Enhancing Scientific Cooperation of an Interdisciplinary Cluster of Excellence via a Scientific Cooperation Portal

Tobias Vaegs[1], André Calero Valdez[2], Anne Kathrin Schaar[2], André Braekling[3], Susanne Aghassi[3], Ulrich Jansen[4], Thomas Thiele[1], Florian Welter[1], Claudia Jooß[1], Anja Richert[1], Wolfgang Schulz[4], Guenther Schuh[5], Martina Ziefle[2] and Sabina Jeschke[1]

[1] IMA/ZLW & IfU, RWTH Aachen University, Aachen, Germany

[2] Human-Computer Interaction Center, RWTH Aachen University, Aachen, Germany

[3] Fraunhofer Institute for Production Technology, RWTH Aachen University, Aachen, Germany

[4] Chair for Nonlinear Dynamics of Laser Processing, RWTH Aachen University, Aachen, Germany

[5] Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University

***Abstract*—In the Cluster of Excellence (CoE) "Integrative Production Technology for High-Wage countries" at RWTH Aachen University, scientists from different institutions investigate interdisciplinary ways to solve the polylemma's tradeoffs between scale and scope as well as between plan and value oriented production. Next to the CoE's four scientific subfields – the Integrative Cluster Domains (ICDs) – there are three additional subprojects performing cross sectional research and providing means for physical and virtual cross-linkage, the Cross Sectional Processes (CSP).**

Scientific cooperation in such a large and diverse consortium – as a meta-structure to the structures present in the member institutes – poses many challenges. To tackle these, an online learning and collaboration platform is developed, called the "Scientific Cooperation Portal", to optimize the cluster-wide cooperation process. Technically building on the Liferay framework, the portal provides basic features like a member list and an event calendar as well as functionalities to help cluster members to gain a deeper understanding of the CoE's current state regarding the diversity in interdisciplinary terminology, patterns in publication relationships, knowledge management and developed technologies.

***Index Terms*—Cluster of Excellence, Interdisciplinary Integration, Scientific Cooperation, Social Media**

I. Introduction

Modern research questions more and more require a collaborative and additionally an interdisciplinary approach, since they often originate from the interfaces between different disciplines [1]. In such a joint research process between different disciplines, however, the participants often face problems resulting from the clash of different cultures e.g. regarding publication behavior or terminology [2].

The Cluster of Excellence (CoE) "Integrative Production Technology for High-Wage countries" at RWTH Aachen University was initiated by the German Research Foundation (DFG) and the German Council of Science and Humanities (WR) as part of the German excellence initiative. The consortium is located in Aachen with various interdisciplinary partners from different faculties of RWTH Aachen University investigating the resolution of the polylemma of production [3], i.e. ways to solve the tradeoff between scale and scope and between plan and value oriented production [4]. The CoE (cf. Fig. 1 for an overview over its structure) consists of twelve subprojects with a total of about 180 researchers and 200 student assistants. These researchers come from various scientific disciplines in varying degrees of completion regarding their education. Bringing all this personnel to the same table and enabling them to cooperate requires a common understanding of terminology, language, methods, competences, cognitive models, perceptions of success, and many more criteria.

Foremost it is necessary to ensure that all members are able to communicate effectively despite the different terminologies in their given discipline. Hence, one of the central challenges of interdisciplinary work is the disciplinary coloring of terminology, which hampers communication if handled unwittingly. Discussions about meanings of terms may occur afterwards when seemingly an agreement has been found. Even when a concept of linguistic/terminological diversity exists, differences in methodology and cognitive models may hinder effective scientific cooperation.

Second, even teams which seem to cooperate successfully may have diverging criteria for what counts as scientific success. Disciplinary differences emerge e.g. in different publication behavior (community size, citation frequency, citation half-life etc.) and a different understanding of what constitutes a "successful" publication. The same applies for other success criteria and the evaluation of their impact (e.g. patents, acquired third party-funding, supervision of theses and teaching). Increasing the awareness of the diversity of an interdisciplinary venture and establishing a culture of valuing this diversity are crucial for moving from a multidisciplinary perspective to an interdisciplinary one.

