Kohlhase, Michael; Berges, Marc; Grubert, Jens; u. a.

Project VoLL-KI : Learning from Learners

Date of secondary publication: 21.05.2026

Version of Record (Published Version), Article

Persistent identifier: urn:nbn:de:bvb:473-irb-115195x

Primary publication

Kohlhase, Michael; Berges, Marc; Grubert, Jens; u. a. (2025): Project VoLL-KI: Learning from Learners, in: Künstliche Intelligenz: KI; Forschung, Entwicklung, Erfahrungen; Organ des Fachbereichs 1 Künstliche Intelligenz der Gesellschaft für Informatik e.V., GI, Berlin; Heidelberg: Springer, vol. 39, pp. 299–309, doi: 10.1007/s13218-024-00846-9

KI - Künstliche Intelligenz (2025) 39:299–309
https://doi.org/10.1007/s13218-024-00846-9

PROJECT REPORTS

Project VoLL-KI

Learning from Learners

Michael Kohlhase[1] · Marc Berges[1] · Jens Grubert[3] · Andreas Henrich[4] · Dieter Landes[3] · Jochen L. Leidner[2,5] · Florian Mittag[3] · Daniela Nicklas[4] · Ute Schmid[4] · Yvonne Sedlmaier[3] · Achim Ulbrich-vom Ende[4] · Diedrich Wolter[4]

Received: 18 April 2023 / Accepted: 4 April 2024 / Published online: 5 May 2024

Abstract
"Learning from Learners" ("Von Lernenden Lernen", "VoLL-KI " for short) is a is collaborative research project with the goal of creating a practical toolbox of instruments at different levels of abstraction to improve the learning experience and outcomes for students of artificial intelligence. *Learning and teaching at tertiary education institutions are currently IT-based but not AI-supported. The VoLL-KI project aims to go this crucial next step.* Using AI approaches (e.g., ML, symbolic AI, statistical AI), several educational technologies are developed on the different granularity of the study programs (e.g., course, semester, program). So, dashboards for study planning, recommender systems improving student advisory services and learning material selection, VR-based learning experiences, educational chatbots, and adaptive learning environments are developed. The systems are mostly deployed as prototypes

Keywords Computer-aided education · Intelligent tutoring systems · Teaching support for artificial intelligence education · Computer-aided learning (CAL) · Data-driven learning quality management · Study course monitoring · Learning analytics

✉ Marc Berges
marc.berges@fau.de

Michael Kohlhase
michael.kohlhase@fau.de

Jens Grubert
jens.grubert@hs-coburg.de

Andreas Henrich
andreas.henrich@uni-bamberg.de

Dieter Landes
dieter.landes@hs-coburg.de

Jochen L. Leidner
leidner@acm.org

Florian Mittag
florian.mittag@hs-coburg.de

Daniela Nicklas
daniela.nicklas@uni-bamberg.de

Ute Schmid
ute.schmid@uni-bamberg.de

Yvonne Sedlmaier
yvonne.sedelmaier@hs-coburg.de

Achim Ulbrich-vom Ende
achim.ulbrich@ceushb.uni-bamberg.de

Diedrich Wolter
diedrich.wolter@uni-bamberg.de

1 Introduction

Artificial Intelligence (AI) will change society, economy, and education. Universities have to face new challenges in research and teaching. The project VoLL-KI aims to improve tertiary education on three different levels, combining data-focused and knowledge-based AI approaches. Namely, evidence-based improvement of study programs on the macro-level, context-adaptive, evidence-based, rectifiable recommendations for individual study planning on the meso-level, and learner-specific, automated diagnosis and support of learning assets on the micro-level.

[1] Department for Computer Science, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

[2] Computer Science, University of Sheffield, Sheffield, England

[3] Informatik, Hochschule Coburg, Coburg, Germany

[4] Informatik, Otto-Friedrich Universität Bamberg, Bamberg, Germany

[5] Wirtschaftswissenschaften, Hochschule Coburg, Coburg, Germany

Based on preliminary work on knowledge graphs, error libraries for programming, intelligent tutor systems, explainable and interactive machine learning, chatbots, virtual reality, and recommender systems, the project will develop intelligent learning support systems. Within the project's duration of four years (2021–2025), methods and systems in the project will be piloted in curricula of Computer Science, Artificial Intelligence, and eventually related areas at the three universities involved (Coburg University of Applied Sciences and Arts (HSCo), Friedrich-Alexander-Universität Erlangen Nürnberg (FAU; coordination), Otto-Friedrich-Universität Bamberg (UBa).

