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RESEARCH ARTICLE

Teaching technology assessment in a learning factory environment: An educational match?

Heike Eder*,[1], Christian Ramsauer[1], Kai Rüdele[1], Verena Schnaitter[1]

Abstract · Technology assessment (TA) is taught in higher education through various formats. Beyond traditional lectures, alternative teaching and learning approaches are increasingly being discussed and tested. Against this background, the article investigates the suitability of learning factories (LFs) for TA training. A half-day teaching module was designed for an existing LF, combining flipped classroom methods with hands-on exercises to introduce students to key aspects of technology assessment. Initial results paint a mixed picture: While students appreciated the practical group work enabled by the LF setting, opinions varied regarding its added value.

Technikfolgenabschätzung in der Lernfabrik: Eine gute Kombination?

Zusammenfassung · *Technikfolgenabschätzung (TA) wird an Hochschulen in verschiedenen Formaten vermittelt. Als Ergänzung zum klassischen Frontalunterricht werden zunehmend auch alternative Lehr- und Lernformate diskutiert und erprobt. Vor diesem Hintergrund untersucht der Artikel die Eignung von Lernfabriken (LF) für den praxisnahen TA-Unterricht. Für eine bestehende LF wurde ein halbtägiges Unterrichtsmodul entwickelt, das den Flipped-Classroom-Ansatz mit praktischen Übungen kombiniert. Ziel ist es, Studierenden zentrale Aspekte der Technikfolgenabschätzung näherzubringen. Erste Ergebnisse zeigen ein ambivalentes Bild: Während die Teilnehmenden die durch die LF-Umgebung ermöglichte praktische Gruppenarbeit schätzten, gingen die Meinungen hinsichtlich des Mehrwerts auseinander.*

Keywords · *engineering education, experiential learning, VDI 3780*

Contemporary trends in technology assessment teaching

The advancement of existing technologies and the emergence of new ones necessitate that (future) engineers are able to evaluate the associated opportunities and risks. Thus, technology assessment (TA)[1] which historically emerged outside the university sector (mainly in parliamentary and extra-university research contexts) has in recent years entered higher education curricula with increasing intensity (Grunwald 2022).

The integration of TA into university courses raises the question of which teaching formats are effective for building the most relevant competencies. Answering this issue is not straightforward, since TA requires not just critical reflection on technological advancements but also interdisciplinary cooperation, along with the capacity to integrate ethical, societal, and sustainability considerations into decision-making. This blend of theoretical knowledge, methodological competency, and soft skills is hardly to convey through traditional lecture-based teaching.

This research article investigates the potential of learning factory (LF) environments for teaching TA. First, selected teaching practices and traditions reported in literature are reviewed. The next section introduces the concept of LFs and their relevance within engineering education. In what follows, the article presents a dedicated TA training module, including its design and implementation. With the presented and discussed feedback of the module's pilot implementation, this research article provides key insights and outlines avenues for future research.

Approaches of teaching technology assessment

TA typically is taught only as part of courses or elective subjects rather than as an independent discipline especially in technical education. Here, TA is understood as a systematic process for evaluating technological impacts across societal, ethical, envi-

* *Corresponding author: heike.eder@tugraz.at*
[1] *Institute of Innovation, Industrial Management, Graz University of Technology, Graz, AT*

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1 Mentionings of the discipline of technology assessment are referred to in the abbreviated form "TA", mentionings of concrete assessments of a specific technology are referred to as "technology assessment.".

ronmental, and economic dimensions. This study adopts a pragmatic, practice-oriented perspective tailored to engineering education.

A web-scraping study by Jerchel et al. (2022) shows that at technically oriented state universities in the DACH region, TA is embedded only selectively and in isolated cases, with largely missing systematic integration into research and teaching. Within existing courses that cover TA, teaching formats range from lectures, seminars and method-based case studies to simulations and integrative and transdisciplinary teaching research projects. Their common goal is the teaching of skills in dealing with complex, uncertain, and ambivalent technological consequences that go beyond purely disciplinary perspectives.

