Development and modernisation of the teaching concept for PROduct Safety in University Education (PROSUmEr)

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Abstract

Designing products, such as machines, in line with safety and health requirements can contribute significantly to avoiding hazards posed by dangerous products. In this respect, higher education is required to provide future professionals with comprehensive and profound knowledge in order to prevent hazards at an early stage. For this purpose, a blended learning concept for higher education had already been implemented since 2009 on behalf of the Federal Institute for Occupational Safety and Health (BAuA) and was recently refined in terms of its content, didactics, technical aspects and licensing by the TU Dresden (TUD). The updated educational concept consists of five topics comprising a total of 14 learning modules. For each topic, a learning arrangement and a knowledge module have been implemented as central documents alongside multimedia presentation slides, exercises and examination tasks, and a web-based learning application. A flexible, target group-oriented use of the educational concept in academic teaching and learning is facilitated by the modular structure and the parallel implementation of the learning content within the classroom learning materials and the web application. Its numerous practical exercises promote practice-oriented knowledge construction, foster learning transfer and thus, provide students with an ideal preparation for their future work. The teaching and learning materials, which can also be used with mobile devices, are provided as open educational resources (OER). They can be used by members of all interested institutions and university chairs who have already been teaching in the field of product and machinery safety or would like to do so in future. This licensing model allows users to actively participate in updating and enhancing the teaching and learning materials. The educational concept is provided using a cross-university learning management system that contains document management services as well as a variety of digital communication and collaboration tools, including forums, digital learning diaries, and wikis. These tools are meant to extend the methodical applications of the educational concept. The concept has been evaluated using a comprehensive mixed-method design involving students from the immediate target group. The results of the evaluation attest to the high quality of the educational concept and indicate its manifold opportunities for being used in higher education. The specified technical and legal conditions furthermore permit secondary target groups such as vocational schools and enterprises to use and adapt the provided materials free of charge.

Keywords: Machinery safety, Product safety, Product design, Mechanical engineering, Educational concept, Higher education, Blended learning, Learning application, Open educational resources, Free license

Kurzreferat

Eine sicherheits- und gesundheitsgerechte Gestaltung von Produkten wie beispielsweise Maschinen kann maßgeblich dazu beitragen, Gefährdungen durch gefährliche Produkte zu vermeiden. Diesbezüglich ist auch die akademische Ausbildung in der Pflicht, zukünftigen Fachkräften als frühzeitige Präventionsmaßnahme den Erwerb von umfassenden und fundierten Fachkenntnissen zu ermöglichen. Zu diesem Zwecke wurde ein bereits 2009 im Auftrag der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA) umgesetztes Blended Learning-Konzept für den Einsatz in der akademischen Lehre von der Technischen Universität Dresden (TUD) unter inhaltlichen, didaktischen, technischen und lizenzrechtlichen Gesichtspunkten weiterentwickelt. Das modernisierte Lehrkonzept setzt sich aus fünf Themenkomplexen mit insgesamt 14 Lernmodulen zusammen. Zu jedem Themenkomplex wurden je ein Lernarrangement und Wissensbaustein als zentrale Dokumente sowie multimediale Präsentationsfolien, Übungs- und Prüfungsaufgaben und eine webbasierte Lernanwendung umgesetzt. Der modularisierte Aufbau sowie die inhaltlich duale Umsetzung von Präsenzlernmaterialien und Lernanwendung ermöglichen einen flexiblen, zielgruppenorientierten Einsatz des Lehrkonzeptes im Rahmen von akademischen Lehrveranstaltungen. Zahlreiche Anwendungsaufgaben begünstigen dabei eine praxisnahe Wissenskonstruktion, fördern den Lerntransfer und bereiten Studierende somit optimal auf ihre späteren beruflichen Anforderungen vor. Die auch auf mobilen Endgeräten verwendbaren Lehr- und Lernmaterialien werden allen interessierten Institutionen und Professuren, die bereits im Bereich Produkt- und Maschinensicherheit lehren bzw. zukünftig lehren möchten, als freie Bildungsressource (Open Educational Resource) zur Verfügung gestellt. Dieses Lizenzmodell ermöglicht den Anwendern, an der Aktualisierung und Weiterentwicklung der Lehr- bzw. Lernunterlagen zu partizipieren. Die Bereitstellung erfolgt über ein hochschulübergreifendes Lernmanagementsystem, welches neben einer Dokumentenverwaltung auch vielfältige digitale Kommunikations- und Kollaborationswerkzeuge, wie etwa Foren, digitale Lerntagebücher und Wikis, enthält. Diese erweitern die methodischen Einsatzmöglichkeiten des Lehrkonzeptes. Die unter Verwendung eines umfassenden Mixed-Methods-Designs mit Studierenden der unmittelbaren Zielgruppe durchgeführte Erprobung bescheinigt dem Lehrkonzept eine hohe Qualität und deutet dessen vielfältige Potentiale für die akademische Ausbildung an. Die definierten technischen und rechtlichen Rahmenbedingungen erlauben darüber hinaus auch sekundären Zielgruppen wie etwa Berufsschulen und Betrieben die freie Nutzung und Anpassung der Lehr- bzw. Lernunterlagen.