To overcome these and other challenges of interdisciplinary cooperation and to support the performance of such interdisciplinary research consortia, new approaches are needed for the cross linkage of the different researchers and institutes as well as for the transfer of solutions between them. Therefore, the CoE

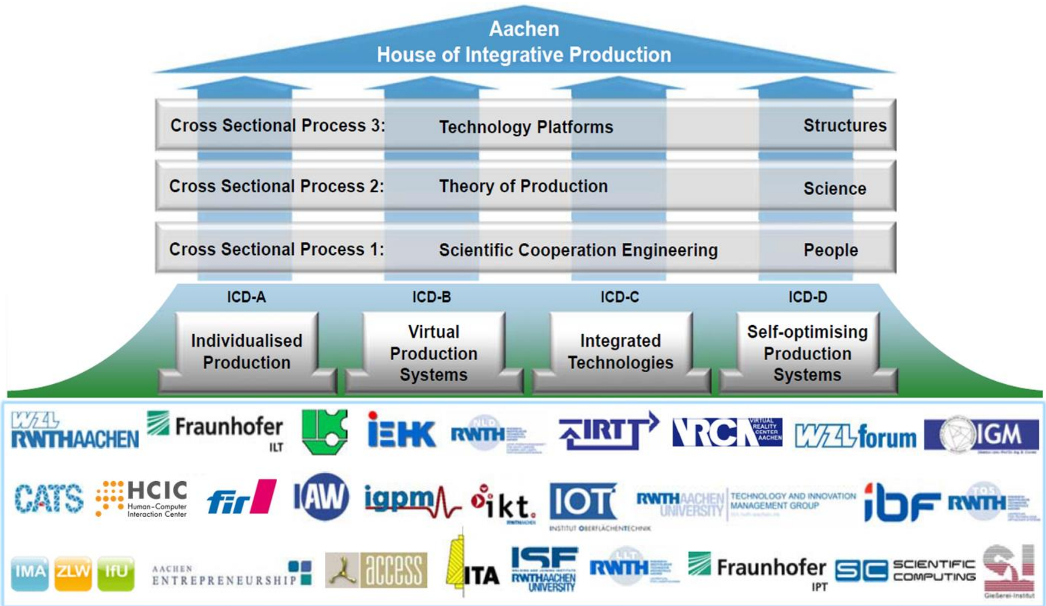

Figure 1. Structure of the CoE with its four Integrative Cluster Domains (ICDs) and three Cross Sectional Processes (CSPs)

next to several collaborative projects from the field of production technology additionally comprises cross-sectional projects entrusted with this task, the "Cross Sectional Processes" (CSPs). Here, concepts of supporting the integration of the different disciplines into the CoE on a physical and virtual level are designed, implemented and constantly evaluated [5]. Among other approaches, an online platform is developed, which offers different applications to the cluster members.

This paper is structured as follows: In section II this platform, the Scientific Cooperation Portal (SCP), is introduced. The section describes the technology behind the portal as well as its basic features to help researchers in their everyday work. Section III describes the applications offered by the portal that are used to advance the research efforts of the CSP, before section IV ends with first experiences with the portal and a short outlook onto further functionality.

II. The Scientific Cooperation Portal

In this section the Scientific Cooperation Portal (SCP) jointly developed by the team of the Cross Sectional Processes 1 and the Cross Sectional Processes 3 is presented with its basic functionality to assist cluster members in their daily work as well as its research functionality to advance the research of the CSPs.

A. Technology

The social software framework that is used to set up the SCP is a Liferay Server. Liferay is open-source enterprise portal software that is free of charge and runs on JavaEE Servers (e.g. Tomcat Server) connected to an SQL database (e.g. MySQL). It was chosen because expertise in Liferay Development was readily available in the team and the feature set of Liferay extends beyond the leading commercial competitor (i.e. Sharepoint). Liferay offers a social community platform, allowing the forming of communities of interest, which get access to community specific functions and content. Users of the software can become members of these communities and connect with other users, accessing their personal profile and their contact information. Typical social features such as blogs, messages, chats, message boards and wikis are also part of Liferay.

