Development, Implementation and Acceptance of an AI-based Tutoring System: A Research-Led Methodology

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Abstract: This Design-Based Research (DBR) project aims to develop an intelligent tutoring system (ITS) for higher education. The system will collect teaching and learning materials in audio and video formats (e.g., podcasts, lecture recordings, screencasts, and explainer videos), and store them on a learning experience platform (LXP). Then, the ITS will process them with the help of speech recognition to gain data which, in turn, will be used to power further applications: Using artificial intelligence (AI), the platform will allow users to search the materials, automatically compiling them according to criteria like lesson subject, language, medium, or required prior knowledge. By the end of the last DBR cycle, the ITS will also provide a more active form of support: It will automatically generate exercises based on predefined patterns and teaching materials, thus allowing learners to check up on their learning progress autonomously. In order to closely match the ITS's features to the needs and learning habits of students in higher education, the development of this AI-based tutoring system is accompanied by an interdisciplinary team which will continuously re-evaluate and adapt the concept over the course of several DBR cycles. Our goal is to derive implications for the system's technical development by collecting and evaluating educational research data (mixed methods design; primary and secondary research methods).

1 INTRODUCTION

As the digital transformation of higher education progresses, more and more teaching/learning materials (TLM) are made available online, both open access and within the universities' learning management systems (LMS). These materials allow students to create learning environments best suited to their specific interests and needs. Wherever, whenever and whatever they want to learn: Thanks to the constantly growing number of online materials, they can now study or review materials at their own pace.

When it comes to audio and video recordings, however, finding materials dealing with the exact topic on which a student has chosen to focus may still prove surprisingly challenging—even for the tech-savvy students of today. On the one hand, search engines, open educational repositories (e.g., databases like cccoer.org or oercommons.org), and LMS (e.g., Blackboard, Canvas, or Moodle) still rely on manually created metadata. If this metadata does not contain a comprehensive list of keywords covering all of the topics presented in a recording, students will often fail to find appropriate learning materials. On the other hand, the platforms allocating the recordings rarely provide more than rudimentary assistance to users who are researching topics in the context of self-study. For example, students looking for a definition of "singular value decomposition" might find a promising mathematics lecture available online. However, a 90-minute lecture on linear algebra might only dedicate a few sentences to singular value decomposition, leaving students to manually sift through the entire recording to find out what time frame provides the information they need.

Considering the importance of efficient self-study in higher education, it would be desirable for video and audio TLM to support a faster, more intuitive mode of research. Ideally, students would directly find the fifteen minutes of a recording dealing with their topic. But what if a more sophisticated search

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was not the only feature of an LMS that supported self-study? What if students could filter the materials by topic *and* by learning objective? And what if they could receive recommendations on further materials for in-depth study—including exercises tailored to fit their previous knowledge? The more precisely TLM could match individual learning processes, the more easily students could focus on the content.

Cue modern technology: "AI-based tools and services have a high potential to support students, faculty members and administrators throughout the student lifecycle" (Zawacki-Richter et al., 2019, p. 20). Applied to the problem of finding audio and video TLM online, AI makes it possible to optimise search processes and support students adaptively by providing individual feedback. This way, intelligent tutoring systems (ITS) can help students review their lessons, prepare for exams or acquire entirely new skills through self-study.

The ideas are certainly out there, but the reality in higher education leaves much to be desired. To date, no German university uses intelligent search functions to help students identify recordings they might want to use as instructional materials. And although there is a growing demand for AI-based applications in higher education—which in Germany is currently backed by an equally growing number of research grants (Bundesministerium für Bildung und Forschung, 2020, 2021; de Witt et al., 2020)—none of the systems developed thus far used instructional design to shape their frameworks, thereby ensuring that the AI-based generation of exercises closely matches students' habits and needs (e.g. Zawacki-Richter et al., 2019).

2 CONCEPTUAL DESIGN

The project described in this article aims to create an ITS called HAnS (short for "Hochschul-Assistenz-System", i.e., "assistance system for higher education") which is meant to support students from different disciplines in their quest for self-directed digital learning. Developed and implemented collectively from 2021 to 2025 by twelve cooperating German universities and research institutes, it will exemplify the benefits of AI and Big Data in higher education and—ideally—serve to drive innovation within the field of technology-based learning

The system itself builds upon existing learning materials and addresses three educational and/or technical potentials: (1) automatic transcription and indexing of audio-visual educational resources (e.g., lecture recordings, instructional videos, screencasts, and podcasts), (2) personalised search and recommendation of learning materials, and (3) dynamic generation and gamification of individual learning offers. These three potentials will be combined to create the framework of an ITS that both students and teachers can use to improve the effectiveness of self-study in higher education.

