciplines working next to each other [6]. This leaves interdisciplinary potential unused. Section II of this contribution introduces the dimensions in which the integration of the disciplines can be achieved. Afterwards, section III introduces three sets of integration methods to foster interdisciplinary cooperation covering all dimensions of integration. Section IV explains how the effectiveness of the implemented methods can be investigated, before section V summarizes this contribution and gives an outlook on further research.

II. DIMENSIONS OF INTEGRATION

According to the current state of research the integration of the different disciplines in several dimensions is required to obtain interdisciplinarity within a consortium. Inspired by Gibbons [13] and Bergmann [14], Jahn specifies four dimensions of integration, whose composition and conditions need to be understood in order to combine different disciplines into a consortium and generate added value in scientific research and knowledge [3]. He defines the following four dimensions: social/organizational, factual/technical, communicative and cognitive/epistemic (cf. D1-D4 in Figure 1).

A. Social/organizational dimension

The social and organizational dimension intends to define and relate both different interests and activities of involved disciplines as well as between subprojects and organizational institutions. It is about a distinction and merging of different stocks of scientific and non-scientific knowledge. Controversial research interests and topics influenced by research and funding policies need to be brought to a common denominator. Furthermore, the gap between research findings, their usefulness and the validity of research results has to be filled. The challenge is to combine controversial research approaches and results in order to bring them together aiming at compatibility of interests and activities to build a collective identity [15].

B. Factual/technical dimension

The technical dimension provides a transformation of technical solutions to create a normative embedded system, which is sustainable and functional. The use of technical solutions has to be integrated in aspects of daily life, social fabric as well as the work process and discipline-specific methods and workflows. The technical tools used to exchange ideas should integrate problem solutions and make them practicable. User-oriented technical solutions facilitate the application of solutions through technical means, which should not disturb the work flow, but support it and be integrated into the work process [3].

C. Communicative dimension

The communicative dimension focuses on the distinction and linkage of different interdisciplinary linguistic expressions and communicative practices. The development of a common speech practice in everyday research is substantial for the integrative knowledge generation and common solution findings. In this way discipline-specific terminologies can be expanded and integrated into them. The aim is to achieve a basic interdisciplinary understanding despite the still important differentiation of the individual disciplines [16].

D. Cognitive/epistemic dimension

The cognitive or epistemic dimension aims at distinguishing and associating different discipline-specific knowledge as well as connecting both scientific and practical knowledge [17].

The goal is to understand the methods and concepts of other disciplines, to recognize own limits and explicate common methodological and theoretical developments. Different points of view in research have to be mutually understood, which enables the consortium to arrive at joint findings. The merging of interdisciplinary knowledge leads to a solution exchange in different disciplines. An integrative consolidation of methods and research findings used in a discipline might be useful for the other discipline and thereby produce an added value for both.

All dimensions of integration are essential to foster interdisciplinary collaboration [3]. With these dimensions, different research levels are covered, so that interdisciplinary cooperation, organization, network, communication, knowledge supply and technology can be integrated into the interdisciplinary work process of a consortium [14]. Section III introduces three sets of methods which in combination support the integration of different disciplines into an interdisciplinary consortium covering all dimensions of integrations.

III. INTERDISCIPLINARY INTEGRATION METHODS

Among various implemented measures to tackle the demands gathered during the past funding phases of our research subjects [5] three sets of interdisciplinary integration methods are explained here in detail. They were designed to achieve an integration of the different disciplines into the consortia in all dimensions mentioned in section II. Additionally, they serve the most prominent demands discovered in the areas of a cooperation platform, enhanced communication and an understanding of used terminology in the consortium.
Tailor-made means to foster interdisciplinary integration in the areas of physical cross linkage, virtual cross linkage and the acquisition of interdisciplinary terminology were introduced. By combining measures of physical and virtual cross linkage a personal connection between the different actors is supported while the limitations faced by widely distributed consortia can be overcome more easily. A special focus in the cross linkage activities was placed on developing a common terminology as a necessary basis for interdisciplinary research. Figure 1 illustrates how the different sets of methods relate to the dimensions of integration, while Table 1 as well as the following subsections explain their impact on the different dimensions.

