Architectural Design of an Adaptive, Structure-Aware Intelligent Tutoring System

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***Abstract*—Intelligent Tutoring Systems (ITS) for Learning Management Systems (LMS) combine the benefits of user-centered learning and the provisioning of easy-to-use learning content in one place. They typically have two major drawbacks. First, they are LMS-specific (i.e., not adaptive). Thus, many LMS do not include an ITS because existing solutions cannot be reused. Second, they lack in a didactically usable representation of the structure of the learning content (i.e., they are not structure-aware). Therefore, the learner may get lost during the provision of assistance. Overcoming both of these drawbacks at once is a desirable objective, because it allows the learner to take advantage of personalized learning in diverse LMS while accessing a large amount of available learning content. In addition, it allows an ITS to use cross-plattform analytics (CPA) to improve assistance. The main challenge in achieving this objective is dealing with the heterogeneous approaches to structuring learning content used by different LMS. For this purpose, an adaptive, structure-aware ITS is proposed that can work with diverse LMS by using a generic data structure that can represent and process the required learning knowledge data in a system-independent way. The focus of this paper is to outline the architecture of this system.**

Keywords-personalized learning; technology-enhanced learning; learning analytics; educational data mining.

I. INTRODUCTION

The purpose of integrating *Intelligent Tutoring Systems* (ITS) [3] into *Learning Management Systems* (LMS) is to combine LMS-specific advantages (e.g., easy-to-use provision of a large amount of learning content in one place [2]) and ITS-specific benefits (e.g., adaptation of learning content to the user's needs [5]). There are typically two major drawbacks to combining ITS and LMS.

1) The ITS are designed for a specific LMS only (i.e., they are not *adaptive*) such as the one developed for Moodle [13].
2) The LMS lack in a didactically usable (e.g., graphical) representation of the learning content structure that can be controlled by the ITS (i.e., they are not *structure-aware*) [14].

The former causes that neither implemented didactic concepts can be reused nor derived user assistance profiles can be considered in different LMS [5]. The latter can result in the user not being able to follow the assistance that is related to the structure of the learning content, and subsequently getting lost in the learning space during the guiding process [7]. This is due to the fact that ITS are intended to guide the learner through the learning content, while LMS are mainly designed for self-employed learning. To bring the two together, the ITS must be coupled with the content structure of the LMS in a way that is comprehensible to the user.

Related work addressing these two drawbacks and the corresponding research challenges is summarized in Section II. In Section III, an adaptive, structure-aware ITS is proposed that overcomes both drawbacks at once.

II. RELATED WORK

Previous work on ITS adaptation has been primarily concerned with adapting these systems to the learner [12], and rarely with adapting these systems to different learning environments in which they might be integrated. Thus, the ITS developed so far are usually independent systems [11] that cannot make use of the large amount of learning data that is available in the established LMS.

The research that has been done to integrate intelligent tutoring mechanisms into learning environments [1], has mainly focused on developing learning-environment-specific systems that are limited to working with environment-specific data. To overcome this limitation, Mangaroska et al. investigated how learning data from different e-learning systems combined in a learning ecosystem can be represented and processed system-independently [9]. For this purpose, the authors proposed a cross-platform architecture [10] that includes three e-learning systems from which learner-generated data is collected. This data is converted into the unified *Visualized Education NTNU System Object Notation (VSON)* and processed by a visualization dashboard. The main focus of this research is the generic integration of learning-analytics in e-learning systems and the investigation of what *cross-platform analytics* (CPA) means for learning design research [8]. As far as known, it has not been investigated how an ITS integrated into an LMS can make use of the collected data, while the purpose of the proposed system is to provide didactically traceable assistance functionalities based on this data in a system-independent way. Thus, the focus of this research is on how to generically provide assistance functionalities and the corresponding system-specific assistance components of the ITS LMS independently.

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How to integrate ITS functionalities into arbitrary LMS was investigated by Palomino et al. [4, 6]. For this purpose, a system was developed that is LMS-independent by using a generic data structure for the learning content and that enables learning sequences piecewise conditional on the learner's performance measured by grades [5]. A prototype editor for defining these sequences has been implemented in Moodle. As far as known, there has been no investigation of the possibility of creating or generating a structured visualization of the learning content from the generic data structure. Furthermore, although the data structure is system-independent, the ITS parameterization component (i.e., the path specification editor) and the ITS assistance component (i.e., the learning sequence mechanism) are currently dependent on Moodle. The focus of this research is therefore on what kind of assistance can be provided system-independently and how the corresponding components can be built and automatically provided for diverse LMS.

III. ADAPTIVE, STRUCTURE-AWARE ITS

Overcoming the two drawbacks mentioned in Section I is particularly challenging due to the heterogeneous approaches to structuring learning content used by different LMS. For this purpose, a structure-aware ITS is proposed that can be used for diverse LMS by the utilization of a generic, LMS-independent learning knowledge data model. As shown in Figure 1, this system includes two assistance components that have to be integrated into the considered LMS and that are described in Section III-A and III-B. Both of these components can be provided automatically in order to make the ITS as system-independent and thus as adaptive as possible. The data that is required for the generation and dynamic parameterization of these components is stored in a generic data structure presented in Section III-C. This data is retrieved from the diverse LMS using a thin adaptation layer which is described in Section III-D.