Schlagwörter: Maschinensicherheit, Produktsicherheit, Produktgestaltung, Maschinenbau, Lehrkonzept, Hochschulbildung, Blended Learning, Lernanwendung, Open Educational Resources, Freie Lizenz

1 Introduction

Hazards caused by products can be significantly reduced when products are designed in a way that ensures users' safety and health. Accordingly, product safety is of growing importance for both national and international consumers (Deutsche Gesellschaft für Qualität, 2018; TÜV SÜD, 2017). However, various studies point to a gap between users' requirements and the way these are taken into account by manufacturers, in particular with regard to machinery safety (Bentz, et al., 2017; Bentz, et al., 2018; Lange, et al., 2005; TÜV SÜD, 2017). According to experts, one of several reasons lies in the insufficient teaching of legal requirements regarding machinery safety within engineering education (Lange, et al., 2005). However, a sound knowledge of these requirements is a prerequisite for prospective product designers and constructors to apply them in their future professional practice (Neudörfer, 2016). For this reason, in 2009 the Federal Institute for Occupational Safety and Health (BAuA) commissioned the development of an academic teaching concept for the safety- and health-conscious design of products and, in particular, machines. Approximately 30 German universities are currently using the blended learning concept (Schmauder, et al., 2009). Two user surveys that have been carried out show the high relevance and didactic quality of the concept but also point to an increasing need for updating and optimising, especially with regard to its content, didactics and certain technical aspects. Within the scope of this project, the educational concept was fully revised, enhanced regarding licensing, and tested under field conditions.

2 Procedure

The project started with a preparation of the state of knowledge in work package (WP) 1. For this purpose, the results of the conducted user surveys were reviewed and specific requirements for modernisation and enhancement were derived. In parallel and based on research a learning management system (LMS) was selected to technically provide the educational concept (WP 2). The analysis and research results were used to draft a media-didactic concept (WP 3). The subsequent implementation of this concept (WP 4) included both the revision and updating of the teaching and learning materials in terms of content and didactics. Furthermore, a structure for their technical provision within the previously selected LMS was designed and implemented. Within the LMS, tools for communication and collaboration between the providers (i.e. BAuA and TUD), lecturers and students were set up (WP 5). A prototype was tested under field conditions and accompanied by a user survey (WP 6). Based on the user feedback, the concept implementation was revised and subjected to full-scale testing. WP 7 covered the preparation of documentations during the entire project period. In addition to internal and external reporting, this also included further products to support both the distribution (e.g. abstracts, user agreement, product logo and flyer) and the application of the educational concept (in the form of a comprehensive product documentation).

3 Modernisation and enhancement

3.1 Revision of subject matters

The content structure of the previous educational concept was revised and clarified. In particular, references to the rules for and regulations of product and machinery safety were updated and the methodological procedure for risk assessment was concretised. Furthermore, contents were added concerning the significance of product safety, including possible legal consequences of placing dangerous products on the market. In addition, the design approaches for risk mitigation were adapted to the current state of the art. The modernised educational concept for product safety is divided into five topics, each consisting of one or more teaching or learning modules (see **Fig. 3.1**).

