Lessons Learned 6, 1 (2026)
Submitted: August 7, 2025
Accepted: December 31, 2025

DOI: https://doi.org/10.25369/ll.v6i1.101
ISSN: 2749-1307

Learning by Brewing: An Innovative Teaching/Learning Concept for Automation Technology

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Abstract

The Learning by Brewing teaching/learning concept combines theoretical training in automation technology with practical application on an experimental brewing system. Through close integration of lectures and laboratory work, students not only acquire technical skills in process control technology, sensor technology, and actuator technology, but also develop their social skills through small group work. A central element is the development, implementation, and validation of a complete automation system. The optional BRAUtomation course also allows for creative, competition-based in-depth study. The concept promotes interdisciplinary thinking, motivates through its high practical relevance, and aims to increase the attractiveness of the automation technology major.

Das Lehr-/Lernkonzept Learning by Brewing verknüpft die theoretische Ausbildung in der Automatisierungstechnik mit praxisnaher Anwendung an einer experimentellen Brauanlage. Durch eine enge Verzahnung von Vorlesung und Labor erwerben Studierende nicht nur technische Kompetenzen in Prozessleittechnik, Sensorik und Aktorik, sondern entwickeln auch ihre sozialen Kompetenzen durch Kleingruppenarbeit weiter. Ein zentrales Element ist die Entwicklung, Umsetzung und Validierung eines vollständigen Automatisierungssystems. Die optionale Veranstaltung BRAUtomation erlaubt zudem eine kreative, wettbewerbsbasierte Vertiefung. Das Konzept fördert interdisziplinäres Denken, motiviert durch hohe Praxisnähe und soll zur Steigerung der Attraktivität des Studienschwerpunkts Automatisierungstechnik beitragen.

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This article was originally submitted in German.

1. Introduction

The engineering profession plays a central role in technical and social progress, especially with regard to digitalization, climate change, and demographic changes [1]. Nevertheless, the shortage of skilled workers is growing, while at the same time the number of students in engineering subjects is declining [2]. This development particularly affects electrical engineering and information technology and increases the pressure on universities to take action. It is therefore necessary to create training programs that are practical and geared to the requirements of industry [3][4]. The decline in student numbers also increases the challenge of making engineering study programs more attractive and compatible with further education [5].

In the sixth semester of the bachelor's degree program in electrical engineering and information technology at Karlsruhe University of Applied Sciences, students specializing in automation technology learn the graphical and mathematical modeling of technical processes and their implementation in programming. In the accompanying laboratory, they apply key process automation methods in practice. The spectrum ranges from modeling, scaling, and filtering to control and regulation functions in industrial plant models.

In addition, a comprehensive, practice-oriented experiment on a brewing plant in small groups was introduced in the 2024/25 winter semester. The realistic project work not only promotes technical skills, but also teamwork, self-management, interdisciplinary thinking, and creative problem solving [6]. The close cooperation between students and teachers creates a dynamic learning environment and strengthens essential social and communication skills that are indispensable for a holistic engineering education. Such project-based learning scenarios, in which technical processes are simulated using real objects from industry, represent best practice in engineering education [7]. They enable students to directly apply what they have learned in theory and form a bridge between university knowledge and industrial practice.

By consistently focusing teaching on practical relevance and real industrial applications, the sixth semester also makes an important contribution to increasing the attractiveness of the degree program: Students are specifically trained in an environment that addresses current challenges such as digitalization, process automation, and sustainable energy supply. At the same time, such practical formats support the development of skills in areas that are increasingly in demand by companies and offer students the best conditions for a successful transition into professional life. Last but not least, innovative learning concepts such as the project described also serve to attract new target groups to the program and counteract the decline in engineering subjects [8].

This article presents the Learning by Brewing concept as a way of increasing the appeal of automation technology. Through direct application in the form of a laboratory experiment on an experimental brewing system, automation becomes tangible and motivating for students. The aim is to teach skills in a practical way, which makes an important contribution to attracting young talent to the technical field. Initial findings indicate that the targeted combination of industrial relevance and student-centered learning methods is an effective way to address current challenges such as the shortage of skilled workers and declining student numbers, while at the same time ensuring high-quality, future-oriented engineering education (see Section 5: Experience & Evaluation).

2. Content and structure of the combination of lecture and laboratory

The work is carried out as part of the Automation Technology lecture and serves to deepen theoretical knowledge through practical applications at a slightly different pace. The lecture notes use a brewing plant (see Figure 1) as a continuous example to illustrate the principles of automation technology. In addition, provides a practical introduction to the topic by giving students their first contact with the laboratory and the brewing plant in the second lecture unit.