A. Physical Cross Linkage

In the area of physical cross linkage a set of means was implemented consisting of various formal and informal meetings to inform colleagues in the consortia about one’s activities and findings. These meetings are also used to collaboratively develop a common understanding of the topics researched by the consortium. The means are especially suited to cover the social and organizational dimension, where interdisciplinary integration can be achieved through bringing together all actors and taking into account different interests and activities. Various personal networking meetings foster a personal exchange between the participants in face to face interactions and strengthen personal benefit [18].

The factual/technical dimension, however, is hardly covered by this set of methods. Physical networking does not include technical aspects, because here the personal and social component dominates, which is hard to transfer via technical tools. Personal presence does not necessarily require technical solutions to exchange ideas, interests and activities, although the personal experience can be complemented by technical tools [19].

The communicative dimension is related to social interaction and exchange, which often takes place in a personal circle. Therefore a common language integrating discipline-specific terminology is important to create a basic interdisciplinary understanding. The set of methods “physical cross linkage” acts at this dimension and aims at a discipline-specific language transfer through personal meetings, where a transparent and equal understanding of processes and contents is discussed [20]. However, as opposed to the specific means of “terminology acquisition”, in the process of physical cross linkage the creation of a common language happens in a natural and therefore unstructured way.

The exchange of knowledge via physical presence offers a more diverse use of cognitive channels than any other medium [21]. Therefore “physical cross linkage” is a powerful set of integration methods concerning the cognitive/epistemic dimension [22]. On the one hand scientific outcomes can be exchanged directly within a personal presentation; on the other hand there is an
opportunity to get in touch with methods and concepts of other disciplines.

B. Virtual Cross Linkage

In the field of virtual cross linkage a tailor-made virtual learning and cooperation platform was developed for each consortium to complement the means of “physical cross linkage”. It fosters the exchange among the different actors and supports the joint development of solutions and their internal and external transfer. The different groups, projects, and the people involved are connected independent of time and place, and networking outside physical meetings is supported. This leads to an enhanced social integration despite the challenges created by differences in time and place [19].

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<tr>
<th>Dimensions of integration</th>
<th>Physical cross linkage</th>
<th>Virtual cross linkage</th>
<th>Terminology acquisition</th>
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<td>Social/organizational</td>
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“Virtual cross linkage” heavily builds up on technical means to interconnect the different disciplines internally as well as externally. The different technical tools are designed not only to be easy to use but also to be well integrated into the every-day work of the partners. The aim is to create an added value for its users by providing ways to present findings in a more formal way as well as to exchange ideas with colleagues in a more informal manner [23].

Similarly to the means of “physical cross linkage” their virtual counterparts lead to an enhanced understanding of the different disciplines by fostering interdisciplinary communication processes. Due to terminology usage a basic insight is produced and accomplishes the fundament of physical and virtual meetings. However, the development of the understanding takes place in a rather arbitrary and not well managed way as opposed to the highly structured way of “terminology acquisition”.

Analysis of physical cross linkage shows that the personal benefit of the events decreases with an increasing number of participants. It is therefore recommended to focus on meetings within subprojects [8]. Additionally, the diversity in interdisciplinary research projects often derives from the inclusion of organizationally and geographically distributed participants [24, 25]. To exploit the advantages of physical meetings, these need to be held in the right frequency and with a manageable number of participants. They require a relatively high effort from the actors in a consortium distributed over a larger area. Therefore, virtual means are a good addition to “physical cross linkage”, as it enables flexible meetings with lower effort for the participants.

C. Terminology Acquisition

“Terminology acquisition” is another set of virtual integration methods comprising means of acquiring and visualizing the terminology used by different actors in the consortium. This happens mainly through an online tool, where actors in the consortium can contribute definitions, combined with the automated extraction of characteristics of the used terminology from given communication data.

For a joint research effort as well as for the social and organizational interaction within, a mutual understanding of the participants plays an important role. “Terminology acquisition” aims at a common understanding and a shared language among the actors in the consortium. This is needed to formulate contributions to the common research problem, define common goals and exchange information about disciplinary methods.