A. Knowledge Graph Editor

The first assistance component, called the *knowledge graph*, is a graphical representation that visualizes the learning content. It is embedded in the *knowledge graph editor* which is integrated with the considered LMS. The editor can be used in two different modes. One is intended to support the learner and is called *read-only mode*. The other one is intended to support the configuration of the ITS by the teacher and is called the *editing mode*. In the *read-only mode* the *knowledge graph editor* can support the learner in the following ways.

1) It provides an overview of the learning content, it's structure and the learner's progress.
2) It offers the ability to graphically navigate within the content, including the convenient selection of learning content suggestions.

In the *editing mode*, the *knowledge graph* can be used by the teacher to parameterize the assistance process for the following purposes.

1) The specification of the metadata for the learning content

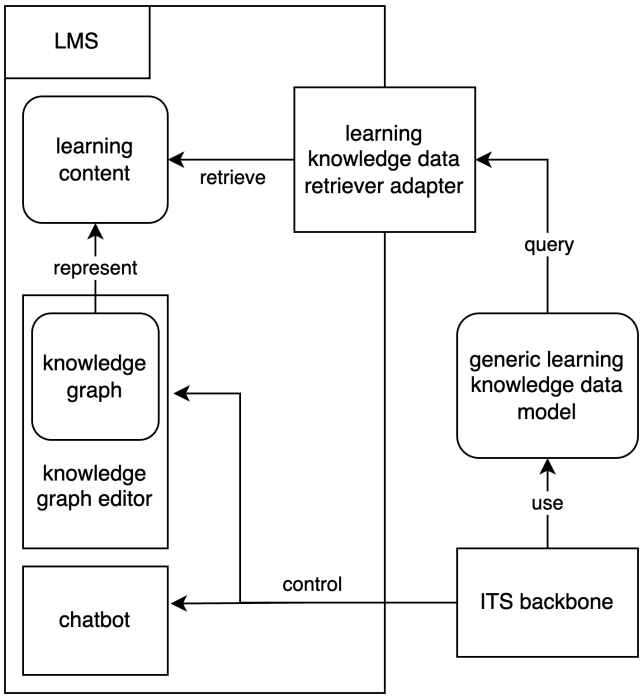

Fig. 1. Conceptual architecture of the proposed adaptive, structure-aware ITS.

2) The definition of the content-related dependencies between the learning content

B. Chatbot

The second component for providing assistance is a *chatbot*. It is integrated into the considered LMS and provides typical ITS functionalities such as suggesting learning content. This component is controlled by the *ITS backbone*, which processes the data from the *generic data model* (see Section III-C). The *ITS backbone* is also coupled to the knowledge graph editor, so that it can influence the content representation. This means that it can cause the representation to be restructured according to the learning content suggestions accepted by the learner, or it can cause the adaptation of the representation to the learner's state of knowledge.

C. Generic Data Model

With regard to the intended assistance functionalities, the presented components require two types of data, the so-called *learning knowledge data*. First, information about what content the learner is studying and how this content is structured is required for the composition of the knowledge graph. Second, information about the learner's interaction with the system is needed to adapt the knowledge graph to the learner's progress and to determine appropriate assistance mechanisms.

Since the learning knowledge data must be system-independent, a *generic learning knowledge data model* is proposed that is used for two different purposes. On the one hand, it is responsible for the system-independent provision of data for the algorithms that determine which assistance

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processes are required and when. On the other hand, it is used for the automatic provision of the ITS components that are integrated into the LMS under consideration. This is necessary to ensure that the ITS is as system-independent and therefore as adaptive as possible.

D. Data Retriever Adapter

The information stored in the generic learning knowledge data model is queried by a thin adaptation layer, which is responsible for the coupling between the adaptive ITS and the considered LMS. This layer is implemented by a *learning knowledge data retriever adapter*. In order to minimize dependencies on the LMS, and because the adapter must be system-specific, it encapsulates no more functionality than retrieving the required data.

IV. CONCLUSION AND FUTURE WORK

To overcome two major drawbacks of current ITS for LMS, the architectural design of an adaptive, structure-aware ITS was presented. This system provides assistance using a chatbot and a graphical representation of the learning content structure. The data required for the respective assistance scenarios is retrieved through a thin adaptation layer and stored and processed in a generic, LMS-independent data model. Although the adaptation layer has to be system-specific, it encapsulates no more functionality than the plain data retrieval and is therefore easy to implement for an appropriate LMS. The actual ITS functionality is implemented system-independently, depending on the data that can be delivered by the LMS-specific adaptation layers. In addition to the parameterization of the assistance components, the data from this model is also used for the automatic provision of these components.

In summary, using the ITS with the proposed architecture, the learning content of diverse LMS can be adapted to the user's needs. The approach will be evaluated in terms of applicability and effectiveness considering a subset of appropriate state-of-the-art LMS.

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