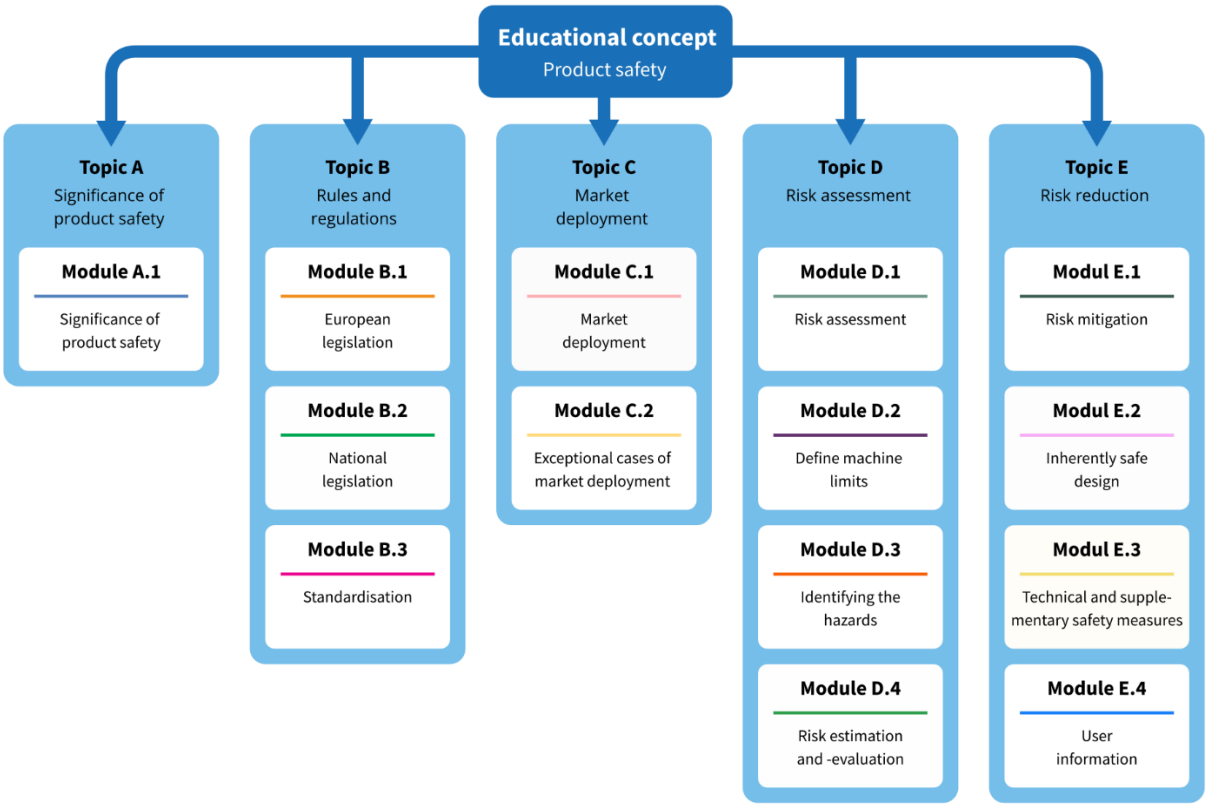

Fig. 3.1 Content structure of the educational concept for product safety (Source: TUD)

In topic A 'Significance of product safety', fundamental legal aspects of product safety are explained and possible product faults as well as resulting consequences are pointed out. Subsequently, advantages of safety-oriented product design are identified (Neudörfer, 2016). Topic B 'Rules and Regulations' provides information on the structure of European as well as national rules and regulations, such as the Machinery Directive 2006/42/EC and the German Product Safety Act, together with their specifications for product and machinery safety. In addition, an overview of standardisation is given (Sterk, 2005). The topic C 'Market deployment' describes the requirements that manufacturers must fulfil in order to place machines with conformity assessment and CE labelling on the market. In addition, special cases of placing ma-

chinery on the market are provided as examples. Topic D 'Risk assessment' describes the iterative process of risk assessment. It, for instance, explains how accidents and work-related diseases occur, how to define machine limits, how to identify hazards, and how to assess and evaluate risks. The procedure for reducing risks is described in topic complex E 'Risk mitigation'. It shows how to reduce risks using a three-step procedure involving an inherently safe design, technical and supplementary protective measures as well as user information (Schmauder, et al., 2014).