In **phase 1** of the lecture, the theory behind basic and process flow diagrams as well as piping and instrumentation diagrams (P&IDs) is taught (see Figure 2) [9]. These diagrams are essential in plant and process engineering, as they show all relevant equipment, machines, flow lines, fittings, and measurement, control, and regulation tasks.

Fig. 1 : Experimental brewing plant with pneumatically controlled valves, ultrasonic sensors for level measurement, and PLC control; touchscreen not shown.

The P&I diagram is based on the process flow diagram and is supplemented by the integration of process control technology, giving it the highest information content among the technical flow diagrams. Both the basic and process flow diagrams of a typical brewery are used as more complex examples of these types of diagrams.

Following the theoretical introduction, **phase 2** begins, in which the knowledge learned is directly applied. This practical phase takes place immediately in the next lecture. The students are divided into two groups: one group works with the brewing equipment, while the other group examines a shampoo production facility. Halfway through the lecture, the groups switch places. Both test stations require intensive examination of the technical details of the respective equipment. The developed P&ID flow diagrams must comply with current standards.

The brewing system itself is a complex system that encompasses the various process steps of beer brewing, such as mashing, lautering, and wort boiling. For a detailed description of the brewing process, please refer to Palmer [10] and, for those with a keen academic curiosity and background in biochemistry, Narziß et al. [11]. The experimental brewing system is equipped with modern sensors and actuators and was developed and built as part of student project work. The system consists of a combination of components from the hobby brewing sector and automation technology, which correspond to the current state of the art. 's brewing system has a total of nine controllable valves, two pumps, two heating elements, four temperature sensors, a combined flow and original wort sensor, and two ultrasonic level sensors.

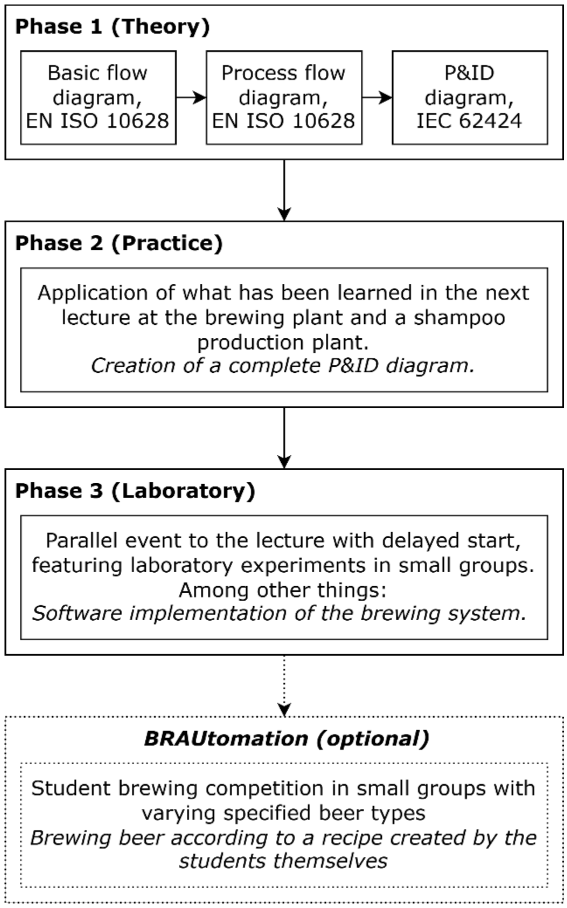

Fig. 2 : Early insights into the automation laboratory: Phase 1 teaches theory (2nd unit), Phase 2 applies it in practice (3rd unit), Phase 3 starts in parallel with the lecture. In BRAUtomation, the optional application of the developed systems takes place within the framework of a competition.

All components are connected to a programmable logic controller, which enables the brewing system to be programmed. The R&I flow chart plays a central role here as a user interface, as it clearly displays all components and their interactions and enables operation. In addition to simple actions such as switching the pumps on and off or opening and closing

the valves, temperature control for all three pots of the brewing system has been implemented. Furthermore, a fully automatic mode has been implemented, which efficiently controls the temperature and flow of a brewing process according to a specified recipe.
The combination of theoretical knowledge and practical application strengthens the students' professional skills through an almost real-life commissioning process. They not only learn about technical planning and implementation, but also how to use production systems such as the brewing system. This promotes a deeper understanding of the requirements of modern automated systems and optimally prepares them for future challenges in this field.

In the subsequent laboratory (**phase 3**), which further deepens the content of the lecture on automation technology in a practical way, the students work in small groups on various experiments covering different aspects of automation. One of the experiments is the software implementation of the brewing system, in which a small group of students puts the theoretical basics they have learned into practice.
This experiment comprises several tasks, including the control of pneumatic valves and precise temperature control with heating rods. To ensure complete automation of the system, pumps and sensors for level and flow must also be integrated and programmed.