Figure 2. Customized view of the SCP using Liferay Themes

Liferay provides web-authoring mechanisms including workflow management (incl. roles such as authors, editors, etc.). This allows customizing the look and feel of Liferay to make users feel at home (cf. Fig. 2). It furthermore supports document and media management with versioning. All content generated in Liferay can be tagged, categorized, commented, rated, and accessed from different applications (i.e. portlets) that interconnect the various forms of data available to the Liferay server. By writing own applications developers can leverage the framework of Liferay to make their own data accessible by other applications and access other information (e.g. profile data).

B. Basic Features

The previously described Liferay technology already provides a set of basic features, which support the scientific cooperation of the cluster employees.

A full member list gives information about involved institutes and researches as well as their contact details. In addition, each member has an own profile, which can contain a picture and information about further research interests outside the CoE. An extension to Liferay called “Social Office” also enables plenty of other social networking features, e.g., networking between different users, a display who is online at the moment combined with a simple chat and a messaging tool.

One feature to improve the scientists’ collaboration is the calendar. It shows all CoE-related appointments and also sends reminder messages to participants upon request. The forthcoming Liferay update will come with a revised version of the calendar, which extends the current functionality by an improved user interface (similar to the well-known Google Calendar) and new technical interfaces to synchronize the CSPs’ calendar with established tools and devices at the different participating institutions.

As in all knowledge intensive organizations transparency is a key need of employees within the CoE. The sum of all basic features therefore originates from the necessity for any large cooperation to disseminate information across all members of the cooperation and to avoid hampering flow of information across hierarchy. Furthermore, the portal offers different standard tools to organize contents, e.g. a simple content and file management system or a typical wiki application.

III. RESEARCH APPLICATIONS OF THE PORTAL

The SCP serves as a dual purpose solution, beyond the aforementioned function; it generates valuable data for the research of the CSPs directly from the CoE itself, which in turn can be used as performance indicators for the cybernetic management approach of the CoE. These aspects are also addressed by specific features of the SCP (i.e. Terminologies, Publications, Technologies, and Project Management).

A. *Terminologies*

The Cluster Terminologies application is one of these applications and helps members to become aware of and cope with differing terminologies. Fig. 3 depicts a view showing all definitions stored for a given term.

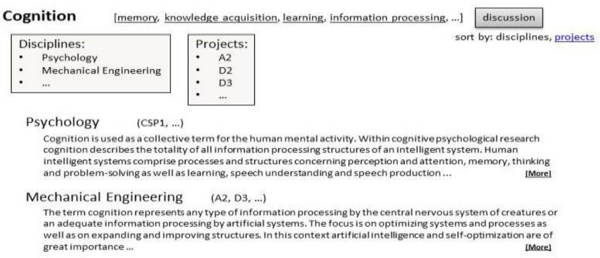

Figure 3. View on an example term in the SCP

The application provides cluster members with the possibility of getting an overview over different terms, which are supposed to be central terms from research activities of the CoE as well as from the scientific fields involved. Together with these terms the application presents various definitions for each term reflecting the fact that the same term (or very similar terms) can be defined differently depending on the scientific discipline. Every definition is assigned to one or more disciplines and to one or more subsidiary projects of the CoE, where the term is used as the definition indicates. Definitions can also be contrasted with common understandings of the term outside the CoE, if a research topic is examined from a different perspective or in a different way in the CoE.

Reading the data stored for a term, the user directly recognizes how many definitions exist for this term and how ambiguously it is used and understood in different disciplines. Thus, the user learns about definitions from other scientific fields leading to an integrated understanding of the diverse terminologies. Moreover, the application provides the possibility of starting online discussions about every definition. New opinions can be introduced, discussed and if necessary integrated into existing definitions. Thus, the application’s database always contains the current working definition of terms inside the CoE.

The user is provided with different ways of accessing the definitions. Next to a simple alphabetical list or glossary function of the defined terms the user can browse through a structured list of the scientific disciplines, which define terms from their perspective. Moreover, the organizational structure of the CoE provides a graphical way of discovering which terms are used and defined in the different subsidiary projects. Additionally, the defined terms are tagged with keywords, which help to examine the terminology on a specific topic.

