Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 32 (2015) 126 – 131

www.elsevier.com/locate/procedia

The 5th Conference on Learning Factories 2015

Die Lernfabrik – Research-based Learning for Sustainable Production Engineering

Stefan Blume[a,*], Nadine Madanchi[a], Stefan Böhme[a], Gerrit Posselt[a], Sebastian Thiede[a] and Christoph Herrmann[a]

[a] *Institute of Machine Tools and Production Technology, Technische Universität Braunschweig, Langer Kamp 19 b, 38106 Braunschweig, Germany*
* Corresponding author. Tel.: +49-531-391-7168; fax: +49-531-391-5842. *E-mail address:* stefan.blume@tu-braunschweig.de

Abstract

Engineering Education directed at topics like sustainable production or life cycle engineering needs adequate teaching approaches. Methods like research-oriented teaching, project-based learning or game-based learning are suitable techniques to promote a deeper understanding and develop competencies in respect to complex dynamic systems. However, providing appropriate teaching environments which allow for self dependent learning and practical experiences while making state of the art research insights available is quite challenging. Die Lernfabrik has been developed to suit these exact issues by providing a didactic framework for sustainable production engineering education in a real factory environment. This paper introduces a new didactic concept to combine the benefits of research-based learning approaches in engineering curriculum with the physical infrastructure of Die Lernfabrik. While gaining theoretical background in a related lecture, students utilize machinery and installations of the learning factory independently for experiments to solve their self-chosen research questions. Application and validation of the concept are exemplified by the TU Braunschweig course Energy Efficiency in Production Engineering, focusing on energy efficiency solutions for production systems. It could be proved that the individual learning motivation and success of the students as well as their competency to solve real engineering problems was significantly improved by the new approach.

Peer-review under responsibility of the organizing committee of 5th Conference on Learning Factories (CLF 2015)

Keywords: Die Lernfabrik; Learning Factories; Sustainable Production Engineering Education; Research-based Learning; Energy Efficiency

1. Die Lernfabrik

Factories are a place for innovative, creative and efficient value creation of industrial goods [1]. They represent a local concentration of the primary factors of production: buildings, equipment, material and personnel as well as the derived factors knowledge, skills and capital [2]. The German government committed itself to a sustainable economy and energy policy as well as to a digital economy and society by introducing their high-tech strategy in [3] – in alignment with the European regulation to establish the Horizon 2020 framework program [4]. To maintain the competitiveness of factories, education of new and further qualification of existing personnel is a determining factor. Especially in the domain of production engineering education, suitable methods to address the needs towards a more sustainable development are needed. At the same time enablers like digitalisation should be addressed in existing curricula. Against this background the Institute of Machine Tools and Production Technology of the Technische Universität Braunschweig introduced *Die Lernfabrik* in spring of 2012 [5] to create a learning factory environment for the fields of sustainable production and life cycle engineering. The trigger for the initiation of Die Lernfabrik was the often difficult employability of method-based skills of the sustainable production paradigm in the research-led lecture *Energy Efficiency in Production Engineering* and in the dissemination of results from publicly-funded research projects in the mentioned fields. Accordingly, the central focus of Die Lernfabrik is structured in three columns (see Fig. 1).

The three columns of Die Lernfabrik range from learning in active research projects in a near-industrial factory environment with actual production machines and technical building services to learning equipment for class room

Peer-review under responsibility of the organizing committee of 5th Conference on Learning Factories (CLF 2015)
doi:10.1016/j.procir.2015.02.113

lectures. The *research lab* is the first column and focuses on the dissemination of research project results by implementing developed prototypes in factory environments. Accompanied by internal research work (e.g. dissertations, master theses), a continuous internalisation [6] of knowledge is being realised. The second column is a research-based learning environment named *experience lab*. The experience lab focuses on practice-oriented application of methods and tools on a physical small-scaled modular production system. The scaled-down production equipment and process chains allow the establishment of a safe and accessible learning environment for the learner. The learners are free to modify and rearrange processes and production equipment and to apply organisational measures to experience the dynamic response from the production system with all systemic interdependencies. According to this setting, the experience lab allows to generate method-based knowledge by students and experts (externalisation) and the derivation of new research questions and ideas by knowledge combination. The third column – *education lab* – focuses on the transfer of knowledge on predefined learning paths directed at a rather less research-based learning experience but a more application-oriented one. For this the education lab provides partially mobile learning equipment with build-in courses and guided practical experiments in closed learning cycles.