The terminology acquisition measures make use of technical means as well, but the focus lies in the gathering and presentation of the content, which needs to be supported technically to be performed. The main purpose of the set of methods – namely the acquisition of the terminology used – is rather non-technical [25].

Communicative integration is addressed to some extend by all the presented sets of methods. However, especially “terminology acquisition” contributes to a transparent and equal understanding of processes and contents. It specifically provides a platform for the actors of a consortium to become aware of and discuss about the differences in their terminology. This understanding leads to a more efficient knowledge generation and fosters a joint finding of solutions [20, 22, 26].

“Terminology acquisition”, to a similar extend than “virtual cross linkage”, helps to illustrate, compare, exchange and advance information and knowledge about the topics of the consortium. It creates an advanced understanding of the terminologies present in the consortium as well as the awareness of the mere existence of different terminologies. This knowledge supports the actors in understanding results of their colleagues as well as participating in consortium-wide discussions about relevant topics.

IV. HOW TO MEASURE INTERDISCIPLINARY INTEGRATION

To foster interdisciplinary cooperation with the objective of increasing effectivesness of interdisciplinary research consortia, measurement approaches are necessarily implemented and adapted to the needs of interdisciplinary consortia as examples for publicly
funded, non-profit organizations [27, 28]. Thereby the measurement of interdisciplinarity is essential, e.g. to reveal the impact of research work and/or give recommendations to improve collaborative cooperation. Beyond that, means of measurement can verify the holistic covering of the previously presented dimensions through adequate sets of interdisciplinary integration methods. Each method is reflected against the backdrop of its performance capability with regard to all dimensions enabling conclusions about its effectiveness.

The integration and promotion of interdisciplinary cooperation and their success has to be measured iteratively [29]. Thus, established performance measurement methods from the private sector are adjusted and introduced within scientific research consortia. For instance, with the help of the balanced scorecard (BSC), objectives of the research alliances are improved and the cross-hierarchical communication and cooperation can be promoted [30, 31].

The BSC comprises four perspectives: internal perspective/research cooperation, perspective on learning and development, output/client perspective and financial perspective. To measure the performance of a consortium, key performance indicators (KPI) were identified (e.g. frequency, quality and benefits of meetings; scientific cooperation; publications [30]) within the interdisciplinary research context and gathered once a year. The analysis of this data enables the derivation of recommendations of actions for the management of a consortium to enhance its interdisciplinary cooperation. As an example for enhanced communication and cooperation measures (outlined due to BSC results) within the first funding period of the CoEs at RWTH Aachen, colloquia for research assistants, a tailor-made advanced training program for PhD-students, adaption and expansion of the cluster-internal knowledge map, initiation of informal summer fairs, thematic exchange by regular project meetings and the organization of Summer Schools can be listed.

Public funding organizations such as the DFG and the WR express the need for developing further concepts to measure, steer and regulate interdisciplinary collaborations [32, 33]. Building on existing elaborated methods like the BSC, additional measures are launched within the current research work. At this, a performance measurement and management approach shall be developed. Bottom-up interdisciplinary cooperation shall be promoted with the vision to accompany performance measurement by performance management and to cope with the mentioned dimensions of integrations. While measurement is merely the process of assessing progress towards achieving predetermined goals, management builds on that process, adding relevant communication and action achievements against these predetermined goals [34]. Further need for research is especially focused on evolving performance measurement to foster interdisciplinarity and occupy the whole dimensions of integration.

V. OUTLOOK

During the upcoming funding phase of the three research subjects the effectiveness of the implemented methods will be assessed regularly. Together with their participants the contained tools will be enhanced, and new demands will be incorporated.

Since we see the problems resulting from differing terminologies inside interdisciplinary research consortia as prominent, further ways of supporting the actors of the consortia in coping with problems especially from the field of terminology acquisition will be implemented.

Creating awareness for the mere fact that the disciplines inside a consortium use different terminologies and that this leads to potential problems is a first step. With the data from “terminology acquisition” and the corresponding visualization, however, tools can be imagined, that directly support the actors in their daily work. An example for this would be the assessment of joint interdisciplinary publications for their potential of misunderstandings. Differing disciplines of authors as well as included terms, for which fundamentally different definitions exist, would in this case suggest a raised potential.

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