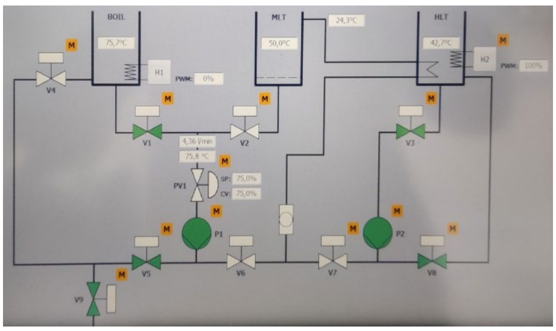

Fig. 3 : Resulting graphical interface of the laboratory experiment with functional control of the brewing system elements and display of sensor values.

Another component of the experiment is the development of a graphical user interface (see Figure 3) as a human-machine interface (HMI). This interface serves to enable operators to intuitively control and monitor the brewing system. The HMI visualizes important process parameters such as temperature, fill level, and flow rate and allows manual intervention in the process sequence, for example, starting or stopping pumps or changing setpoints.
In summary, students not only learn how to use modern automation technology, but also the importance of a user-friendly interface for the efficient operation of complex systems.

3. BRAUtomation

In addition to the automation technology courses, an optional student brewing competition, BRAUtomation, takes place every semester. Up to ten small groups of students compete against each other. At the beginning of the semester, a type of beer to be brewed is specified and tried-and-tested sample recipes are provided. To participate in the competition, students are provided with the basic ingredients (malt, hops, and yeast) according to the sample recipes. However, they can also create their own recipes based on these. The participating groups then implement the selected recipes on the experimental brewing equipment at under expert guidance. Finally, a team of experts from local breweries will evaluate the beers, which will determine the award winners. They will taste the brewed beers and evaluate them based on defined criteria (e.g., style conformity, aroma, mouthfeel) [12].
The award ceremony takes place during a closing event in cooperation with industry partners. Alcohol-related aspects of the competition and, in particular, the closing event are voluntary and take place in a closed university setting.
The overarching goal of BRAUtomation is, on the one hand, to test the automation solution for the brewing system, which may have been developed in the laboratory, in practice. On the other hand, students from lower semesters also take part, who gain an initial insight into possible fields of application for automation technology through the competition and can take these impressions into account when choosing their specialization in the third semester.

4. Didactic concept

The combination of lectures and laboratory work described above represents an innovative and practical teaching and learning concept based on the idea of research-based and experience-based learning. This concept pursues a learning environment in which students actively build up knowledge acquired through their own research and practice, which illustrates the approach of research-based learning [13]. This is particularly important in engineering education, as technical competence today must be linked more than ever to the ability to independently analyze new challenges and develop practice-oriented solutions.

The didactic concept is methodically aligned with the principle of constructive alignment, which provides for the coherent coordination of learning objectives, teaching and learning activities, and examination formats [16]. Phase 1 provides a thorough introduction to technical flowcharts, in particular piping and instrumentation flowcharts, which are applied in a practical laboratory exercise in Phase 2 in the lecture immediately following. This gives students an early insight into the automation laboratory. This promotes a direct practical relevance. In addition, the distance between theory and practice is shortened and typical learning barriers that can arise from abstract knowledge content are prevented.

The close temporal relationship between theoretical input and practical implementation in the individual phases supports sustainable learning, as students can immediately test and reflect on new content. This not only strengthens their understanding of the content, but also promotes self-directed and cooperative learning skills. The direct link between theoretical knowledge transfer and practical application is thus a central didactic element of the concept.

The use of the university's own brewing facility serves as a continuous application example and a so-called best practice model for the exemplary deepening of complex content in automation technology [15]. The choice of a practice-relevant and sustainability-related product such as beer brewing offers a motivating and tangible context. In this context, not only technical processes but also process understanding and quality management are taught in a real-life scenario. The clear connection between theory and practice increases student motivation and highlights the visibility and social relevance of automation technologies in everyday life.

The subject-specific knowledge previously acquired using the consistent example of the brewing plant is applied in phase 3, or the actual laboratory. The goal of a holistic engineering education is taken into account here. In this phase, the aim is not only to acquire technical skills in the areas of sensor technology, actuator technology, and process control technology, but also to develop social, communicative, and society-related skills through targeted group work. An essential component of this is the group work scenario.

Students work in teams to solve complex problems, which promotes their ability to cooperate across disciplines, exchange different points of view, and solve problems together. This simulates real engineering projects in which teamwork, communication, and coordination skills are indispensable. In addition, social and ethical issues are reflected upon in order to enable engineers to develop technology responsibly and with an eye to its social impact [14]. The promotion of such "soft skills" is particularly essential in view of the increasingly interdisciplinary and team-oriented working environment in technical professions. The concept addresses this by combining classic technical content with the promotion of teamwork, communication, and critical thinking [14].