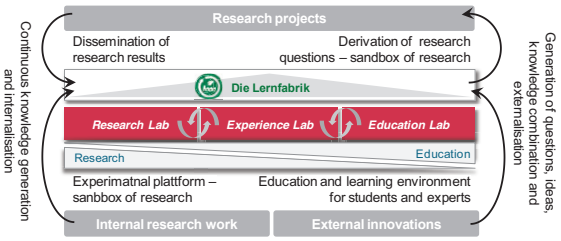

Fig. 1 Knowledge generation cycle with the organisational structure of Die Lernfabrik

Furthermore, Die Lernfabrik is open for the integration of external innovations from research communities and industry. As the research lab provides all facilities and equipment of a common small and medium sized manufacturing company, but is not bound to the constraints of a real throughput and quality-driven production site, external research partners find an environment for testing and evaluation of prototypic equipment, processes and materials. The innovative ideas and the combination of knowledge gained by the users of Die Lernfabrik allow the derivation of new research questions to be answered in cooperatively applied funded research projects to close the loop of continuous knowledge generation and innovation.

2. Basic Didactic Concept of Die Lernfabrik – Experience Lab

Progress in domains like sustainable production or life cycle engineering relies on a deep understanding of the underlying principles as well as on practical skills. Thus, engineering education directed at these complex topics needs adequate teaching methods and learning environments. Otherwise students will not be able to develop useable competencies and merely accumulate factual knowledge. Teaching methods are required which are directed at the development of competencies and therefore close the gap between knowledge (the university) and action (the professions) [7, 8]. Regarding industrial engineering Jaeger et al. especially refer to system competency, problem solving competency, social-communicative competency and methods competency as vital elements [9]. Methods like research-based learning, project-based learning or game-based learning are suitable techniques to promote a deeper understanding and develop competencies in respect to complex dynamic systems including interlinked thinking and decision-making as well as practical skills in teamwork and communication [10]. Learning factories can promote these methods [11]. This does not imply that learning factories could not be used with other didactic concepts in mind. In tutorials, demonstrations or lectures, for instance, a learning factory can be a means of illustrating and visualizing general concepts or specific correlations. However, in regard to complex and multifaceted fields like sustainable production or life cycle engineering learning factories should enable the participants' ability to critically assess common approaches and allow for individual learning experiences.

From this competency-based and action-oriented perspective a learning factory can be understood as an interactive model which reproduces parts of specific technical, economic, political or social systems, and offers a simplified access to the complex correlations in these systems. Through a system of rules and interfaces the participants are able to interact with the model and thereby to determine the outcome of different actions. As the consequences of their actions are limited to the context of the learning factory, the participants can experiment with new strategies. By reflecting the results of their decisions they form a personal model about the implicit model of the factory and make assumptions about the elements and relations of the system [12]. Thus, not only knowledge is transformed into action but new knowledge is generated as well. This two-way connection of knowledge, action, and feedback leads to experience and responsibility [7] as well as competencies in decision-making [13]. Therefore, a learning factory as a learning environment can be used as a setting for behavioral rehearsal: „Learning Factories pursue an action-oriented approach with participants acquiring competencies through structured self-learning processes in a production-technological learning environment" [11].

To reflect the close relationship between research and education in Die Lernfabrik (compare Fig. 1) as well as the specific requirements regarding the education in fields like sustainable production and life cycle engineering research-based learning was established as basic didactic concept for the Experience Lab.

3. Application of Research-based Learning

3.1. Research-based Learning (RBL)

The original idea behind research-based learning is derived from Humboldt's vision for higher education. His idea was that "universities should treat learning as consisting of not yet wholly solved problems and hence always in a research mode" ([14] translated from [15]). This shows that neither the traditional up-front-teaching style nor a traditional research routine is appropriate for university education [15]. Humboldt's vision rather aims for the unity of research and teaching, where the university is mainly considered as a research institution with the primary task to pass on knowledge and to discuss it critically. Further, this vision is characterized by a close university community that comprises learners and teachers and allows an open discussion between them. Moreover, this vision is based on the belief that all disciplines contribute to a comprehensive education. Thus, scientific thinking is not supposed to be limited to one specific discipline of science, but to be interdisciplinary [16].