All this information is gathered, presented and discussed in a persistent way so that it can be established in the CoE instead of getting lost due to staff turnover. New members can always get an overview over the current state of the cluster terminologies.

B. *Publications*

Publications depict a form of scientific cluster output. They (ideally) contain information about research progress and cooperation. By looking at the author list of a publication one can understand who cooperates with whom. Additional information can be made available when using the SCP from the user profiles. By this, one can assess how much interdisciplinary cooperation is actually occurring [6, 7] in the regarding publication.

Nonetheless reducing scientific efforts to publications is an oversimplification when trying to assess researchers’ performance. Performance measurement from bibliometric data (alone) is controversial since differences between disciplines impede comparing simple metrics such as citation counts.

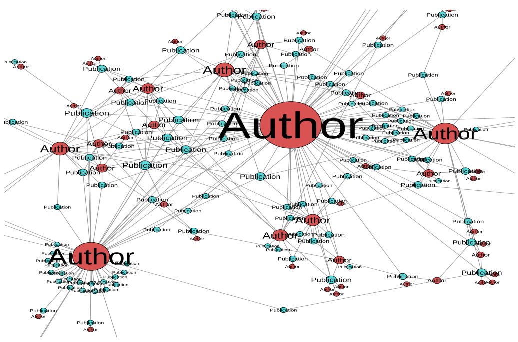

Figure 4. Exemplary publication graph – authors are denoted as

In this approach the focus lies on assessing degrees of cooperation between researchers on a meta-level scale (i.e. the whole CoE). For this a graph-based approach for publication analysis is used (cf. Fig. 4). By constructing co-authorship graphs the amount of cooperation (as portrayed in publications' author lists) can be measured [8]. Enriching the purely bibliometric data with sociometric data can help visualize the social precursors for successful scientific cooperation: e.g., are spatial nearness or the familiarity of authors a motor for successful cooperation? Gathering more information about social factors and their impact on cooperation might allow the derivation of supporting measures.

In this context the approach of publication visualization is focused on both providing general information about the whole CoE performance and an individualized view on publications. Users will see with whom they have published, about what topics, and will get an egocentric view of their publication network. This allows users to understand their own publishing behavior and identify further authors in their thematic proximity who could enrich their personal work [9].

Extracting further information from publications allows additional analyses like grouping publications according to keywords used to find other publications from the CoE that deal with similar topics and might lead to further cooperation between the respective authors. On a meta-scale level, related topics can be identified if their respective publications appear in proximity without necessarily being directly interconnected.

By providing the means of egocentric micro-level visualization of bibliometric data as well as meta-level visualizations to steering agents the publication relationship analysis application supports the management of the cooperation in the CoE.

C. Technologies

In order to bridge the gap between research and industry, promoting technology and knowledge transfer becomes increasingly important. Especially small- and medium-sized enterprises, having only little R&D resources themselves, depend on external technology development activities to remain innovative [10]. In contrast, academia research needs industrial partners, who are capable and willing to commercialize their technologies as in most public funding programs dissemination activities are required by the funding body.

Meanwhile, modern web technologies offer more and more "social" functionalities and open up new ways of user interaction. These social features offer a great potential for supporting technology transfer [11] especially in its early phases by bringing together technology demand and supply [12]. However, technology transfer portals have to be designed carefully in order to meet future users' needs and thus being successful in operation [13]. A technology transfer application is developed in the CSPs through an iterative implementation approach on the SCP.

Technology transfer beyond the CoE will be supported by the SCP by bundling of and simplifying access to the technologies developed within the CoE and the corresponding technology experts behind them. Furthermore, it should serve as a discussion forum and meeting point of expert communities for connecting people and technologies within the CoE. This will be achieved by the following core functions:

- Users are able to present themselves and their expertise in individual user profiles, connect their technologies to their individual profiles, define their interests and get updated about selected technologies.
- Users are able to find other experts within the CoE and be found by potential cooperation partners and discuss their technologies and possible applications in expert communities. Fig. 5 shows one of the implemented functions of the SCP, where technologies can be described in an application oriented way, including a short description, future fields of applications, technology suppliers or experts as well as the current technology readiness level.