The aim is to actually implement newly acquired knowledge and immediately experience the impact of the learned methods.

Beecroft and Schmidt (2012), for instance, describe the application of scenario methods for teaching TA in a course at Darmstadt University of Applied Sciences, where theoretical input was combined with group work, homework assignments, student presentations, and discussions, offering a multifaceted learning experience. Beyond such scenario-based approaches, simulation and role-play formats have also been applied in TA education: Theatrical technology assessment (TTA) combines constructive TA with improvisational theatre and role-play simulations, enabling students to explore socio-technical dynamics and diverse stakeholder perspectives. Pilot studies at the University of Twente indicate that TTA fosters critical reflection, anticipation, and competence in dealing with complex challenges, although careful consideration of timing, teaching materials, and interdisciplinary integration is required (Visscher 2020). Similar approaches have been implemented at TU Darmstadt (Dusseldorp 2012) and at the University of Hamburg (Beusmann and Kollek 2012).

While all of the approaches mentioned above can be implemented within conventional classrooms, some educational approaches may benefit from additional equipment or even require special facilities in order to unfold further potential for teaching TA. A more recent innovation in this regard is the use of immersive technologies such as virtual and augmented reality (VR/AR): By combining simulative and interactive properties, VR/AR applications have shown potential in the context of Education for Sustainable Development (ESD). Expert evaluations suggest that the use of these technologies can enhance knowledge transfer, deepen the understanding of action, and promote student participation and decision-making (Ebinger et al. 2022).

Across the approaches discussed above, student feedback, if covered in the according sources was positive. At the same time, the identified challenges point to important conditions for success: Teaching methods and content need to be adapted to the specific context, and discussion-based formats require active participation and the willingness to engage with perspectives that may differ from one's own. Opportunities to further anchor and expand TA in higher education lie in long-term cooperation with civil society actors and TA research institutions, with doctoral students acting as potential multipliers. In this context, real-world laboratories are increasingly discussed as practice-oriented environments for learning and research (Jerchel et al. 2022).

The topic of TA teaching in higher education has also been addressed in a dedicated TATuP Special topic titled 'Technology assessment and higher education: Theories, applications and concepts' (Hemminger and Eimler 2022), which provides an important background for this study. Building on these discussions, and acknowledging the plurality of TA approaches and methods, this research article focuses on the implementation of one concrete and operationalizable TA approach in a learning factory environment.

Exploring technology assessment education in a realistic learning environment

The role of learning factories in engineering education

A LF is a learning environment imitating processes and technologies of an industrial site used for education, training, and research. It can be classified as a real-world laboratory for manufacturing or production. The associated didactical concept usually focuses on experimental and problem-based learning (Abele et al. 2015). The continuous improvement philosophy is facilitated by learners' own (inter)actions and interactive involvement (IALF n.d.). As production-related workflows are often focus of LF trainings, engineers and process planners frequently constitute the target audience (Tisch et al. 2016); however, they can also be beneficial for other groups and roles such as managers.

Zancul et al. (2020) and Durão et al. (2024) claim that LFs are able to support TAs, but do not indicate a related training program. Further references to TAs in relevant literature about LFs (Abele et al. 2019, 2024) could not be identified by the authors, which implies that there are likely no explicit training courses available on this subject.

While LFs are discussed as suitable environments for supporting technology assessment, explicit TA training formats in learning factory settings have so far not been reported. This gap motivates the integration of TA into a LF course and the development of the training module presented in this article.

Fig. 1 The LEAD Factory in (training) operation (a); Exploded view of the scooter (b). *Source: Institute of Innovation and Industrial Management*

LEAD Factory's training module on technology assessment

The LEAD Factory ('lean management, energy efficiency, agile operations, and digitalization') is a LF operated by the Graz University of Technology. It is a small-scale real-life training manufacturing site that offers easy access to hands-on training experience in realistic production scenarios (Ramsauer et al. 2024a, 2024b). Its mission is to create a knowledge hub that encourages the exchange of ideas and promotes the adoption of new technologies and processes. Several sequential workstations replicate value-creating activities (Fig. 1a) enabling learners to develop technical, organizational, and problem-solving competencies relevant to state-of-the-art production. Additionally, the LEAD Factory serves as a technology demonstrator as well as a collaborative platform where students, researchers, and company partners can work together. Its flexible setup allows participants to analyze, optimize, and apply solutions directly on-site. Due to the LF's laboratory nature, interventions in the setting can be made without any risk, unlike in an actual factory or production line.