On the basis of this vision, the concept of a research-based learning was developed. According to Huber it can be defined as a form of learning, where the learners design, experience and reflect the entire process of a research project, with the goal to generate new findings and results, which may also be interesting for a third party. The process involves the development of a research question and derivation of a hypothesis, the selection and implementation of an appropriate method as well as a review and presentation of the results. Here, the learners work independently or in active participation on the research project [17]. Thus, teachers are facing the challenge to make the actual research process visible and not just the results. It is therefore critical to arrange learning situations along with appropriate research questions [18].

However, it is essential that research-based learning is initiated in the minds of learners and creates a connection between teaching and research in their minds [15]. They are supposed to experience science as a social process with cognitive and emotional experiences. In this case the practical results are not as important as the theoretical insights and deeper understanding of social and scientific responsibility [17].

In addition, there are also further concepts that focus on a combination of research and learning and are interdependent with research-based learning. Healy and Jenkins classified four different ways of engaging students with research and inquiry, as depicted in Fig. 2.

Research-led activities focus on the understanding of research findings, while a research-oriented concept focuses on the understanding of research processes, teaching inquiry skills and techniques. For both approaches the students mainly play the role of a passive audience. The research-tutored concept, on the other hand, encourages an open and active discussion between learners and teachers on research content and the research-based concept focuses on learning through actually conducting a research project. These two concepts consider the students to be active participants [19, 20].

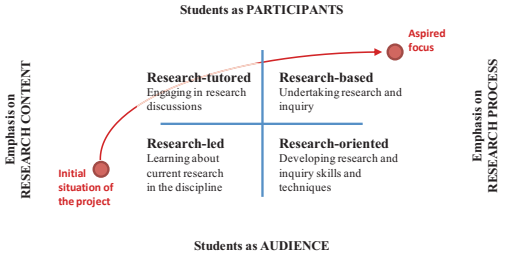

Fig. 2 Classification of concepts regarding the relationship between teaching and research, adapted from [19]

All four ways differ from each other in terms of involving students and research aspects, but Healy and Jenkins consider them to be interdependent and valid. Effective education programs and modules should contain aspects of all of them. The appropriate balance between the activities, however, always has to be adapted to the boundary conditions. For university education they recommend, for example, that the students spend more time with activities from the top half than the bottom half of the model shown in Fig. 2 [20].

3.2. Application in University Course: Energy Efficiency in Production Engineering

The integration of research in teaching has attained considerable relevance during the last decades as it combines the teaching of theoretical knowledge with the development of methodological and social skills, which are considered to be crucial for a good professional. Due to the benefits of action-oriented learning compared to traditional frontal teaching, the concept of research-based learning was applied in Die Lernfabrik and embedded within the course *Energy Efficiency in Production Engineering*. The underlying course was offered by the institute since 2010 for engineering students in master programs. This course in English language deals with concepts, methods and tools for the design of a sustainable industrial production, its content being influenced by recent research projects of the institute in the context of energy efficiency. The idea of the course is to make students as future engineers aware of their responsibility, which arises from the great impact of industrial systems on the environment and society [21]. Hence, systemic thinking for the realization of a sustainable development must be considered as a key aspect in academic education. It should address all three pillars of sustainability – economy, ecology and society [22]. Against this background a holistic factory perspective constitutes the core element of the lecture, which is not limited to the production machines as value creating parts of the production but also includes the building shell as well as the technical building services, the latter providing the production machines with energy and media [23]. In particular the flows and dynamic interactions between these elements, e.g. through interdependent energy and resource inputs or outputs, have to be understood and analyzed, allowing both prediction and improvement of economic and ecological key performance indicators.