In a next step, these technology profiles will be linked to the already existing user profiles. In the future, users will also be able to define, which parts of the information about themselves and their technologies will by publicly accessible and thus be visible to possible external cooperation partners, such as interested companies or other research institutions.

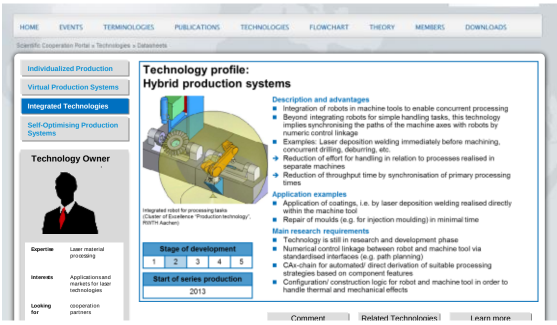

Figure 5. Technology profiles linked to user profiles

D. Project Management

Subprojects in interdisciplinary research corporations usually show complex work package structures. To keep track of the different work packages and to ensure that all team members have the same knowledge base, the FlowChart App is developed and evaluated within the CoE and for the SCP. The main objective is to generate a web-based tool that is easy to understand and has an intuitively operable user interface, which creates a transparent view on the knowledge gaining process.

To achieve that, ideas from existing project planning tools are combined to a pictographic language approach which

a) reflects the organizational structure inside interdisciplinary and interinstitutional projects,

b) shows the initial situation and the main project goals, and

c) shows the project work packages, its dependencies and interlinks on a time schedule.

An example flow chart is shown in Fig. 6. In the background different work package groups are indicated by different colors. Different work package groups may also indicate different institutions or different resources. Inside these work package groups the initial situation or needs are placed in the left column. On the right hand side two columns carry information about the project outcome. These columns are separated by practical project results or means, like new machines or new processes and results that reflect the knowledge or tools gained inside the project.

Inside the central area the work packages are situated on a time schedule. Interlinks between the work packages depict the dependencies between work packages and their contribution to the final results. The horizontal extent of a work package reflects the amount of time that is planned for this work package. The degree of fulfillment is drawn into the work package box using background gradient coloring.

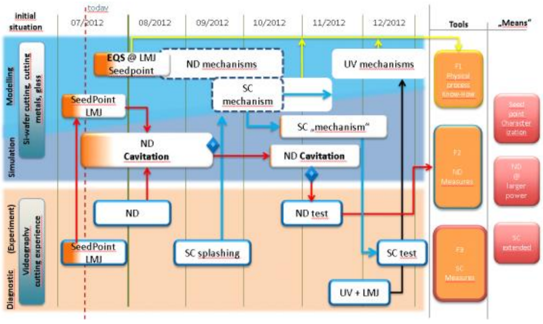

Figure 6. The FlowChart application

The resulting image is a flow chart that shows the state of the project and the upcoming work packages on a single presentation slide, which is easy to explain to project members as well as customers. To make it easy to create, share and distribute flow charts, a web-based application that will be placed on the SCP is implemented.

To measure the acceptance and effect of the FlowChart approach inside interdisciplinary and interinstitutional research groups, interviews and surveys will be performed inside the CoE. The resulting application is a project management tool that is reduced to the information that is essential to understand the knowledge gaining process inside the project.

E. Data Gathering

The SCP requires specific types of data to be useful to the researchers. Large-scale interdisciplinary research efforts bear the problem of lacking transparency regarding personal information of the many individual researchers. Thus they require an active management of information regarding human resources, individual research efforts, and interfaces between researchers (i.e. information on users' disciplines, scientific methods, publications, terminologies, and technologies). Only when these are made readily available, the strength of the weak-tie network can be leveraged and lead to an emergence of an innovative interdisciplinary research output [14].