3.2 Didactic modernisation

In the context of the modernisation and enhancement of the previous educational concept, the integrated teaching and learning format (blended learning) was retained. It didactically combines conventional forms of teaching with technology-supported learning in a purposeful way (Kerres, 2018). The provided didactic modules, that is guidelines and presentation slides for lecturers as well as documents and examination assignments for students and a local learning application, were revised according to cognitivist (Butcher, 2014; Mayer, 2014; Moreno, et al., 2003) and constructivist design principles (Siebert, 2012). In addition, the teaching concept was extended by numerous exercises. The modernised educational concept consists of

- **learning arrangements** that serve as a guideline for lecturers regarding each topic and point out its learning goals and structure as well as give hints for the methodical-didactical implementation including competence assessment,
- **knowledge modules** that can be used either by the lecturers to acquire and impart knowledge or by the learners to independently work out the content of a topic,
- multimedia **presentation slides** to visualise and support the teaching of the subject matters by the lecturers,
- **exercises** with exemplary solutions for supported, individual or cooperative repetition and application of the subject matters by the learners,
- **examination questions** in various formats (e.g. decision questions, multiple choice, etc.) that can be used for formative or summative assessment of competence acquisition, and
- a **web-based learning application** (Web Based Training), which can be made available to the learners for independent development, repetition and application of the subject matters as well as for learning progress control.

The constructivist approach of the previous teaching concept was thereby strengthened and extended in consideration of empowerment didactics. In this context, the completely parallel implementation of all contents in the knowledge modules or presentation slides as well as the web-based learning application in particular contributes to lecturers being able to create comprehensive and methodologically diverse learning opportunities. The contents are practically illustrated by four newly integrated key product examples (drilling machine, brush cutter, industrial robot, and packaging line). These examples are referred to within various exercises and thus, promote learners' active construction and self-regulated knowledge transfer into new domains. The modernised technical provision of the educational concept via an LMS and, in particular, the implemented digital communication and collaboration tools (e.g. forums and wikis) enable further methodological and didactic approaches.

The educational concept was designed for institutions and university chairs that already address the subject of product and machine safety or would like to teach or research on these aspects in future. The comprehensive teaching and learning materials are intended to serve the individualised and target group-oriented conception and implementation of a university lecture with a recommended volume of 15 semester doubles (i.e. approximately one university semester). The student's workload is suggested to be awarded with four European Credit Transfer System (ECTS) points.

3.3 Technical implementation and provision

The previous teaching and learning materials and their annual updates had been distributed by mail using DVD-ROMs. In contrast, the enhanced educational concept is provided via the web-based LMS 'Online platform for academic learning and teaching' (OPAL) (Fischer, et al., 2010). This economically and ecologically more efficient approach supports, structures and automates the provision of the learning materials in a significant way (Handke, et al., 2012).

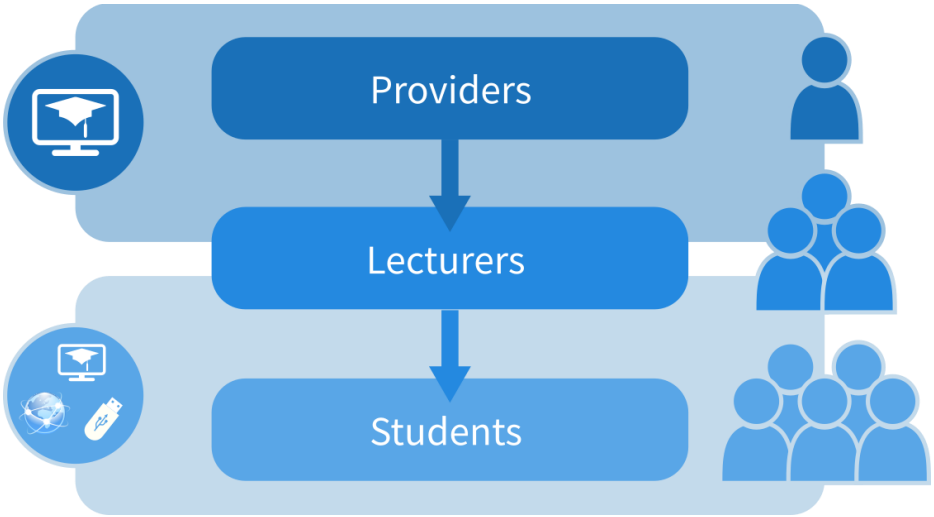

Fig. 3.2 Two-level distribution of the educational concept for product safety (Source: TUD)

The components of the teaching concept are made available by the providers (BAuA and TUD) via an OPAL course (see **Fig. 3.2**), which can be accessed via a web link. According to the license terms, any interested lecturer can access or download the electronic documents of the educational concept as well as the learning application. Certain parts of the course are restricted to prevent 'unauthorized' persons or entities from accessing it. Users can authenticate for this area by registering for the course using a (free) OPAL account and then signing the user agreement. The 'internal' area provides both editable formats of all electronic documents and tools (such as online contact forms and forums) that enable teachers to communicate with the providers and each other as well as to participate in the further development of the educational concept.