The State of University Education The body of students is progressively becoming more heterogeneous. As a consequence, it is almost impossible to base the teaching—both in starting bachelor programs and in master programs—on a common ground [15]. We expect that the recent Covid pandemic will only aggravate this problem. At the micro-level (Fig. 1), data on study progress are provided by an established data warehouse system (CEUS) [11] and will be continuously extended over the course of the VoLL-KI project. Data on existing and desired competencies of individual students are complemented with competency data for specific groups—e.g., defined by gender or educational biography.

Decisions on study affairs are usually still taken with little information and overburden students [16]. Study planning decisions, in particular, are overwhelming for many students [35]. In the context of various possible module choices, organizational constraints, and individual personal backgrounds, it is crucial to support students in their navigation through their studies and their attainment of goals and competencies [41]. At the meso-level (Fig. 2), this individual-level and cohort data is examined via student progress (predictive) analysis and learning analytics. It is used to generate module recommendations in order to support individual study planning within a digital study planning assistant application. Some higher education institutions have instituted planning systems that support transparency and autonomy, so students can request explanations, explore alternative options, and correct premises.

In the last years, universities have introduced quality management processes in education. But the collected parameters are often relatively course-granular and cannot yet be used for a directed improvement of study programs [14] or even the derivation of concrete study recommendations. At the macro-level, the group/cohort-level data can be used for the data-driven validation and optimization of study programs. If we extend this course-level data with a domain model that contains fine-grained representations of the concepts, objects, skills, and their relations, we can provide user-adaptive (micro-level) services like tutor systems or user-adaptive course materials to individual students or small groups.

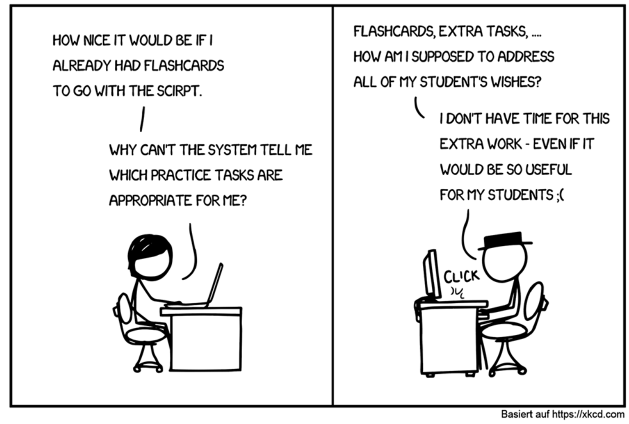

Fig. 1 VoLL-KI use cases at the micro-level

Fig. 2 VoLL-KI Use Cases at the meso-level

Project Motivation The extension of these models with data from monitoring learning progress and performance trends at individual and group-specific levels will be integrated into the data warehouse and will be provided to the study program planners in a special dashboard. The semantic services at the micro-level will be integrated directly into the course materials and the learning management systems of the institutions.

Research, development, and deployment in the VoLL-KI project are carried out by researchers from the areas of AI, AI-near parts of Computer Science, and Computer Science Education. The methods and systems will primarily be applied to the Computer Science study programs of the three partner institutions—a large, engineering-focused department of computer science, a medium-sized interdisciplinarily oriented CS department, and a small application-oriented one. Toward the end of the project, the successful components will be expanded to other study programs, and the results will be integrated into the quality management processes of the participating institutions.

Initially, the VoLL-KI project partners focus on computer science study programs as an application domain for AI methods in tertiary education. As in the other STEM disciplines, the heterogeneous preconditions manifest mainly in the pre-existing proficiency in mathematics. The CS study programs are very demanding and under heavy student demand. This impedes the individualization of studies, which is so important for study success. Student bodies are diverse: At Coburg University of Applied Sciences and Arts (HSCo), many students enter university and Computer Science studies with a non-classical educational path. Otto-Friedrich-Universität Bamberg (UBa) offers a CS master program tailored specially to international students, who have greatly differing competencies from the bachelor programs of their countries of origin. At Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), the placement of the CS department in a large engineering school is one of the reasons for a comparatively low proportion—compared to, e.g., UBa—of female and diverse students. All three universities currently lack specific data to carry out root cause analyses, particularly on drop-outs. Courses are largely oriented towards "teaching to the middle," and there are currently preciously few learner-specific offers.

2 VoLL-KI Project Goals

As we have seen above, there is a substantial need to obtain information (both data and knowledge) on individual study trajectories to deal with individual and group-specific study difficulties at all levels. VoLL-KI will address three areas of problems by AI methods and systems:

1. Heterogeneity with respect to the basic competencies: students bring in very different proficiencies from diverse educational biographies [13].
2. The gender- and minority problem: In STEM disciplines, women and ethnic minorities are underrepresented [48].
3. Lack of evidence-based methods in study program design and further development: reliable data and substantiated models are missing.