The *developmental goals* of the project are the science-driven design and integration of a learning experience platform, including components for natural language processing, speech recognition, and indexing. To train the ITS, we use authentic audio-visual TLM provided by teachers from various German universities. The system adaptively assembles these materials based on user information and educational guidelines embedded in the system to generate dossiers on specific topics and individual exercises for self-study.

Per its design-based research framework, the project pursues three *processual goals:* The creation of the AI-based system, its iterative evaluation and adaptation. Therefore, the integration of the ITS prototype into existing learning ecosystems will be accompanied by educational research, continuous testing, and formative evaluation.

Usage goals, in turn, are interactions between users and the ITS. As the HAnS system will become part of everyday teaching and learning processes at the twelve universities involved in the project, the sheer number of interactions will significantly improve the AI.

2.1 Agile Development Guided by Educational Research and Formative Evaluation

The technical development of the ITS will be guided and continuously evaluated by a group of researchers specialising in higher education. Their analyses serve several purposes. During the first stages of development, they will provide a more thorough understanding of the initial situation: How have AI-based technologies been applied to post-secondary education so far? Which theoretical models were used to create their frameworks—did they involve instructional design? And how have the applications affected teaching and learning processes? To gain an overview of projects and concepts which have already been published, we will create a scoping review (Levac et al., 2010) of the research on the application of AI in higher education.

Scoping reviews are still considered a relatively new approach to examining the state of research. Focusing on the scope of information available on a given topic, they provide a comprehensive overview of the existing literature (Peters et al., 2020; Munn et al., 2018). Unlike systematic literature reviews, however, they include neither an evaluation of the results nor critical analyses of the methodology used in the gathered literature. Instead, scoping reviews provide a way to map a field of research quickly yet thoroughly. The wide range of results inherent to this approach proves especially useful when few studies deal with the exact topic and methodology of a project, forcing researchers to collect and compare findings from different fields.

As a starting point for a joint DBR project to which several teams will contribute their expertise, the scoping review has three distinct advantages. Firstly, its methodology allows the research team in charge of this preparatory study to collate data from various academic fields and leave the evaluation of the results to the specialists taking on the different aspects of the design during the later stages. Secondly, scoping reviews are particularly well-suited for mapping quickly evolving fields of research such as AI in higher education: "[A] systematic review might typically focus on a well-defined question where appropriate study designs can be identified in advance, whilst a scoping study tends to address broader topics where many different study designs might be applicable" (Arksey and O'Malley, 2005, p. 20). Thirdly, the open-end structure of the scoping review can be adapted to match the iterative structure of DBR development cycles. If during later cycles new areas of research become relevant to the project, more topics and keywords can easily be added to expand the scoping review.

In order to test the HAnS system as development progresses, we will initially implement prototypes of the learning materials, evaluate them formatively, and experimentally test them under controlled conditions with small groups of learners. This way, the system improves with each cycle. At the same time, constant educational analysis ensures that data protection, transparency, and ethics are used as crucial guiding factors for the development and implementation of the tutoring system. Students and teachers will be included explicitly in this process as future users, so their concerns and hopes can be comprehensively addressed as development progresses. Once the automatic modules for the creation of exercises and monitoring users' achievement of learning objectives have reached a satisfactory level of maturity, a summative evaluation will follow.

What sets the HAnS apart from other ITS is its focus on audio and video recordings. Automatic transcription helps users identify learning materials that deal with specific topics. However, an improved search function is only the first step towards the intended learning experience platform. HAnS also uses the transcripts to automatically create exercises that will help users review the information provided in the recordings. This might, for example, allow students to prepare for exams by revisiting online lectures and using quizzes generated by the AI to check whether they remember the technical terms introduced in these lectures.

Overall, HAnS aims to provide a quick and efficient way to structure self-directed learning throughout higher education. To ensure that students can use the ITS from their first semester until their final exam, the system must accommodate different learning objectives (e.g., gaining new knowledge vs. re-activating or expanding existing knowledge) and skill levels. Therefore, the system will supplement the multiple-choice tasks, cloze tests, and question/answer catalogues with recommendations for further study. On top of this, related learning materials will be pointed out to users as links to recordings available via HAnS or as automatically created cross-references to external sources.