Similar to the previous teaching concept, lecturers can provide students with relevant teaching materials tailored to their individual conditions and preferences (see **Fig. 3.2**). From an economic and ecological point of view, the use of a learning platform is highly recommended (Handke, et al., 2012). The teaching concept includes a variety

of assisting services for the individual technical provision. In addition to a guideline for own distribution strategies, this also includes a sample course preconfigured for the import into the LMS OPAL. As an alternative, a course concept is provided, which can serve the lecturers as a model to design their own LMS courses. However, it should be noted that the effective use of LMS courses and tools requires sufficient expertise, methodological and media skills among the lecturers, which they may have to acquire prior or accompanying to a lecture (Kerres, 2018).

The (in contrast to the previous teaching concept) web-based implementation of the learning application or availability of the educational concept allows broad and technically almost unlimited access via the web browser of stationary or mobile devices. The learning application is provided in the Hypertext Markup Language (HTML) 5 and Sharable Content Object Reference Model (SCORM) web standards, ensuring a high level of portability to alternative systems.

3.4 Licensing and distribution

The previous licensing required contracts, which granted the users only limited usage and exploitation rights. This approach has been comprehensively reflected and substantially changed. The revised educational concept is made available as a freely accessible teaching, learning and research resource (open educational resource; OER). Its open licenses allow users to use, modify, and distribute it free of charge (Atkins, et al., 2007) under the terms of the license agreement[1]. Thereby, the rights granted for educational and scientific purposes by the Act on the Harmonisation of Copyright Law to the Current Requirements of the Knowledge Society (UrhWissG) are expanded to more extensive usage possibilities. These, for example, include the full editing and distribution of files. In order to facilitate this, all teaching and learning materials are (in contrast to the previous educational concept) provided in open source file formats. They can be edited with free-of-charge, cross-platform software, such as LibreOffice and OpenOffice. Licensing the concept as OER is intended to counteract uncertainties regarding exploitation law, to enable the continuous and context-specific adaptation of the teaching and learning materials in the light of the increasing dynamisation of knowledge and thus, to significantly increase the user acceptance and lifespan of the educational concept (Follert, et al., 2017; Malina, 2015).

The license terms are clarified in a user agreement that can be concluded with the BAuA by interested users in order to gain further access to the educational concept (e.g. editable document formats). Supplementary products were created to support the distribution. For example, a product logo was designed and incorporated into all components of the educational concept as well as the flyer to ensure high recognition. Project reports and abstracts support the transfer of the project's results to the professional public. Furthermore, a comprehensive user documentation was prepared to aid the lecturers in using the entire educational concept.

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[1] All electronic documents of the educational concept are provided under the license 'Creative Commons Attribution-Share Alike 4.0 International' (CC BY SA 4.0). The web-based learning application is licensed under the 'GNU General Public License 3' (GPLv3).

4 Testing

In order to ensure quality at an early stage and to consider the user's point of view, the implementation of the concept design was tested both accompanying and after completion of its development. The testing was carried out by a specialist lecturer during the lecture 'Product Ergonomics and Product Safety' at TU Dresden. Participants were students of the specific target group (from the diploma course 'Mechanical Engineering' majoring 'Production Engineering'). To validate the evaluation results and, particularly, the suggestions for improvement, the educational concept was evaluated in parallel by experts from the fields of product safety, media didactics and media design.

4.1 Method

Testing accompanying the development of the materials focussed on selected modules of the entirely redesigned, web-based learning application. For the final testing, the lecturer designed and conducted a complete academic lecture based on all components of the educational concept covering eight doubles periods (i.e. one term). The documents were provided to the students through a course at the LMS OPAL. In all survey phases, qualitative-quantitative online questionnaires served as measuring instruments. They were developed on the basis of validated scales (Hassenzahl, et al., 2003; Laugwitz, et al., 2008; Roca, et al., 2006) and supplemented by ad hoc questions, scales and items. In addition, a qualitative focus group discussion (Lamnek, et al., 2016) was conducted with the students as part of the testing accompanying the development of the concept to examine selected aspects in greater depth. In addition, the experts gave feedback on a learning module using an annotation tool. The quantitative data collected were analysed in a semi-automatic descriptive way using data analysis software. The qualitative data was evaluated by means of a structuring content analysis (Mayring, 2015).