To reach these goals, VoLL-KI will evaluate and deploy individualized measures that

i) support students in a semester and long-term study-planning and thus their navigation inside and between modules in the implicit or explicit dependency graph, ii) automate personalized and interactive course materials and feedback, and iii) provide positive learning situations.

based on domain, competency, study trajectory, and success data. Often, students require low-threshold impulses to surmount critical difficulties and finish their study program successfully. VoLL-KI aims to augment the digital interaction of students and universities—from choosing study programs and courses to studying in an e-learning platform—using AI methods, including semantic navigation, recommendations, and individual interaction with personalized tutors such that all students are reached. To clarify: the goal is not to produce "high-performance computer scientists," but to reduce the number of STEM students who drop out of their studies "because of computer science" of run into follow-up problems.

From a system engineering point of view, our plan is not to develop a single, integrated demonstrator. Our experience is that it is hard to get adoption, as institutional requirements differ dramatically, as do pre-existing local IT landscapes. Instead, we will develop a toolbox of modular components that can be adopted and integrated individually. The downside of this approach is that there will not be a singular "off-the-shelf system"; but the upside is that each institution may select freely components that suit their needs. Also, the integration of small components into an existing infrastructure is eased. We envisage that some parts will contribute to existing open source projects (e.g., Moodle), others may catalyze their own open source communities, whereas other parts may see less take-up. It is our belief that this maximizes the overall utility that we can generate in this project.

In summary, learning and teaching at tertiary education institutions are

currently IT-based but not AI-supported. The VoLL-KI project aims to go this crucial next

step.

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3 Prior Work/Experience of the VoLL-KI Partners

VoLL-KI consists of three integrated but formally independent sub-projects that pursue different (but synergistic) key aspects of holistic data- and knowledge-supported higher education and its design, develop and evaluate them independently at the three sites and bring the results together. The universities supply expertise in domain modeling, knowledge representation, educational modeling, and data-driven analyses to build AI-based educational technology and recommender systems (see Fig. 3).

The analyses and measures planned in the VoLL-KI project build on a broad body of preliminary work: the data warehouse system CEUS (Computerbasiertes

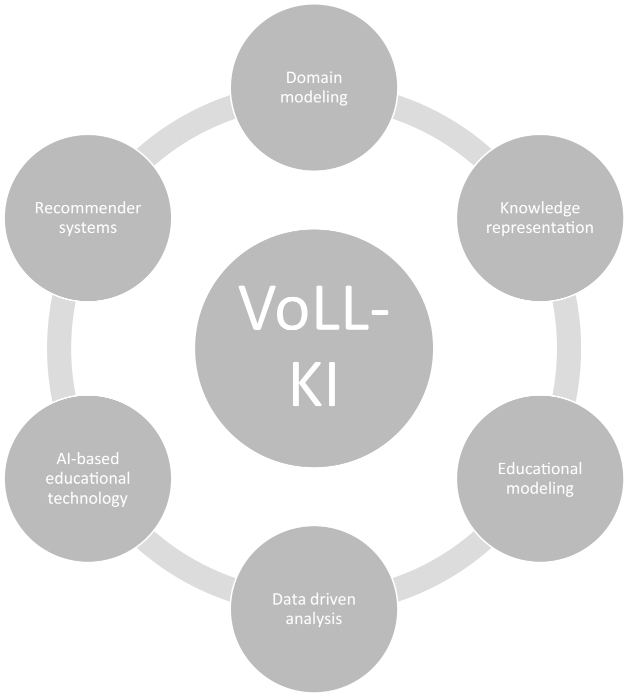

Fig. 3 Overview on the competences contributed by the three universities to the VoLL-KI project

Entscheidungsunterstützungssystem für das Hochschulwesen in Bayern ≙ computer-based decision support system for higher education in Bavaria; [11]) is developed at UBa and is the central point of information about study data at UBa and FAU (and the majority of Bavarian institutions of higher education). In VoLL-KI, CEUS will be used for storing and analyzing (macro- and meso-level) study data and will be extended systematically over the course of the project.

In the context of supporting students' module choices and competency-oriented studying, UBa builds on prior experiences gained in the BilApp project that addresses the complex field of teacher's education [18] and first experiences with CS programs [17].

FAU has extensive experience in knowledge-based AI and CS education: The knowledge representation and management group has developed the concept of theory graphs [23, 37] as a highly modular and foundation-independent knowledge representation format for knowledge representation of flexible formality in the STEM disciplines [7, 24] and specialized it into a Learning Object Graph for educational purposes [22]. A semantic variant of LaTeX [25, 47] has been used to annotate over 5,000 pages of course materials in CS and AI. The knowledge management services implemented in the MMT system [33, 36] allow to generate customized and interactive course materials from this semantic corpus [26]. The CS education group worked on competency models for teaching computer science [4, 32] including subject matter knowledge and pedagogical content knowledge (PCK). Furthermore, error models [6, 19] and feedback models for programming [29, 50, 51] were developed. Additionally, the group focuses on modeling programming concepts to systematize the necessary subject matter knowledge for novice programmers [5]. Further work on programming assignments [40] contributes to the intended systems in the VoLL-KI project.