Furthermore, the AI will generate a ranking of individual sections taken from different video or audio files linked to specific metadata. This contributes to a more nuanced search function, allowing students to filter the learning materials for specific content (e.g., related academic fields, recommended semester, or theory vs. application) and choose materials in accordance with their personal study preferences (e.g., text-based, numerical or graphical visualisation of concepts explained in the recordings). We expect this tailoring of learning materials to students' objectives, needs, and preferences to improve academic performance significantly once the AI-based recommendation feature reaches a sufficient degree of maturity.

Through users' constant interaction with the ITS, innovative learning materials are created and continuously adapted to the current state of educational technology. Students will, for example, be able to rate whether they have reached their learning objectives and leave feedback for the teachers who have created the learning materials. At the same time, users can add their recommendations for further study on a particular topic to the HAnS database. This feedback loop will help us assess the quality of the materials and the accuracy of the educational design framework.

The algorithms for the personalised search and individualised generation of exercises and recommendations are continuously and automatically adapted through a collaborative evaluation process. Both will become more customised through user interaction. HAnS workshops for students and teachers will accelerate this part of the development process: The more users interact with the AI, the faster the ITS can grow into a system that offers spot-on individual support. Easy access to the system must therefore also be one of the main concerns guiding the development of the HAnS interface. Successful implementation of the ITS at the twelve universities participating in the project requires an AI-based tutoring system that can be connected to different LMS. For this reason, compatibility with a variety of systems will be one of the basic features of the software—and may later serve as the cornerstone for the expansion and transfer of HAnS to other virtual learning environments and institutional contexts.

2.2 Design-based Research Methodology

The HAnS project combines agile technological development with the equally agile methodology of design-based research (DBR). As a framework, DBR allows researchers to generate theoretical insights through a hands-on approach (Design-Based Research Collective, 2003; McKenney and Reeves, 2012; Reimann, 2013; Bakker and van Eerde, 2015). Applied to the learning sciences, this usually means that researchers identify a specific issue within a learning context and create an intervention to solve it. Then, they put their solution to the test, documenting and evaluating the results so they can be used as the starting point for another development cycle. Refined over the course of several DBR cycles, the intervention comes closer and closer to an ideal solution—and in the meantime, it also provides researchers with new insights and data (Jahn, 2017). Thanks to this two-pronged approach to teaching and learning, "[d]esign-based research is increasingly used as a research approach that succeeds in advancing current teaching-learning research and pedagogical practice in equal measure through theory-based design processes" (Knogler and Lewalter, 2014, p. 2; cf. also Hasselhorn et al., 2014).

Our ITS is meant to solve a core problem of digital self-study: Students have to possess advanced research skills *and* invest a lot of time to find learning materials that suit their interests and needs. This applies particularly to audio and video recordings. As an intervention, we will create an ITS that supplies students with well-indexed learning materials and individually generated exercises.

The development of HAnS follows Easterday's (2018) approach to DBR, which adapts iterative structures used in software development for research purposes. By synchronising the workflows of research and technical development, the specialist groups can coordinate their tasks and create synergy between the different departments of this interdisciplinary project. The procedure is iterative and cyclical, i.e., there will be multiple alternations between exploration, design, and evaluation. Educational research will monitor the development of HAnS and adapt the system to potential user groups' preferences, habits, and needs. Continuous evaluation will allow the more research-oriented groups within the project team to derive design recommendations which we will then use to shape the next iteration of the prototype.

The development of HAnS comprises three survey phases. Survey phase I evaluates conclusiveness and feasibility of the project, survey phase II assesses the initial local benefit and theoretical soundness of the assistance system, and survey phase III evaluates both the verifiable effectiveness of the system and its guiding principles, which may then be generalised and applied to other learning contexts. As the system reaches higher levels of maturity, the test scenarios and methods used to gauge the effectiveness of the ITS will also have to change.