4.2 Participants

In the first phase of the development accompanying testing, a total of 13 students (92% male) aged 21 to 29 answered the online questionnaire completely. In addition, eight experts (63% female) aged between 24 and 55 participated in the evaluation. Fourteen students (93% male) at the age of 21 to 36 or older took part in the second phase of evaluation accompanying the development. A total of 19 students and three experts participated in the final individual testing of the topics. The final questionnaire concerning the whole final testing period was fully answered by 13 students (62% male) aged 21 to 26. The overall age distribution of participating students in all testing phases is comparable to the age structure of large student surveys on learning with digital media (Persike, et al., 2016).

4.3 Core findings

The design of the provided teaching and learning materials tended to be exciting, interesting, creative and modern or contemporary in all test phases. It was, furthermore, emphasised in an explicitly positive way in both the focus group discussion and the expert annotations. Participants assessed the performance of the learning

application as fast and nearly free of errors. Overall, there were very few technical shortcomings in the use of all teaching and learning materials during the entire testing period. The provision of the teaching and learning materials at the LMS OPAL was regarded to be practical and contemporary by the students and was therefore fully endorsed. The focus group particularly emphasised the platform independence to be a major advantage. The quality of the information provided was assessed to be positive in all testing phases and improved continuously over time. Furthermore, the participants confirmed a very high user-friendliness of the teaching and learning materials. On the basis of 85 percent of the usability test tasks being correctly solved within subjectively decreasing processing time and with decreasing difficulty, the system quality can be regarded as very good, too. Participants considered both the structure of the learning application and the overall educational concept to be effective. During the final testing, the questions for exam preparation, the practical exercises and the web-based learning application were regarded to be particularly useful and helpful. This resulted in a very positive overall impression for both test phases (see **Fig. 4.1**) as well as in a individually perceived high increase in the participants' knowledge. Participants particularly highlighted the very high quality and density of information as well as the clear and practical transfer of knowledge and skills with reference to actual examples of products.