HSCo has a tradition of advancing higher education through novel learning settings, in particular focusing on interdisciplinary, learner-centered, competence-oriented, and holistic approaches. Two large-scale projects in this context were "Coburger Weg" and EVELIN. In particular, the latter one focused on various issues in software engineering education, in particular subject-matter didactics for software engineering [42], interactive environments for learning computer programming [10], activating and inductive learning [44, 45], competence assessment [43] with emphasis on non-technical competences [46], and learning support tools such as an adaptive environment for learning videos [27].

4 Structure and Contribution of the Project

Enhancing cooperation and realization of synergies is a major goal of the VoLL-KI project, and so research, development, and deployment work is structured into five work areas:

1. **WA1: Data/Models** supplies a solid foundation for the evidence-based educational services.
2. **WA2: Navigation** aims for individualized study recommendations at the module and study program level.
3. **WA3: Learning Situations** realizes interactive learning experiences via AI systems.
4. **WA4: Feedback** supplies individual help and explanations in specific learning situations.
5. **WA5: Course Program Design** uses data from all work areas above for evidence-based management of study programs.

WA2/3/4 are situated both on the level of concrete learning objects (micro-level) and at the level of individual study planning (meso-level) and mainly but not only addresses the students themselves. An important aspect of the exploration of students' individual planning processes and study paths is that, due to the reliance on various systems within the higher education system landscape, the work towards individual study support reveals organizational and structural obstacles both on the micro- as well as the macro-level. **WA5** addresses the program directors and the study program directors, and the examination boards.

The five work areas above address different didactic aspects. While **WA1** is mainly concerned with the generation and curation of data and models to give a basis to the competence-oriented diagnostic and a represented structure for scaffolding knowledge-based AI services the remaining work areas focus on competence-oriented education at different levels of granularity. The focus is on handling heterogeneity, self-regulated learning, and sustaining motivation for learning. We take an inclusive view on heterogeneity in VoLL-KI: among others, heterogeneity of the student body with respect to educational biographies and the—strongly manifested in CS—gender problem will be addressed. All aspects of **WA2/3/4** serve not only the improvement of the individual level of competency but also the improvement of confidence in their own qualifications, in the sense of a self-efficacy expectation. Through the use of AI-based systems, we expect relief for the available teaching resources, which then be repurposed into individual support e.g., through “inverted classrooms” or customized in-depth excursions.

An additional contribution puts individual study progress at the meso-level into the center of attention. Joint analysis of study trajectory data and competency models for courses can reveal gaps in individual student’s competence profile, and derived and targeted recommendations can promote individual competency gain. Such targeted recommendations are also produced at the level of individual study planning. They are based on the analysis of prior module choices, competencies, as well as individual goals and interests. Individual study planning is closely related to the micro-level (course) and the macro-level (study program). As such, it contributes to tertiary education in the sense of addressing organizational and structural challenges in both areas. **WA5** specifically focuses on curricular facets, to e.g., highlight and rectify imbalances with respect to the competencies to be gained over the course of a study program.

5 Initial Results of the VoLL-KI Program

After about a third of its lifespan, the VoLL-KI project is well underway with developing the basic functionalities of AI-based education support systems at all three levels. It