Within each of these three phases, three DBR cycles will take place (*α cycle, β cycle, γ cycle*). Since complex interventions such as HAnS usually comprise several components (e.g., automated practice tasks, learning level checks, or feedback processes), there will also be several so-called micro cycles as each of those components is created within

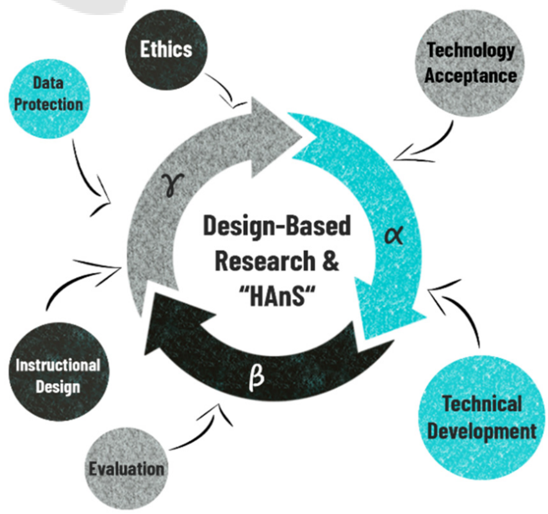

Figure 1: DBR cycle of "HAnS".

its own, smaller DBR cycle running parallel to the main development cycles.

The *α cycle* focuses on mapping students' study conditions and learning requirements as well as the personal, social, and cultural contexts which affect (digital) self-study. Additionally, we will conduct decoding interviews with teachers according to the guidelines developed by Riegler and Palfreymann (2019) to establish which intended learning outcomes (ILO) and subject-specific requirements teachers anticipate when they create learning materials for higher education. By comparing these ILO with students' actual learning outcomes (ALO), we aim to identify so-called bottlenecks, i.e., challenging learning situations in which students might profit from additional support and explanation the ITS could provide *in lieu* of absent teachers (Riegler and Palfreymann, 2019).

In the *β cycle*, the focus shifts from the success factors of digital self-study to the ITS prototype in use. Here, we assess the quality of the learning materials, students' decision for or against the AI-based tutoring system, and their interaction with the assistant. This includes students' subjective interpretation of their experience with HAnS and their wishes regarding design and functionality. Within the same cycle, we will again interview teachers, focusing this time on the selection and evaluation of their teaching materials. We will also interview both user groups about their acceptance of relevant project components.

In the *γ cycle*, we will determine the effects of the ITS on students' knowledge, supra-disciplinary cognitive effects, and key competencies necessary for self-organised learning by way of an impact analysis including both the ALO and the underlying mechanisms responsible for the learning environment's impact. From this evaluation, we will derive design recommendations for effective learning. In addition, the third DBR cycle also contains a "bottom-up ethics" approach to users' perspectives on the ITS. We will systematically evaluate learners' and teachers' opinions on the AI-based tutoring system to incorporate their hopes and concerns into the next iteration of the prototype.

2.3 Empirical Methods

The following empirical mixed-methods approaches are used within the DBR framework to guide the HAnS project through its development cycles:

We will use **impact analyses with a quasi-experimental (waiting) control group design** to identify predictors of success and conditions for the transfer of the HAnS concept to other subjects and framework conditions (scaling). We will derive statements on possible adaptations and the generalisability of the system from the results. The data for these analyses will be collected from teachers and learners. To guide the inquiry, we will develop impact models with both groups. Within the framework of the impact analyses, the question of impact mechanisms will also be addressed through "process tracing" (Beach, 2017).

Longitudinally structured, quantitative online surveys will evaluate students' ALO and the achievement of learning objectives as seen by teachers and learners (triangulation). Besides identifying changes in learning behaviour and academic success over time, the longitudinal design of these studies will also allow us to contrast survey results of students and teachers from different academic disciplines. This will provide additional information on the effectiveness of the prototype and, more importantly, the potential of HAnS as a learning tool in particular fields of study. Central dimensions and indicators for these surveys, therefore, include target group characteristics, media, and content of the learning materials, planning and implementation with usage situation, learning location, and reflection methods.

Parameterisation creates reliable data from subjective information provided by HAnS users and developers. For this, we will compare the self-reports collected as part of the longitudinal section with objective parameters or methods of analysis, such as frequency analysis, interaction analysis, causal modelling, sentiment analysis (via text mining), or topic analysis in the text material (via Dirichlet analysis). The data basis is the HAnS data protocol, i.e., the interaction of developers and users with the different iterations of the prototype.

An evaluation of already existing digital teaching materials from different disciplines will provide a baseline for the development of the prototype. In later stages, we will evaluate the ITS through a representative survey with probabilistic sampling, based on purposive case type selection, qualitative sampling plans, and descriptive data with a view to teacher and learner perspectives. At the beginning of the project, however, we will evaluate how audio and video recordings are used as learning materials without any AI-based support. The criteria used in this analysis—such as the use of additional media, students' motivation, and the ILO teachers associate with certain learning materials—will later be used to compare the effectiveness of HAnS to that of learning materials provided without the AI-based features of the ITS.