The course contents and structure have been revised within the funded project, leading to the structure depicted in Fig. 3. The current course consists of three elements:

- A theory module with a lecture, imparting theory and background knowledge about designing energy efficient production systems
- A practice module, offering hands-on experience in Die Lernfabrik of the IWF as a research and learning lab with realistic industrial machinery and equipment
- A laboratory module, focusing on deeper knowledge regarding selected lecture contents

The research-based learning is mainly addressed in the practice module, which therefore has been completely redesigned. It previously comprised a defined practical research task, which was carried out under the instruction of the teaching staff [21]. It mainly incorporated elements of research-led and few elements of research-tutored approaches, focusing on the research contents but not on the research process as such (see Fig. 2).

The objective within the recent project was to establish a research-based learning approach, coupled with the existing IWF learning factory, which can offer open access to its infrastructure for hands-on experiments during the semester. The goal of the new practice module is not necessarily to produce groundbreaking new research results, but to experience the process of scientific working and to develop the methodological and social skills of the participants. This may also include the insight of failures, as research is not always leading to positive results, as long as it is approached unbiased. From now on the students are supposed to pass through a whole research cycle in small teams of three to five students, starting with the formulation of a lecture-related research question and the study of corresponding scientific literature. Physical experiments can then be done in the learning factory, followed by a data analysis with tools and methods presented in the lecture. The results and achievements have to be interpreted, presented and critically reflected by each group. Fig. 4 gives an overview about the typical steps of a research cycle in engineering, serving as an orientation for the students attending the course. The experience lab serves as an ideal base for such a self-dependent answering of research questions, as it is intentionally made for learning purposes and offers a lot of possibilities for open research. As shown in Fig. 3, the practice module comprises some additional elements, focusing on written and oral presentation skills. The idea of a digital research diary was developed to document research results in a systematic, comprehensible manner, to promote self-awareness and to make the students' research process transparent for the teaching staff.

Altogether this new course concept requires a higher degree of self-dependence and teamwork abilities and supports methodic working abilities by applying typical scientific methods. The direct transfer of knowledge as well as related methods and tools from the lecture provides the students with a better understanding of the theoretical and methodological aspects and leads to a better learning success.