In order to promote interdisciplinary and systemic thinking, principles and content from other disciplines are also integrated. For example, aspects of the development of user-friendly graphical user interfaces (HMI) are covered. These take into account ergonomic design criteria and aspects of inclusion. This trains sensitivity for user-centered technology development. At the same time, the chemical and process engineering fundamentals of beer brewing are incorporated, giving students an in-depth understanding of the process. Social science reflections, in which the societal implications of technical developments are critically examined, round off the concept. This integrative approach trains students' ability to place technical issues in the broader context of social and ecological responsibility and to develop sustainable solutions.

The didactic innovation of the teaching-learning concept consists in the complete automation of a real process system: in contrast to simulations or partial experiments, students go through the entire development cycle from control programming to measurable product quality. This holistic view of the system distinguishes the approach from conventional laboratory experiments, which are usually limited to proving the function of individual components and are mostly found in university teaching. Students participating in the optional wedding competition also have the opportunity to experience what they have learned or, if applicable, developed themselves, not only from a developer's perspective, but also from a user's perspective.

In summary, the didactic concept makes an important contribution to competence development in engineering education through its combination of project-based learning, realistic applications, and research-oriented teaching. It is geared toward the requirements of modern university teaching, which is characterized by digitalization, sustainability, and interdisciplinarity. This is in line with current educational policy guidelines and recommendations, which call for practical, action-oriented, and reflective training of engineers in order to equip them as best as possible for the challenges of the future [14].

5. Previous experience & evaluation

The implementation of the experimental brewing plant as a central element in the automation technology lecture laboratory represents an innovative teaching and learning concept that has been widely accepted and met with great interest by students and teachers alike. The system enables the practical teaching of theoretical content by embedding it in a realistic technical context. In particular, the close integration of lectures and laboratory work is perceived as conducive to understanding complex interrelationships in automation technology. Since the summer semester of 2025, BRAUtomation has been evaluated using an online questionnaire. In addition to open-ended questions about the students' study situation, the questionnaire includes closed items on a four-point Likert scale (yes, rather yes, rather no, no), such as:

1. I feel confident in dealing with piping and instrumentation diagrams.
2. I can operate an industrial plant independently via an HMI.
3. I can correctly interpret pump circuits based on plans.
4. The competition has increased my interest in automation technology.

A participant in the electrical engineering program emphasizes the practical added value of the plant:

> *"The brewing plant showed me for the first time how industrial plants are structured in practice. The practical experience was particularly valuable."*

The feedback from previous rounds of the BRAUtomation competition has been consistently positive. In the summer semester of 2025, 26 of the 35 participants took part in the accompanying survey, which was conducted for the first time. About half of these students had already participated in the event several times. Of those surveyed, 80% said that participation had significantly increased their interest in automation technology. A student in the mechanical engineering program sums up this development aptly:

> *"Working on the brewing system as part of BRAUtomation made me realize how exciting the topic of automation technology is for me."*

In addition to increased interest, a significant gain in knowledge was also observed. For example, 65% of students reported feeling capable of operating industrial plants independently via an HMI after the event. In addition, 77% said they were confident in their ability to interpret pump circuits using circuit diagrams, and 58% felt confident in their ability to use piping and instrumentation diagrams.

BRAUtomation is not exclusively aimed at students specializing in automation technology, but is also very popular with students of related subjects such as (media) computer science and other engineering disciplines, as well as employees of Karlsruhe University of Applied Sciences (HKA). In addition, the concept has been positively received by potential employers, including Siemens. Numerous bachelor's theses and project papers address individual aspects of technical implementation and didactic innovations, such as the use of augmented reality, and explore them in depth.

6. Summary & Outlook

Automation technology plays a prominent role within the Faculty of Electrical Engineering and Information Technology: with an average share of 35% to 50% of students, and a total of five specializations offered, automation technology regularly represents the largest student group. The new teaching/learning concept based on the automated brewing system makes a targeted contribution to the qualitative development of this central area of study at the HKA. As an innovative and practical example of best practice in modern engineering education, the brewing system demonstrates how technical content can be conveyed in a clear and motivating way. The experimental brewing system has the potential to increase the attractiveness of the automation technology specialization in the long term and to serve as a model for future teaching formats. Furthermore, there are plans to use empirical research to investigate questions relating to increasing the attractiveness of automation technology and analyzing teaching and learning processes.

Acknowledgements

This work was developed as part of the KIIWI project (reference number: 16DHBKI060) funded by the German Federal Ministry of Research, Technology, and Space (BMFTR). Special thanks go to the sponsors of the brewing system, Bürkert and Siemens AG.

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