Although small-scale and simplified in certain aspects, the LEAD Factory allows students and professionals to tackle real-world industrial challenges, primarily concerning (the assembly of) a physical product (a scooter, Fig. 1b).

Originating as a lean production training site, it has evolved to address other trending subjects in the field of industrial engineering, such as ergonomics (Wolf et al. 2019), digitalization (Hulla et al. 2022), energy efficiency (Ketenci et al. 2022), and carbon accounting (Wolf et al. 2023; Rüdele and Wolf 2024).

In general, all of the LEAD Factory's training modules adhere to the same didactical concept: After short theoretical sessions covering the fundamentals of a specific concept, participants directly return to the LEAD Factory and apply what they have learned. The aim is to actually implement newly acquired knowledge and immediately experience the impact of the learned methods. Based on the principle of learning by doing, learners gain new and lasting skills and can easily transfer these capabilities to similar situations.

The Faculty of Mechanical Engineering at TU Graz does not offer a dedicated course on TA, despite its importance for prospective engineers dealing with emerging technological developments. To address this gap and to sensitize and educate students about TA, a dedicated half-day training module on TA using the LEAD Factory was developed.

To operationalize TA for educational purposes, the training module follows the structured phases defined in VDI 3780: problem definition and structuring, impact analysis, evaluation, and decision-making (VDI 2000). This framework provides a clear methodological sequence that enables students to actively apply TA concepts within a limited time frame.

The intended learning outcomes for which the module was designed are that, after completing the module, students will be able to explain and discuss core concepts of TA, including:

- what constitutes a technology assessment,
- the purpose and objectives of TA,
- the distinction between TA and value analysis, and
- the role of values in the context of TA.

In addition, one objective of the module, which reflects the characteristics of the LF, is for students to apply TA by working through all phases of a technology assessment, analyzing and evaluating impacts, and developing and communicating their own recommendations for action.

The module was initially conducted in March 2025 as part of a four-day course with 16 students, mostly enrolled in mechanical engineering study programs at the master's level. Given the already mentioned absence of a dedicated TA course prior knowledge on the topic among participants can largely be ruled out. Furthermore, students were not informed in advance (nor

in the course description) that TA would be part of the class, to avoid any kind of self-selection.

The primary document for the syllabus, as with other university courses in German-speaking countries (Gottschick and Schäfers 2012, p. 142; Kattwinkel et al. 2021, p. 2864), is the VDI 3780 (VDI 2000). Moreover, the first part of the module utilizes the learning and teaching notes by Johri (2024). This educational material is appropriate both in content (covering the pros and cons of e-scooters) and in terms of the educational level. It is intended for teaching engineering disciplines and focuses on competencies such as critical thinking and self-awareness within the context of sustainability. Additionally, this toolkit was marked by its up-to-date nature at the time the first course was held.

At the beginning of the training module, the flipped classroom approach was utilized. So, the students had to discover new content and material individually and before class; the class was dedicated to interactive activities. The day before, a homework assignment was distributed, which included the VDI 3780 as a reading assignment along with a video (PBS 2018). The students were also provided with supplementary materials (some of which are also recommended by Johri (2024)), including related press releases (Pyzyk 2019; Iannelli 2021; Stoyanov 2021; Delgado 2023) and scientific publications regarding urban mobility (Brunner et al. 2018; Aman et al. 2021; Schoklitsch 2023) or directly linked to the LEAD Factory (Auberger et al. 2019). The participants were informed that they should prepare themselves to (1) being able to explain the concept of TAs, and (2) being prepared for carrying out a TA via group work.