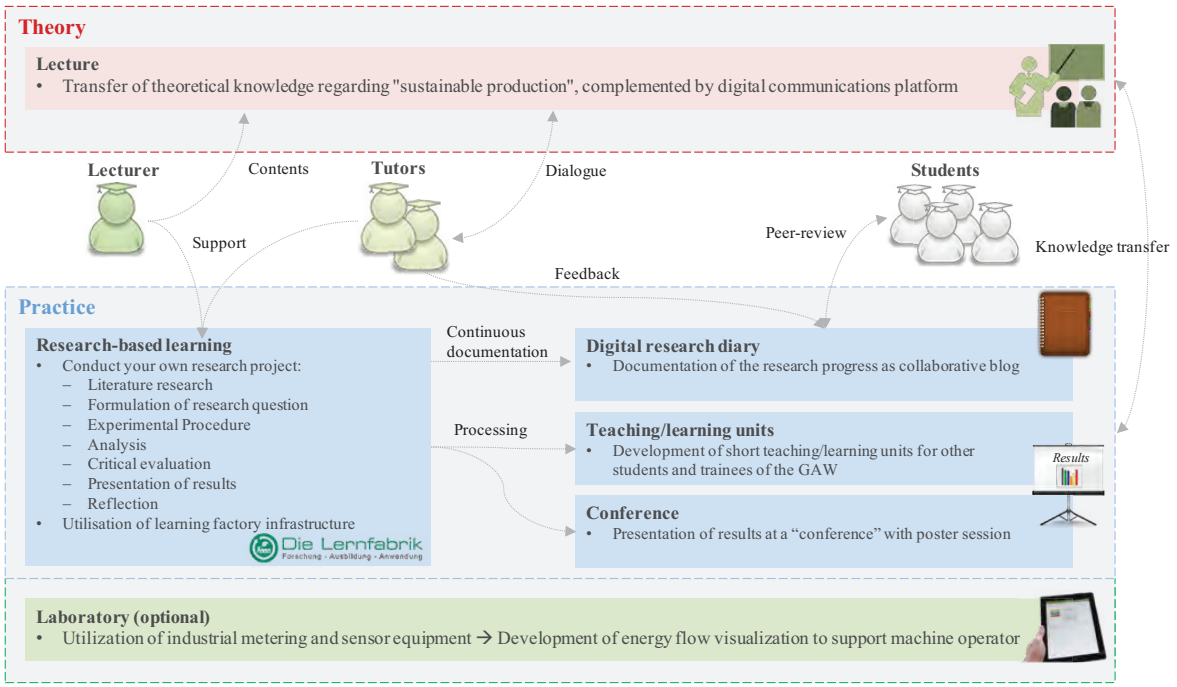

Fig. 3 Structure of the course Energy Efficiency in Production Engineering

One major advantage compared to the initial situation is the increased motivation of the students, who can now work on self-chosen topics of their own interest and are taken as serious researchers. The experiences from the first implementation in summer 2014 are positive, particularly the students feedback was very encouraging. Underlining the benefits of the research-based learning approach, also the examination results improved remarkably compared with the last semesters due to a higher ability of transferring the gained knowledge to new situations.

Fig. 4 Research cycle used as orientation for research-based learning within the course, adapted from [24]

4. Conclusion and Outlook

Based on the experiences made with the lecture “Energy Efficiency in Production Engineering”, research-based learning using the infrastructure of a learning factory can be fully recommended for engineering education. A higher student motivation as well as improved learning results could be stated while personal and social skills of the participants could certainly be developed, although a measurement of this aspect could not be carried out. A learning factory like Die Lernfabrik does not only connect research and education in a merely conceptual way, but in a strongly practical sense. By providing the students with state of the art and ready-to-use research equipment it is an important source and inspiration for the students own research projects. However, it also provides the necessary infrastructure for carrying out the practical elements of research-based learning. In the combination of action-oriented learning methods and corresponding learning environments engineering education will be able to meet the challenges in teaching provided by demanding fields like sustainable production or life cycle engineering.

In future terms the course will focus on an implementation of a more extensive peer-review of the students research projects. This will allow the students to give and receive a profound feedback as it is part of the common procedure of scientific work and further develops their social skills. Additionally, it is intended to combine university education with professional training in order to foster mutual exchange between future engineers and skilled workers. The students will design the learning paths which are implemented in the education lab. Thus, the research results enrich the more practice-oriented professional training. On the other hand the students could profit by the enhanced learning experience as they impart their gained knowledge and competencies.

Acknowledgements

The presented work was developed within the research project *Forschendes Lernen in der Lernfabrik.* This project was funded by the TU Braunschweig innovation programme *Gute Lehre* within the project *teach4TU* of the German Federal Ministry of Education and Research (BMBF) under grant number 01PL12043. Responsibility for the contents of this publication rests with the authors.