The necessary data is collected using both online and offline approaches. Data for the various applications is collected automatically by accessing other data sources, such as the databases of the RWTH Aachen University Library. Additionally users have the ability to upload data or edit data live on the website, allowing them to customize the user experience to their desire.

In many other cases it is necessary to systematically collect data from all cluster members (e.g. sociometric data). For these cases either survey questionnaires or interview studies are conducted and the evaluated data is integrated into the SCP. One example of a reoccurring questionnaire study is the cluster-specific Balanced Score Card [15], which is performed annually. In this study critical measurements (e.g. evaluation of research quality, research cooperation, information policy, etc.) are assessed in regard to subproject and hierarchical level to understand where optimizations should be made.

Another way of generating data is using the colloquia of employees of the cluster staff. In these (usually) full day meetings certain topics that are relevant to all cluster domains are worked on, and the generated results are then systematically treated and improved for online integration on the SCP. The last colloquium dealt with the variety in technologies, terminologies and methods that are used in the CoE. For example, by identifying who uses what type of methods and creating online resources for the applied methods, users can find experts in the CoE in case they are looking for assistance on a certain topic.

Since the SCP offers the opportunity to setup special interest user groups with designated private data stores, these can also be used to generate data for groups. This data can then be used to enhance the user experience for these groups as well. For example, users can get recommended literature derived from their membership in special interest groups.

IV. EXPERIENCES AND OUTLOOK

The SCP is available to the cluster members since November 2013. User profiles of the cluster employees were not prefilled; all user data had to be uploaded by the users themselves. The voluntariness of use and data disclosure leverages the possible negative experiences users have made with other forms of social media in professional contexts [16]. In the first step *transparency* was identified as a fundamental basis, which reflects in the cluster members using the portal predominantly as a kind of yellow pages, to get an overview about the forthcoming events and to download achieved results. In addition, information about former events was accessed and user profiles were filled.

Using Piwik[1] as an analytics tool which corresponds to German privacy laws, e.g., by storing data locally and disguising the users' IP addresses, one can get an overview of the portal usage and expect further findings about the users' requirements [17]. Piwik is used in order to identify intensities of usage of single portal functions so that the prototype of the SCP can be continuously improved and developed in a user-centered way. Frequently used functions can be kept, while rarely used functions can be discarded again.

Next, new features will be enabled one after another and existing functionalities improved. First, an update to the new Liferay version 6.2. is planned. This contains among other novelties the described calendar improvements but also overall interface innovations like responsive design, which increases the user experience on mobile devices. This has been determined to be a key factor in technology acceptance. Second, the different applications and features explained here will be interlinked. For example, the profiles of users who are experts in a specific field will link to a technology datasheet related to the same field and vice versa. This will allow users to identify required corresponding

[1] http://www.piwik.org

experts. Furthermore, the portal will be linked to external data sources like the university library so that for instance cluster-relevant publications can be pushed to the portal and users only have to monitor their publications instead of uploading them manually. This dynamic interconnection of information leverages all key benefits of social media, the effect of which remains to be studied by the CSPs.

To extend the SCP's benefits, sub-communities will become an important part of the portal. These special interest communities (SICs) relate to the specific structures of the CoE and assist researchers in their daily environment. These SICs can flexibly be assigned, customized in their feature set to match given needs, and can therefore react to changes in structures and requirements in a research setting. Accordingly, the SCP is envisioned to become the central information and collaboration platform of the CoE itself, the different cluster projects and groups and in the best of cases even of the single member institutes. In the future this will also constitute the basis for opening parts of the provided information to external interest groups, such as potential cooperation partners from industry.

Next to the support for the Cluster of Excellence the SCP is used to gather data for the research questions the CSP subprojects are concerned with. This data is then analyzed to approach the question about how interdisciplinary collaboration works and which factors influence its output.

One aspect of this is the influence of differing terminologies and the question if the acquisition of the terminology used inside such a consortium is a suitable means of discovering possible synergies between researchers in different subprojects, who are not yet working together directly.