The in-class session on the following day began with students discussing some questions with their neighbors (e.g., "Can you confidently say that e-scooters are an environmentally friendly option?", "Would you produce e-scooters in the LEAD Factory? Why?"). The opinions and insights were then briefly summarized in a whole-class debate. This was followed by a knowledge check (e.g., regarding purpose, value, and types of TAs) lasting about fifteen minutes, also in the style of a class forum. At the end of this theoretical part, some recent research findings (Mayntz 2014; Parolin et al. 2024) as well as pitfalls and criticisms with regard to TAs were addressed.

The LEAD Factory was then employed as a reference point for the practical exercise. Participants were asked to form three groups and conduct a TA for a technology of their choice. In addition to high-level considerations (i.e., city, region/state, country, world), the LEAD Factory should also be central to the TA. The groups also had to agree on one of the previously discussed TA types (problem-induced vs. technology-induced) as well as on the objectives. Subsequently, all phases of the TA according to VDI 3780 had to be worked through and at least one of the proposed methods (e.g., scoring method) had to be applied. Finally, the groups were to explain their results in a short presentation (seven minutes maximum), where the problem is clearly defined and the technology described. A particular focus should be on the affected parties. Assumptions, methods, alternatives, and especially actionable recommendations need to be sufficiently presented.

In this specific class, the groups decided to asses:

- Different types of exoskeletons (problem-induced)
- Augmented and virtual reality (technology-induced)
- Humanoid robots (technology-induced)

In addition to the required results (i.a. each group managed to specify the seven values mentioned in VDI 3780), also further outcomes such as a cost-benefit-analysis or an implementation plan were created.

Evaluation of the training

While each group presented their results, the members of the other two groups provided anonymous feedback. The associated evaluation sheet included two text fields for comments ("What did you like? Which aspects/perspectives have you not considered before?"; "Where is the TA lacking? Missed but relevant aspects/perspectives?") along with a 5-point Likert scale to rate four specific aspects (problem definition, impact analyses/evaluation, decisions/results, and creativity).

Related empirical data is required to determine the advantages of individual didactical approaches.

In addition, the quality of the training module itself was extensively evaluated. Therefore, a two-page training experience questionnaire based on Brent and Felder (2004) was used to gather quantitative (Fig. 2) as well as qualitative feedback from the participants. The statistical analysis suggests that the used examples have room for improvement. The incorporation of the flipped classroom concept and the LEAD Factory was generally rated positively.

Students identified the introduction to TA and the hands-on group work as the most valuable parts of the module. The question regarding the suitability of a LF ("Do you think that other training formats such as lectures, role plays, games are just as good or even better suited to teaching the content of TA?") was answered inconsistently: About half of the students were satisfied with the format, while the others assume that alternative formats could be just as effective.

There were also some critical remarks. For instance, the reading assignments were perceived as too extensive and "a bit