References

[1] Schenk M, Wirth S, Müller E. Fabrikplanung und Fabrikbetrieb. Methoden für die wandlungsfähige, vernetzte und ressourceneffiziente Fabrik. 2nd ed. Berlin: Springer; 2014.
[2] Wiendahl HP, Reichardt J, Nyhuis P. Handbuch Fabrikplanung. Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten. München: Hanser; 2009.
[3] Bundesministerium für Bildung und Forschung. Die neue Hightech-Strategie. Innovationen für Deutschland; 2014 [cited 2015 Jan 12]. Available from: http://www.bmbf.de/pub_hts/HTS_Broschure_Web.pdf
[4] European Parliament and of the Council of the European Union: Establishing Horizon 2020 - The Framework Programme for Research and Innovation. Regulation (EU) No 1291/2013/EC; 2013 [cited 2015 Jan 12]. Available from: http://inea.ec.europa.eu/download/legal_framework/regulation_12912013_establishing_h2020.pdf
[5] Herrmann C, Thiede S, Bogdanski G. Energie- und Ressourceneffizienz lernen. HOB Die Holzbearbeitung 2012; 59 (4):43-45.
[6] Nonaka I, Takeuchi H. The knowledge-creating company. How Japanese companies create the dynamics of innovation. New York: Oxford Univ. Press; 1995.
[7] Crookall D, Thorngate W. Acting, Knowing, Learning, Simulating, Gaming. Simulation Gaming 2009;40:8–26.
[8] Reiner D. Methode der kompetenzorientierten Transformation zum nachhaltig schlanken Produktionssystem. Aachen: Shaker; 2009.
[9] Jaeger A, Mayrhofer W, Kuhlang P, Matyas K, Sihn W. Total Immersion: Hands and Heads-On Training in a Learning Factory for Comprehensive Industrial Engineering Education. The International Journal of Engineering Education 2013;29:23–32.
[10] Cachay J, Wennemer J, Abele E, Tenberg R. Study on Action-Oriented Learning with a Learning Factory Approach. Procedia - Social and Behavioral Sciences 2012;55:1144–53.
[11] Tisch M, Hertle C, Cachay J, Abele E, Metternich J, Tenberg R. A Systematic Approach on Developing Action-oriented, Competency-based Learning Factories. Procedia CIRP 2013;7:580–5.
[12] Ahlbrecht R. Komplexität im Unternehmensplanspiel: ein integrierter, systemtheoretischer und kognitionstheoretischer Ansatz unter Bezugnahme auf den Gegenstand Unternehmensgründung; 2002 [cited 2015 Jan 12]. Available from: http://ediss.uni-goettingen.de/bitstream/handle/11858/00-1735-0000-0006-AFD5-2/ahlbrecht.pdf?sequence=1 [Dissertation]
[13] Fischer H. Ein systemorientierter Ansatz zur Modularisierung von Planspielen mit dem Ziel der Komplexitätssteuerung und Integration in Standardsoftware; 2006 [cited 2015 Jan 12]. Available from: https://ediss.uni-goettingen.de/bitstream/handle/11858/00-1735-0000-0006-AEEA-7/fischer.pdf?sequence=1 [Dissertation]

[14] Elton L. Scholarship and the research and teaching nexus. In: Barnett R, editor. Reshaping the university: new relationships between research, scholarship and teaching. Maidenhead: McGraw-Hill/Open University Press; 2005. p. 108–118.
[15] Humboldt W. Über die innere und äußere Organisation der höheren wissenschaftlichen Anstalten in Berlin. In: Weinstock H, editor. Frankfurt: Fischer Bücherei; 1957. p. 229-241.
[16] Euler D. Forschendes Lernen. In: Spoun S, Wunderlich W, editors. Studienziel Persönlichkeit. Beiträge zum Bildungsauftrag der Universität heute. Frankfurt, New York: Campus; 2005. p. 253–272.
[17] Huber L. Warum Forschendes Lernen nötig und möglich ist. In: Huber L, Hellmer J, Schneider F, editors. Forschendes Lernen im Studium. Bielefeld: Universitätsverlag Webler; 2009. p. 9-35.
[18] Reiber K. Forschendes Lernen als Leitprinzip zeitgemäßer Hochschulbildung. Tübinger Beiträge zur Hochschuldidaktik 2007; 1(3): 6-12.
[19] Healey M. Linking research and teaching exploring disciplinary spaces and the role of inquiry-based learning. In: Barnett R, editor. Reshaping the university: new relationships between research, scholarship and teaching. Maidenhead: McGraw-Hill/Open University Press; 2005. p. 30–42.
[20] Healey M, Jenkins A. Developing undergraduate research and inquiry. York: Higher Education Academy; 2009.
[21] Herrmann C, Bogdanski G, Winter M, Heinemann T, Thiede S, Zein A. Sustainability in Production Engineering - Holistic Thinking in Education. In: Seliger G, Khraisheh MMK, Jawahir IS, editors. Advances in Sustainable Manufacturing. Berlin, Heidelberg: Springer; 2011. p. 25-30.
[22] Ashford NA. Major Challenges to Engineering Education for Sustainable Development. International Journal of Sustainability in Higher Education 2004; 5(3):239-250.
[23] Herrmann C, Thiede S. Process chain simulation to foster energy efficiency in manufacturing. CIRP Journal of Manufacturing Science and Technology 2009; 1(4):221-229.
[24] Creswell JW. Educational research: planning, conducting and evaluating quantitative and qualitative research. 3rd ed. Upper Saddle River: Pearson Education; 2008.