Furthermore, the SCP generates and collects data about the level of cooperation, which itself will be used as research data. By this we can measure the effectiveness of interventions (such as the colloquia of employees) for enhancing interdisciplinary cooperation, which will finally result in new structures emerging from the publication network of the cluster.

Acknowledgment

This work was performed as part of the Cluster of Excellence Integrative Production Technology for High-Wage Countries, which is funded by the excellence initiative by the German federal and state governments to promote science and research at German universities.

References

[1] T. Jahn, “Transdisziplinarität in der Forschungspraxis“, *Transdisziplinäre Forschung: integrative Forschungsprozesse verstehen und bewerten*, Frankfurt am Main: Campus-Verlag, 2008.

[2] J. R. Bryson, “Hybrid Manufacturing Systems and Hybrid Products: Services, Production and Industrialisation”, *Studies for Innovation in a Modern Working Environment. International Monitoring.* K. Henning Eds. Aachen: Center for Learning and Knowledge Management and Department of Information Management in Mechanical Engineering, RWTH Aachen University, 2009.

[3] C. Brecher et al., *Integrative Production Technology for High-wage Countries*, Berlin, Heidelberg: Springer-Verlag, 2012.

[4] Cluster of Excellence ‘Integrative Production Technology for High-Wage Countries’ Renewal Proposal for a Cluster of Excellence – Excellence Initiative by the German Federal and State Governments to Promote Science and Research at German Universities, Unpublished.

[5] C. Jooß, F. Welter, I. Leisten, A. Richert, A. K. Schaar, A. Calero Valdez, E.-V. Nick, U. Prahl, U. Jansen, W. Schulz, M. Ziefle, and S. Jeschke: Scientific Cooperation Engineering in the Cluster of Excellence Integrative Production Technology for High-Wage Countries at RWTH Aachen University, accepted at 5th International Conference of Education, Research and Innovation (ICERI) 2012.

[6] H. Snyder, and S. Bonzi (1998). Patterns of self-citation across disciplines (1980-1989). *Journal of Information Science*, *24*(6), 431-435.

[7] Alexander von Humboldt-Stiftung. Publikationsverhalten in unterschiedlichen wissenschaftlichen Disziplinen. *Beiträge zur Beurteilung von Forschungsleistungen. Diskussionspapier*.

[8] A. Calero Valdez, A. K. Schaar, M. Ziefle, A. Holzinger, S. Jeschke, and C. Brecher. Using mixed node publication network graphs for analyzing success in interdisciplinary teams. *Active Media Technology*. Berlin Heidelberg: Springer. 2012, pp. 606-617

[9] A. K. Schaar, A. Calero Valdez, and M. Ziefle. Publication network visualization as an approach for interdisciplinary innovation management. *Professional Communication Conference (IPCC), 2013*, pp. 1-8

[10] Laube, T.: Methodik des interorganisationalen Technologietransfers. (IPA-IAO Forschung und Praxis, Bd. 483). Heimsheim: Jost-Jetter, 2009, p. 88

[11] D. Czarnitzki, C. Rammer, “Technology Transfer via the Internet: A Way to Link Public Science and Enterprises?,” in *Journal of Technology Transfer*, 2003, p.131.

[12] G. Schuh, S. Aghassi, and A. Calero Valdez: Supporting technology transfer via web-based platforms. *Proceedings of PICMET '13*, D. Kocaoglu Eds., Portland International Center for Management of Engineering and Technology, Portland/ USA, 2013, pp. 858-866

[13] G. Schuh and S. Aghassi: Technology Transfer Portals: A Design Model for Supporting Technology Transfer via Social Software Solutions. *Proceedings of the IEEE International Conference on Engineering and Engineering Management IEEM'13*, 2013

[14] Granovetter, M. (1973). The strength of weak ties. American journal of sociology, 78(6), l.