We will apply **a reconstructive documentary analysis** to records of online group discussions, asking students and teachers to share their opinions and knowledge regarding the potentials and challenges of AI in higher education. This analysis aims to identify the explicit and implicit value systems guiding the potential HAnS users. Considering the project's duration, these group discussions can also be used to effectively counteract the onset of tunnel vision in later research and development cycles. By comparing their expert knowledge of the AI-based tutoring system with the application-oriented perspective of students and teachers, our developers and research teams will gain a deeper understanding of what potential users expect from an ITS such as HAnS.

Ethnographic case studies will further address students' use of the AI-based tutoring system. Based on ethnographic workplace studies covering computer labs at universities and students' private learning spaces, document analyses of the learning units, and subsequent interviews with students will be used to record practises of learning and individual user experiences with the implemented AI-based learning materials.

3 DISCUSSION

HAnS aims to expand the horizon of ITS projects in higher education by creating a comprehensive and, above all, fully functional intelligent learning aid that will be implemented at twelve German universities. To create and evaluate a system as complex as this, we will utilise the combined expertise of twelve groups of specialists from different academic disciplines—ranging from IT professionals and experts on ethics to researchers from the educational sciences. Of course, coordinating such a large and heterogeneous research team presents a challenge. In order to integrate evaluation, research design, methodology, and data, the shared workflows will have to be structured systematically. For this reason, we have decided to utilise a highly innovative methodology. By combining several relatively new, agile approaches, we can apply models from the educational sciences and partial surveys in a way that allows research and evaluation to keep pace with agile software development.

With DBR as its cornerstone, this methodology allows us to combine the different methods of evaluation in which the teams specialise into a shared framework of agile research. The iterative cycles of a DBR project establish a reciprocal link between the evaluation results, the results of the didactic analyses, and the progress of technological development. Processing the findings from the partial analyses of users' needs, wants, and interactions with the prototype which will be contributed by the participating universities, we can derive recommendations for the iterative re-design and adaptation of the ITS. In order to gain a critical perspective on our own findings, we will also create a data feedback loop that will present the results of qualitative and quantitative research to the investigated user groups, creating additional evidence for the plausibility of our interpretations. Communicative Member Checks (Koelsch, 2013) will add another layer of transactional and transformational validity to the results.

The iterative DBR design is framed by a scoping review which will compile and present relevant models and concepts of educational theory. These will guide both the empirical methods and the design of an educational framework for HAnS. Since the expert groups must work in parallel to complete interlocking DBR cycles, we have chosen the scoping review as a method for mapping the existing literature. Consecutive partial reviews would cause the DBR cycles to stagger, but a scoping approach allows us to quickly compile large amounts of research and, consequently, start the first cycle without needing one team to prepare their first contribution to the project months in advance. Instead, we can use the scoping review to form causal models for the first impact analyses as well as the study groups and subjects for the evaluation—and, if necessary, we can still expand our review during later stages, adapting the scope of theoretical research to the results of the empirical studies and the progress of the prototype.

Finally, we must consider that in DBR projects, the context is part of the intervention. Consequently, context variables are not "confounding variables": Instead, they are indispensable for cognition. Generalisations are not based on visible activities but on connections between interventions, contextual conditions and effects about which one makes corresponding assumptions to guide the design, testing and evaluation process (Wozniak, 2015, p. 602). Our goal is to create highly transparent documentation of the entire DBR process so HAnS will not only be developed as a particular ITS, but as a template for an intelligent learning support software embedded in a learning experience platform that is easy to transfer to other learning and teaching contexts.

4 CONCLUSIONS

The particular design challenge of the HAnS project is to develop a digital learning space that takes into account the individual educational requirements and the different cognitive practices of students in higher education. To create an AI-based ITS that generates individualised learning materials, we will have to assess existing courses as well as students' and teachers' situations, skills, and opinions. On top of that, we will also have to find ways to identify locally functioning partial solutions which can be used as starting points for more generalised design principles. From theory formation through application to verification, we intend to cover all of these stages within a DBR framework which allows us to use a problem-solving strategy that is both agile and holistic, drawing inspiration and expertise from the various specialisations present within our team of twelve expert groups.

As a result of this agile approach, we expect to derive design principles that can be directly implemented (exemplarily) in our AI-based tutoring system HAnS, but also provide guidance for future projects: Ideally, our design principles will be easily transferred and adapted to new cross-institutional learning architectures and the educational research which will shape them.

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