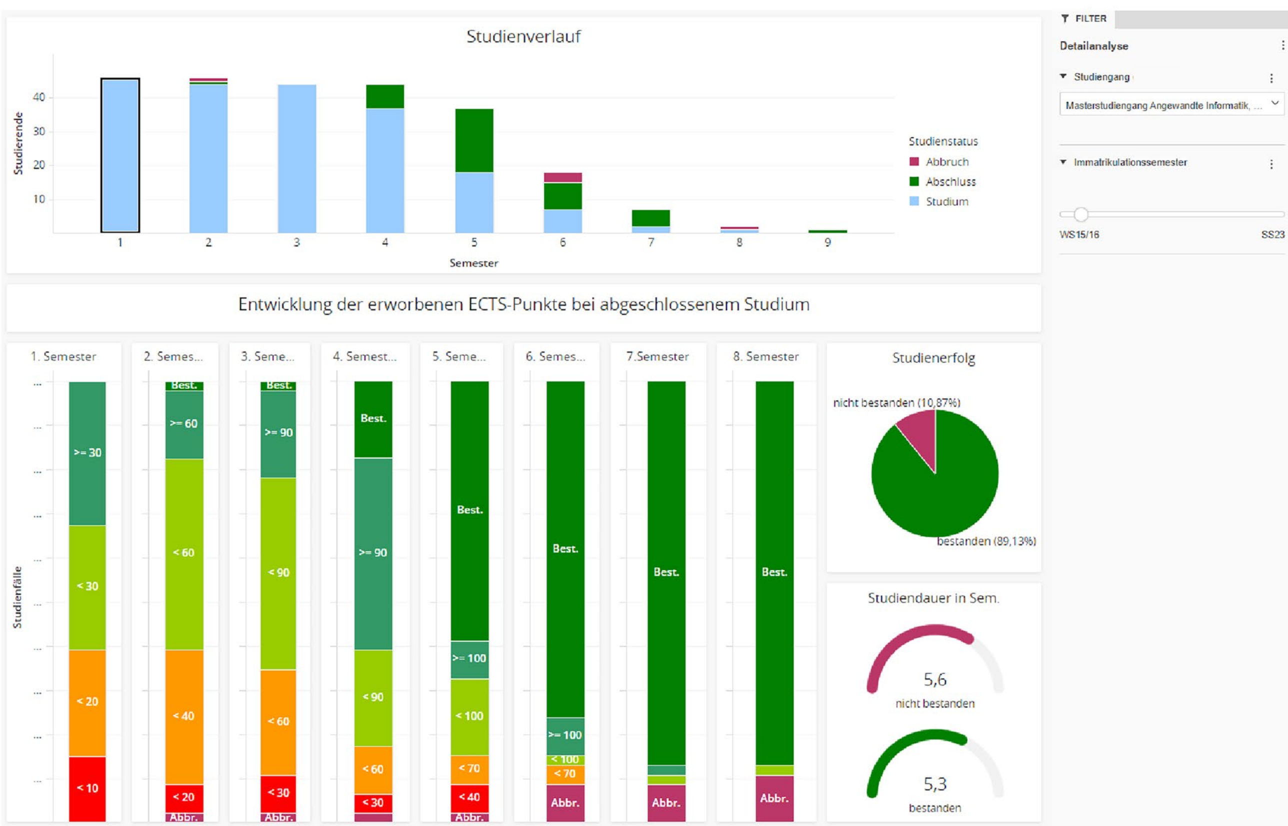

Fig. 4 Prototype of the study planning dashboard in CEUS

is starting to deploy these in university education. We now summarize some of the highlights developed at the different sites.

5.1 CEUS

Related to WA2, an initial exploratory data analysis of the study progress data with respect to module interdependencies and success, exploring potential use and obstacles of the data, has been made. Further approaches and data sources that can be consulted to support students' short- and long-term module choices (i.e., clustering certain student planning 'types', matching module descriptions, and job advertisements) have been identified. As a basis for module recommendations, a prototype of a digital study planning assistant has been developed (see Fig. 4) based on a revisit and extension of the requirement catalog elicited in [17]. This prototype will be evaluated against the current study planning situation at the University of Bamberg, which has been captured in a university-level survey.

5.2 Hybrid Recommender System for Learning Material

The Coburg group follows a holistic didactic philosophy that is learner-centered and addresses context-specific soft skills and factual knowledge. Therefore, all components are integrated into a goal-oriented learning concept that supports individualized learning by adaptive learning systems.

Building on this holistic philosophy, an earlier project (EVELIN) included a first prototype of a recommender system for learning videos [27] as one of its results. This system was primarily used in the context of programming and software engineering education. As a special feature, this environment allows learners to annotate learning videos with so-called problem tags whenever they encounter difficulties in understanding the material. In addition to the learner's behavior, these tags are used to recommend alternative videos that might better suit the learner's particular need. In addition, a so-called topic tree was used as a lightweight ontology for guiding recommendations by referring learners to topics that constitute prerequisites for understanding topics where they encountered difficulties.

This video environment worked well and was used by more than 2000 users across all departments of HSCo during the heyday of the Covid-19 pandemic. Nevertheless, the initial approach has several shortcomings and deficiencies that are supposed to be mitigated in VoLL-KI. For one thing, the topic tree was enriched by additional relationships into a more powerful ontology that captures the dependencies between concepts more comprehensively. This ontology currently covers the domains of (Java) programming and software engineering. Secondly, so far, recommendations are not based on knowledge of the characteristics of the particular user, such as her competence level, prior modules, specific interests, or learning styles [49]. To cope with these deficiencies, an initial learner model that allows to incorporate such knowledge was conceived. This learner model will be extended and refined if needed.

Current activities focus on devising and implementing hybrid recommendation algorithms, extending the scope of the learning material beyond learning videos by, e.g., individualized assignments, quizzes, background texts, or gamified elements, widening the covered domains beyond software development to AI and machine learning, linking learning material to the underlying ontologies, and designing learning elements in a didactically meaningful manner.