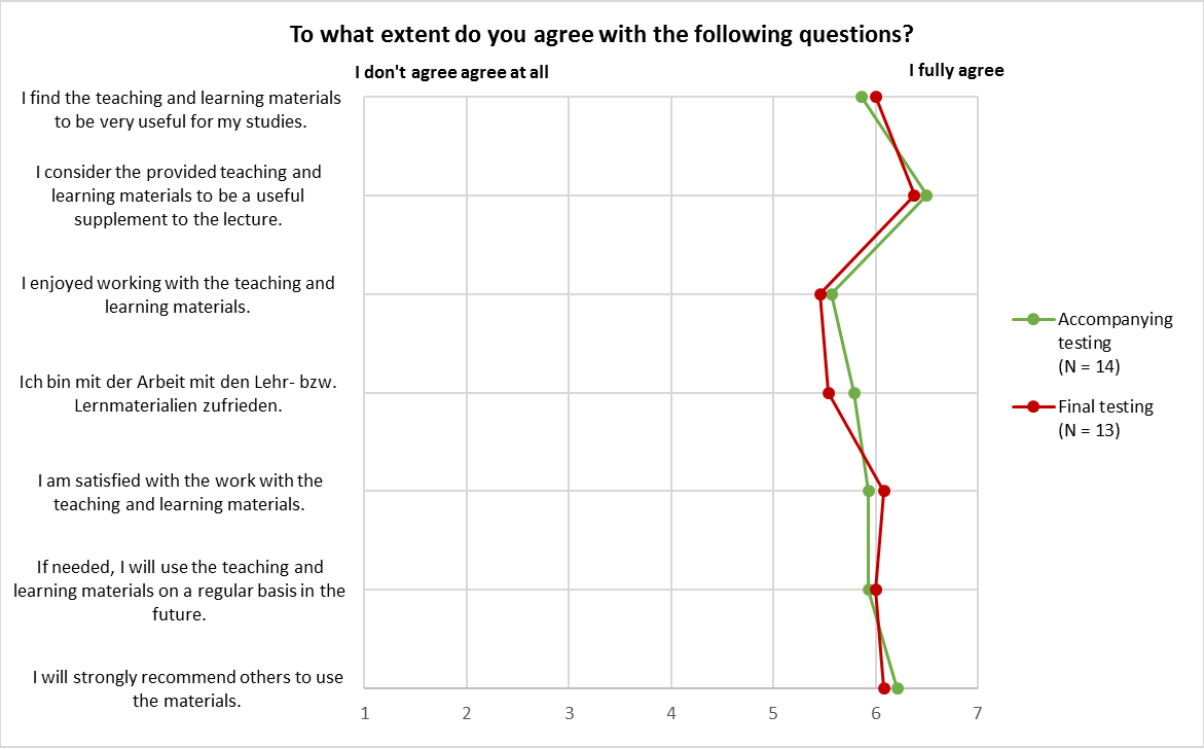

Fig. 4.1 Overall impression of the participants in the two trials (Source: TUD)

During the test phase accompanying the development, a need for revision was identified, particularly with regard to certain design aspects of the learning application and the implementation of the quiz questions and modules. For example, the participants found that there was a lack of orientation regarding their current status or progress in processing the learning application. For improvement, both experts and students suggested to implement a progress indicator, for example in the form of pagination. Furthermore, the students wished to get immediate feedback for every test question

once it had been answered. In addition, the experts suggested to visually revise certain design elements of the learning application and in particular to highlight important information in written text elements as well as to address learners directly within questions and instructions. Few suggestions for improvement by the participants of the final test related to the insufficient accuracy of an exercise as well as the partly incorrect automated analysis of the test modules in the learning application. In addition, the learners provided a variety of useful hints, concerning the didactic use of the educational concept.

4.4 Implications

Based on a review and priority setting of the user feedback in terms of content, didactic and economic aspects, numerous suggestions for improvement were implemented subsequent to the respective trial phases. For example, the main menu, text elements, and specific interactive components of the learning application have been redesigned. Immediate feedback on the correctness of the proposed solutions and explanations regarding the possible answers has been provided for all intermediate and final test questions. In addition, the intermediate and test questions (in particular the assignment tasks) have been improved with regard to their visual and functional design. This also includes the implementation of a page counter as a simple form of a progress bar for all question types as well as for content pages. For more comprehensive exercises a function for immediate interruption was added. This intends to promote learners' methodological and temporal self-regulation of their individual learning process. All identified technical errors, such as in the automatic evaluation of test modules in the learning application, were fixed. Subheadings have been inserted in the presentation slide sets to indicate the beginning of a new module more clearly. In addition, numerous hints for the didactic use of the educational concept were derived from the evaluation results and incorporated into the user documentation.

5 Conclusion

During the project period, the previous teaching concept has been comprehensively modernised and enhanced in terms of content, didactic, technical and licensing aspects. The modernisation of the contents and didactics enables a methodologically diverse and highly adapted use in higher education. This meets the growing demand for individualisation and flexibility in higher education resulting from students' increasing heterogeneity (Schmidt-Lauff, et al., 2013). The technical implementation of the educational concept, which is modularised in terms of content and didactics, and its provision via an LMS facilitate high scalability. Furthermore, the technical setup and the licensing model of OER provide the required framework for continuous adaptation and further enhancement in response to rapidly changing technical and methodological circumstances. It thereby contributes to increased user acceptance and sustainability of the educational concept. Such implementation also allows the didactic adjustment of the concept, to target groups beyond higher education, such as vocational education.

The comprehensive testing using a mixed method design confirms the high quality of the educational concept in terms of content, didactics and technology. It shows the concept’s potential to sustainably integrate the topic of product safety into higher education. This is important because placing dangerous products on the market can have far-reaching consequences for both manufacturers and consumers. These range from costly and time-consuming follow-up work to reputation damaging product recalls and serious accidents with sometimes fatal consequences. Designing safe and health-conscious products roactively on the basis of specialist knowledge acquired in higher education can significantly contribute to avoiding such consequences (Klein, 2013). Institutions and chairs of higher education are encouraged to apply the educational concept and integrate it into their academic work. Furthermore, users are welcome to participate extensively in the further development and enhancement of the educational concept under free licensing. The available opportunities of collective knowledge building exceed the capabilities of individuals by far (Scardamalia, et al., 2015).

For more information on the teaching concept and web access, please visit *www.baua.de/DE/Aufgaben/Forschung/Forschungsprojekte/f2395.html*

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Table of figures

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