[15] F. Welter, R. Vossen, A. Richert, and I. Isenhardt (2011). Network Management for Clusters of Excellence-A Balanced-Scorecard Approach as a Performance Measurement Tool. *Automation, Communication and Cybernetics in Science and Engineering*, Berlin Heidelberg: Springer, *2009/2010*, pp. 195-207

[16] A. K. Schaar, A. Calero Valdez, and M. Ziefle. The Impact of User Diversity on the Willingness to Disclose Personal Information in Social Network Services. *Human Factors in Computing and Informatics*, Berlin Heidelberg: Springer, 2013, pp. 174-193

[17] D. Waisberg and K. Avinash: Web Analytics 2.0: empowering customer centricity.*The original Search Engine Marketing Journal 2(1)*, 2009, pp. 5-11.

Authors

Tobias Vaegs is researcher in the research group “Knowledge Engineering” at the Center for Learning and Knowledge Management (ZLW) in the institute cluster IMA/ZLW & IfU at RWTH Aachen University, Aachen, Germany (e-mail: tobias.vaegs@ima-zlw-ifu.rwth-aachen.de).

Dr. André Calero Valdez is postdoctoral researcher at the Human-Computer Interaction Center (HCIC) at RWTH Aachen University, Aachen, Germany (e-mail: calero-valdez@comm.rwth-aachen.de).

Anne Kathrin Schaar is researcher at the Human-Computer Interaction Center (HCIC) at RWTH Aachen

University, Aachen, Germany (e-mail: schaar@comm.rwth-aachen.de).

André Bräkling is researcher at the Fraunhofer Institute for Production Technology at RWTH Aachen University, Aachen, Germany (e-mail: Andre.braekling@ipt.fraunhofer.de).

Susanne Aghassi is researcher at the Fraunhofer Institute for Production Technology at RWTH Aachen University, Aachen, Germany (e-mail: susanne.aghassi@ipt.fraunhofer.de).

Ulrich Jansen is researcher at the chair for Nonlinear Dynamics of Laser Processing at RWTH Aachen University, Aachen, Germany (e-mail: ulrich.jansen@ilt.fraunhofer.de).

Thomas Thiele is researcher in the research group "Knowledge Engineering" at the Center for Learning and Knowledge Management (ZLW) in the institute cluster IMA/ZLW & IfU at RWTH Aachen University, Aachen, Germany (e-mail: thomas.thiele@ima-zlw-ifu.rwth-aachen.de).

Dr. Florian Welter is postdoctoral researcher and leader of the research group "Innovation Research and Futurology" at the Center for Learning and Knowledge Management (ZLW) in the institute cluster IMA/ZLW & IfU at RWTH Aachen University, Aachen, Germany (e-mail: florian.welter@ima-zlw-ifu.rwth-aachen.de).

Claudia Jooß is researcher and leader of the research group "Knowledge Engineering" at the Center for Learning and Knowledge Management (ZLW) in the institute cluster IMA/ZLW & IfU at RWTH Aachen University, Aachen, Germany (e-mail: claudia.jooss@ima-zlw-ifu.rwth-aachen.de).

Prof. Anja Richert is managing director of the Center for Learning and Knowledge Management (ZLW) in the institute cluster IMA/ZLW & IfU at RWTH Aachen University, Aachen, Germany (e-mail: anja.richert@ima-zlw-ifu.rwth-aachen.de).

Prof. Wolfgang Schulz is director of the chair for Nonlinear Dynamics of Laser Processing at RWTH Aachen University, Aachen, Germany (e-mail: wolfgang.schulz@ilt.fraunhofer.de).

Prof. Guenther Schuh is director of the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University, Aachen, Germany (e-mail: G.Schuh@wzl.rwth-aachen.de).

Prof. Martina Ziefle is director of the Human-Computer Interaction Center (HCIC) at RWTH Aachen University, Aachen, Germany (e-mail: ziefle@comm.rwth-aachen.de).

Prof. Sabina Jeschke is director of the institute cluster IMA/ZLW & IfU and vice dean of the department of mechanical engineering at RWTH Aachen University, Aachen, Germany (e-mail: sabina.jeschke@ima-zlw-ifu.rwth-aachen.de).

Manuscript received 13 March 2014. This work was performed as part of the Cluster of Excellence Integrative Production Technology for High-Wage Countries, which is funded by the excellence initiative by the German federal and state governments to promote science and research at German universities.

Published as submitted by the author(s).