5.3 Virtual Reality-based Learning Experiences

Virtual Reality (VR) has successfully demonstrated learner support in various educational settings [20]. Also, VR has

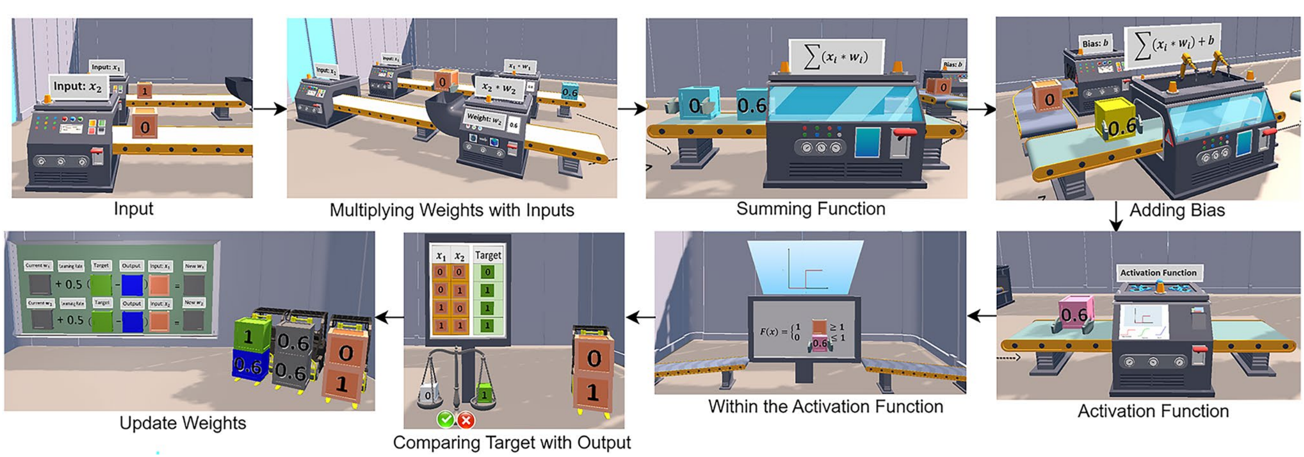

Fig. 5 Current prototype of the visualization of neural networks

been applied to computer science education use cases [1, 8]. However, there is little evidence yet about the effectiveness of using VR over alternative teaching approaches, mainly due to the lack of comparative studies (with few exceptions being [2]). Hence, the VoLL-KI project investigates underlying VR-specific factors potentially influencing learning outcomes. Besides free-viewpoint, and stereoscopic views in large, unbounded display spaces, work will specifically focus on embodied interaction [28] to support the learning process in VR. For potential learning topics, the focus will be on learning networking concepts such as routing or neural network concepts (see Fig. 5). To this end, we will conceptualize and implement both an interactive VR version and a desktop version of the learning experience. Those two systems will be evaluated w.r.t. learning effectiveness. At a later stage, the VR version is planned to be integrated as a web-based experience in an online course management system (Moodle).

5.4 Education Chatbot and Topic Segmentation & Classification of Lecture Recording Videos

The HSCO group is implementing a multi-modal chatbot that supports students studying AI related topics by permitting them to ask questions about the teaching materials and also Wikipedia. This chatbot has a front end with a Web user interface for demo purposes (later, we anticipate further integrations with Moodle and chat systems often used by student groups already to communicate with each other to facilitate adoption). The back end takes a collection of recorded video lectures, applies state-of-the-art speech recognition to transcribe the materials into textual form and applies text segmentation and classification. The resulting document segments are used as retrieval units by the chatbot's back-end to serve as answers. Figure 6 shows the architecture of our chatbot to support learners of AI and its integration with the video analytics pipeline.

At a later stage, units of indexing will be enriched with concept information from knowledge graphs. We are also working on a content middle layer where each retrievable item is addressable via a unique resource identifier.

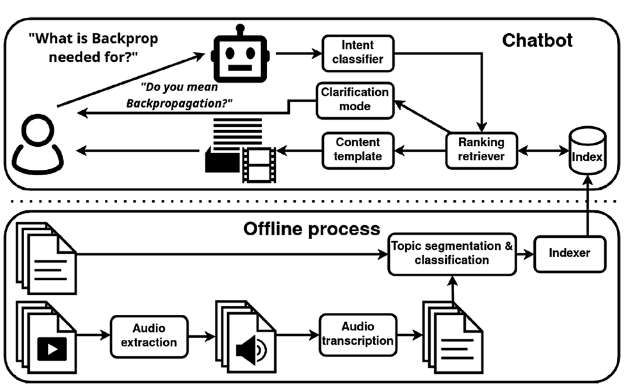

Fig. 6 Current architecture of the VoLL-KI chatbot [9]

5.5 Towards ALEA—an Adaptive Learning Assistant

The FAU group builds on its expertise in domain and competence modeling to supply a coordinated set of interactive and user-adaptive course materials that together constitute a semantically coordinated learning support environment. This is intended as an extension to the presence-lectures at university; we conceptualize it as a semi-supervised (by AI methods) flipped classroom (i.e., a self-study area).