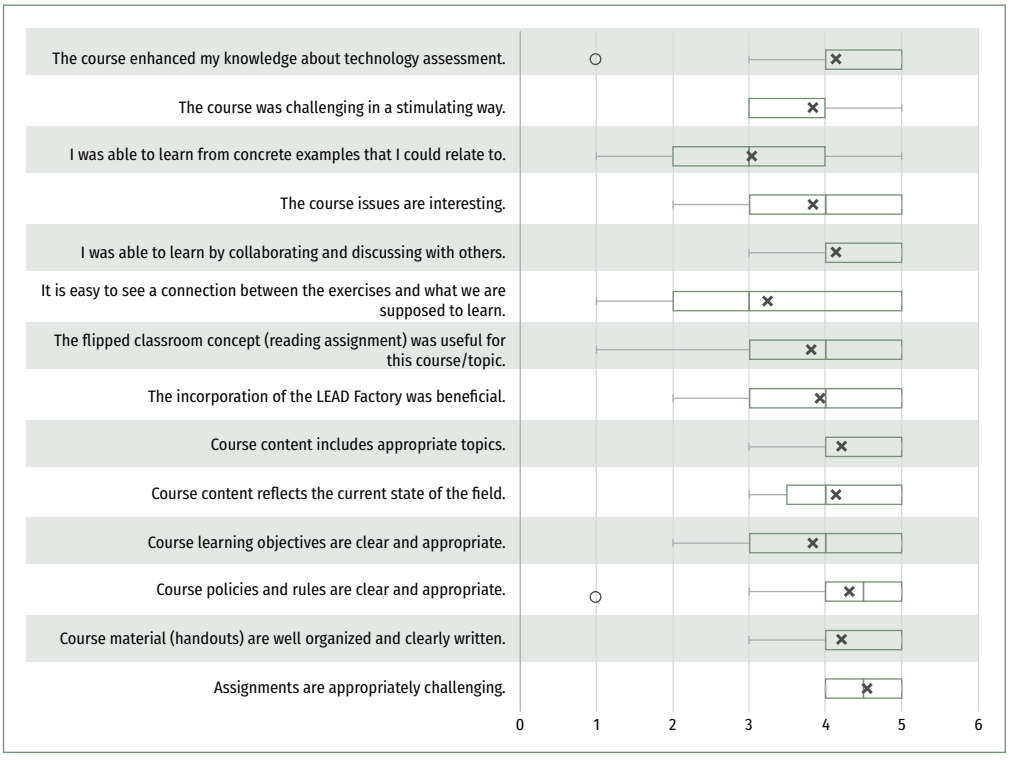

Fig. 2 Participants' (n=16) rating of the training module on a scale of 1 (strongly disagree) to 5 (strongly agree); x indicates the mean value. *Source: Institute of Innovation and Industrial Management*

tedious". A number of participants also would have preferred a more complete example of a TA ("More upfront examples", "Do a simple TA all together").

The overall course rating was 4.8 out of 5, which is similarly good as in previous years (Ramsauer et al. 2024b). On this occasion, one participant stated that the TA section should be given greater emphasis in future, while another stated that it should be omitted. In addition, two participants stated that the theoretical input on TA could be improved.

Conclusion and outlook

The presented evaluation is based on a first pilot implementation with a limited number of participants. The small group size is inherent to the learning factory setting and supports active participation but limits the statistical significance of the results. Furthermore, the study does not include a control group or direct comparison with alternative TA teaching formats. Future research will therefore focus on repeated implementations of the module.

In general, LFs as close to real production environments applied for educational and demonstration purposes effectively bridge the gap between theory and application. For many topics and subdisciplines, they have proven to be ideal to equip future engineers with practical skills. Thus, it is somewhat surprising that no clearly positive conclusion can be drawn for our new training module on technology assessments. The objective to provide students with an understanding of the complexity of technology development and different considerations that need to be made by stakeholders (Johri 2024) was certainly met. However, it cannot be definitively concluded from the feedback that LFs are superior to other teaching methods in terms of competency building.

Besides improvements and repetitions of the described module, (longitudinal) comparative studies with other formats are also needed. Related empirical data is required to determine the advantages of individual didactical approaches. Investigations regarding the transferability of our training module to other disciplines and learning factories constitute also further research directions.

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HEIKE EDER

studied Mechanical Engineering at the Graz University of Technology. She is a university assistant and PhD candidate at the Institute of Innovation and Industrial Management. Since 2025, she is responsible for the LEAD Factory.

PROF. DR. CHRISTIAN RAMSAUER

is full-professor and head of the Institute of Innovation and Industrial Management at Graz University of Technology. He initiated the LEAD Factory in 2014. Between 2021 and 2023, he was the president of the International Association of Learning Factories (IALF).

DR. KAI RÜDELE

studied Management and Technology at Technical University of Munich. He is a post-doctoral university assistant at the Institute of Innovation and Industrial Management. From 2022 to 2025, he was in charge of the LEAD Factory.

VERENA SCHNAITTER

studies Mechanical Engineering and Business Economics at Graz University of Technology. She is a student assistant at the Institute of Innovation and Industrial Management and part of the LEAD Factory team.

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