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COLUMN

The return of intelligent textbooks

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Abstract

The advancement of computational Artificial Intelligence (AI) in the recent decade has been transformative for many domains, including AI in Education. One direction, where it has caused a noticeable increase in research activity, is application of AI technologies to enhance digital textbooks by making them more interactive, engaging, adaptive, and intelligent. For many researchers coming into this field, it would have seemed as if an intelligent textbook is a completely new idea. We would like to provide a historic outlook on this field and outline the important phases that it went through over the last three decades. We hope that such an account can inform interested readers and help them better understand the problems and the approaches of intelligent textbooks.

INTRODUCTION

In the new millennium, we are witnessing a quiet revolution in the area of textbooks, the traditional tools for learning. On one hand, digital textbooks are gradually replacing their printed counterparts. On the other hand, researchers from many fields of AI consider the emergence of a digital textbook as an opportunity to apply various technologies that could further augment them. Over the last 10 years, the research on intelligent textbooks, that is, the use of AI to enrich textbooks, has become one of the leading streams in this area. However, this is rather a "return of intelligent textbooks" since the research on applying AI to textbooks started more than 30 years ago. In this paper, we make an attempt to show the "big picture" of research on intelligent textbooks tracing the history of this work from the 1990s to nowadays. We also try to trace the generations of AI technologies that contributed to the field.

KNOWLEDGE ENGINEERING GENERATION

The first intelligent textbooks were developed in 1990 in the field of adaptive hypermedia. The intelligence and personalization in these books were based on classic AI approach—knowledge engineering produced by domain experts. For every textbook, domain experts determined key concepts presented in it (domain model) and annotated textbook fragments with sets of concepts covered there (content model).

The knowledge of individual learners (student model) was represented dynamically as weighed overlays of the domain model. With relatively simple models, early intelligent textbooks pioneered a range of "smart" functionalities-such as adaptive navigation, adaptive presentation, content recommendation, and concept-based navigation (Henze et al. 1999; Weber and Brusilovsky 2001). More recent work based on

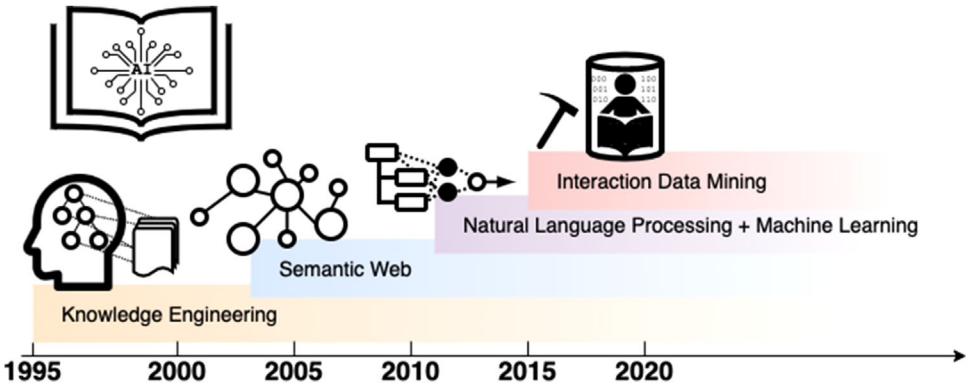

FIGURE 1 The evolution of intelligent textbook technologies

expert-driven knowledge engineering used a finer level knowledge representation that also enabled question answering (Chaudhri et al. 2013). While this generation of intelligent textbooks demonstrated what could be done by representing "knowledge behind pages," the reliance on expensive knowledge engineering made these approaches hard to scale.

SEMANTIC WEB GENERATION

In the beginning of 2000s, the attention of many AI researchers shifted towards Semantic Web (SW) technologies. Standardized formats and modeling languages for shareable and expressive knowledge representation were introduced along with new architectural solutions for intelligent software. This development resonated with the intelligent textbooks community. Implementation of knowledge models as SW ontologies and educational material as linked and annotated learning objects opened up adaptive textbooks architectures and enabled integration of external content. Initial projects developing these ideas focused on proposing new fully ontological architectures that allowed manual extension of adaptive textbooks with external learning objects (Dolog et al. 2004; Melis et al. 2006). Later, successful attempts were made on applying SW technologies to automate integration of external content into adaptive textbooks (Sosnovsky, Hsiao, and Brusilovsky 2012). Another direction of research on SW-empowered textbooks has stemmed from the expressive power of descriptive logic combined with symbolic natural language processing (NLP). It has supported development of semantically annotated textbook prototypes that "understand" their content and can engage in rich interactions with students including meaningful question answering and concept mapping exercises (Chaudhri et al. 2013).

NLP + ML GENERATION

Further advancement in the field of NLP and machine learning (ML) enabled a new generation of research on using the very content and structure of textbooks as a source of knowledge for "smart" functionality. A number of papers explored approaches for automatic extraction of topics and concepts from textbooks (Wang et al. 2016) as well as to mine various kinds of semantic *relationships* between these concepts (Labutov et al. 2017). Ultimately, this line of research leads to automatic construction of full concept-based domain models "behind pages" (Alpizar-Chacon and Sosnovsky 2021). These models can be used to support intelligent and adaptive services pioneered by the early textbooks (such as concept-based navigation or integration of external content), yet without expensive manual knowledge engineering. Another application of NLP technologies that has gained prominence in the last several years is the use of textbooks to generate additional learning content such as assessment questions (Kumar, Banchs, and D'Haro 2015) or definitions (Yarbro and Olney 2021).

INTERACTION DATA MINING GENERATION

The next advancement in intelligent textbooks has been fueled by the growing volume of user interaction data generated from digital textbooks and modern technologies that leverage these data in several directions (Figure 1). For example, interaction data has been used to improve recognition of prerequisite relationships between domain concepts (Chaplot et al. 2016). Data generated by page navigation and highlighting behavior were used to mine students' reading strategies and track their focus of attention (Yogev et al. 2018; Winchell et al. 2018).

More recently, interaction data were applied to infer the knowledge state of students' reading textbooks. Traditional student modeling technologies, which use student problem-solving as evidence of knowledge growth, were redesigned to use users' reading behavior like page navigation and dwell time. This enhances the quality of students' knowledge modeling in digital textbooks and supports maintaining knowledge models for textbooks where student practice evidence is not available (Thaker et al. 2018; Carvalho et al. 2018). Ultimately, advanced domain modeling and the improved student modeling enabled more powerful personalization approaches for digital textbooks platforms to enable adaptive recommendations (Thaker et al. 2020) based on students real-time behavior for advance reading and remediation.

While we titled this paper "The Return of Intelligent Textbooks" to stress an increased interest to this topic over the last few years, our brief review shows that the work on intelligent textbooks has never stopped. It moved on with every new generation of AI technologies, exploring new exciting ways to make textbook "smart," interactive and useful. We expect that this trend will continue and hope that this brief review will be helpful to inform the future work.

CONFLICT OF INTEREST

The authors declare that there is no conflict.

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