The system is web-based and standalone (see https://courses.voll-ki.fau.de) but will additionally be integrated into learning management systems like Moodle (Bamberg/Coburg) and StudOn/Ilias (FAU): A dedicated front-end integrates the semantic services into HTML5 versions of the course materials, that are auto-generated from

a) fine-granular model of the objects/ concepts of the domain (Computer Science and AI) and their intrinsic relationships in the form of a theory graph,
b) a collection of learning objects – definitions, theorems, problems, interpretations, etc. – formulated in (semanti-

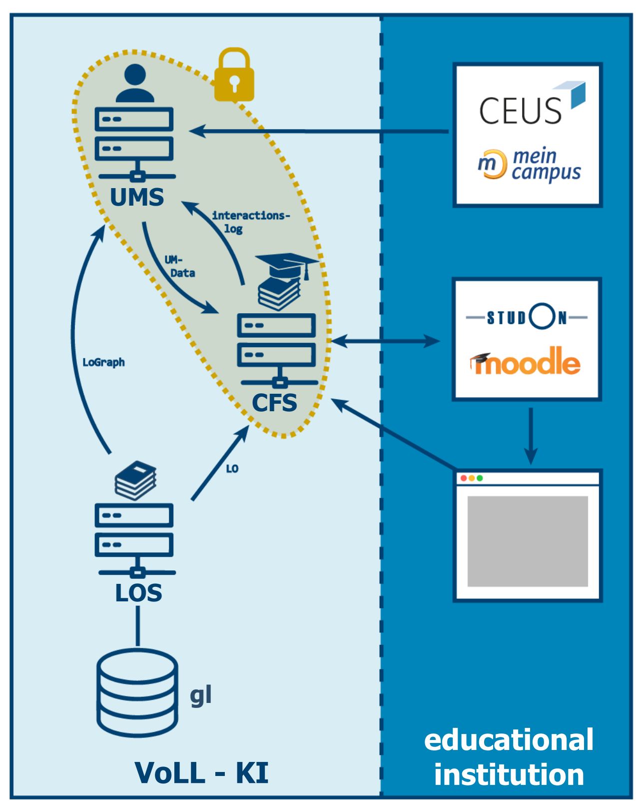

Fig. 7 Overview of ALEA Architecture

cally annotated) natural language and organized by the domain model structure, and

c) a learner model that infers the learner's competencies—a function from domain objects/concepts to a probability space whose dimensions correspond to the Bloom's revised taxonomy [3]—from her interactions with the material,

by a formal knowledge-management back-end. Figure 7 shows an architectural overview. As the learner model contains very sensitive personal data that is only needed in the Course Front-end Server (CFS), these two subsystems are only accessible in a cryptographic trust zone (indicated in yellow in Fig. 7). The sources of the domain theory graph, the learning object collection, and the courses, homework, and exams themselves are collaboratively managed and versioned in a dedicated GitLab instance. These are currently written in sTEX [34, 47], a LaTeXvariant specializing in semantic/didactic annotations. Analogous semantic annotation facilities for standard office formats and Markdown are being developed for additional coverage beyond Mathematics, Computer Science, and AI. The contents are served by a Learning Object Server via dedicated content/knowledge-based REST APIs. The Front-End is realized as a reactive browser application using the React library.

Currently, ALEA provides the following support services:

1. **Info on hover**: on hovering over text fragments annotated as term references i.e., a word or phrase that references a concept introduced or presupposed in the current context, the relevant definition is displayed in a pop-up. Clicking on this pop-up will display additional information, e.g., in the form of
2. **Guided tours**: for any term reference *T*, a guided tour explains the referenced concept *C* by a structured sequence of learning objects that build on the concepts the learner model predicts the learner has mastered and that leads up to *C*.
3. **Multilinguality**: Where the content commons contains language versions that ALEA can give access to these (currently realized for guided tours)
4. **Flash cards** support the reviewing and drill-learning of the concepts introduced in active course materials. Learners are randomly shown flash cards with concept verbalization that can be flipped to view the definition. Learners can self-assess their concept mastery, updating the learner model, which in turn affects the cards shown in a drill.

Future ALEA services include the following:

1. **Exam preparation**: the generation of, e.g., exam-like questions or drill cards based on a flexible domain selection.
2. **Socratic dialogues**: instead of explanations like in guided tours, Socratic dialogues guide the learner toward a chosen learning target via suitably chosen examples and problems.
3. **Tell me more**: a guided exploration of the content commons by suggesting "next topics" that are easily reachable from the knowledge subset.

Most of the services directly depend on the semantic/didactic model of **tasks**—e.g., reading a definition, solving a problem, working through a process—which we will discuss next. Based on a model of computer-science tasks [40], the Y model (Fig. 8) combines cognitive processes and knowledge elements together with problem descriptions; see [31] for details. For the cognitive processes, two taxonomies are used ([3, 12]), whereas the knowledge domain is modeled in OMDoc/MMT [33, 37]. The central aspect is the annotation of answer classes summarizing expected solutions as well as expected errors (only observable). Here, similar errors of students can be combined into one answer class; see [30] for details.

ALEA has been deployed for six courses with a total of more than 1000 students since WS 2022/23 at FAU and is used by a small but rapidly increasing fraction of the students (currently about 10% of actively participating

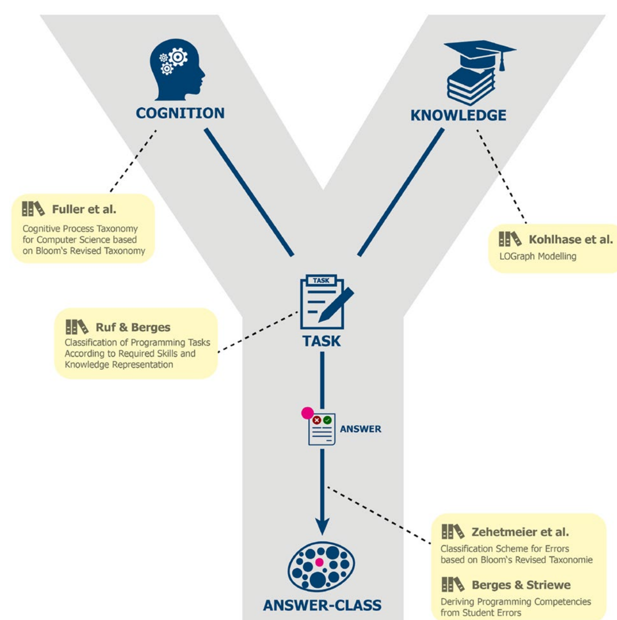

Fig. 8 Overview of combining domain and competence modeling: The Y-Model

students). Note that the quality of the user-adaptivity is mainly determined by the accuracy of the learner model, which is only activated for logged-in users.

5.6 Supporting Students to Cope with Programming Assignments by Automated Explanations

Debugging is a core competence in CS that is hard to acquire. Nearly every experienced programmer has experienced a situation in which an error—what turned out to be a simple error—has required much time to identify and fix. This motivates us to provide assistance to novice programmers when they face a programming task that calls for automated methods. A common approach is to employ evaluation platforms using automated testing [39], also adopted in intelligent tutor systems [21]. These platforms can provide immediate feedback, yet we have learned from our students that test discrepancies are often very hard to understand and hence of little use. However, effective approaches need to go beyond running automated tests as the task of locating and susbsequently fixing bugs is a skill that the programmer acquires with experience and with a firm understanding of the underlying problem [38]. Our work is motivated by the assumption that AI diagnosis techniques may be applied to the testing-based evaluation of student submissions in order to locate potential faults and give concise and effective feedback to students.

6 Conclusion and Future Work

We have presented the aims, work plan, and initial results of the VoLL-KI project. The three project partners are attacking the problem of automatically generating learner-adaptive, interactive course materials and learning situations with complementary but synergistic AI methods. All methods have in common that they rely on detailed domain and context models complemented by fine-grained models of learner behaviors and competencies—true to the project motto: *learning from learners*.

Initial methods and systems have already been developed and deployed locally; we will integrate all our contributions with our teaching processes at all three participating institutions, thereby improving education. This will also allow us to evaluate the efficacy of the various approaches in operational settings and over a longer term.

The components developed in the project will be open-source and largely contribute to existing open-source initiatives like e.g., Moodle. They can be re-used after and even during the project lifetime; we invite the "edutech" community to participate during and after the project.

We also have the definite goal to spread our modular components across educational institutions in Germany and across Europe without forcing the adoption of an all-encompassing framework. Each site can make informed choices about adopting more or fewer components as they see fit for their institution and taking into account their local IT landscape.

Acknowledgements Supported by BMBF Grants 16DHBKI089 / 16DHBKI090 / 16DHBKI091 in the program "KI in der Hochschulbildung". The application process was supported by the High Tech Agenda Bavaria initiative and TAO.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data availability All systems are available at https://www.voll-ki.eu. Here all project data is presented as well.

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