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Does Artificial Tutoring foster Inquiry Based Learning?

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ABSTRACT: This contribution looks at the Intelligent Tutoring Interface for Technology Enhanced Learning, which integrates multistage-learning and inquiry-based learning in an adaptive e-learning system. Based on a common pedagogical ontology, adaptive e-learning systems can be enabled to recommend learning objects and activities, which follow inquiry-based learning (IBL) and multistage learning (MSL) pathways. This paper will show how learning activities and pathways are formalized so that they become suitable for artificial tutoring. Therefore relations between different IBL & MSL learning objects are establish as learning pathways, in a way that they become readable to e-learning systems. Developing specifications for pedagogical meta-data and pedagogical rules derived from learning pathways provide the opportunity to connect technology enhanced learning with IBL & MSL. The reader will learn how the complex structure of inquiry-based learning and multistage learning was adopted to the extent that it can be facilitated by adaptive e-learning systems. Results show that the transition from IBL to computational IBL requires a certain adaption of the student-centred notion to become feasible for computational formalities.

KEY WORDS: Inquiry-based learning, multi-stage learning, adaptive e-learning systems, pedagogical ontology, artificial intelligence

INTRODUCTION

The Intelligent Tutoring Interface for Technology Enhanced Learning (INTUITEL) aims to enhance state-of-the-art e-learning content and Learning Management Systems (LMS) with features that so far have been provided only by human tutors. An INTUITEL-enabled system constitutes an integrated learning environment that configures itself in response to any learner, monitors his/her progress and behaviour, combines these data with pedagogical knowledge and then by automated reasoning deduces guidance and feedback.

This contribution wants to look at INTUITEL from various angles. First, the authors discuss the framework of INTUITEL and outline the

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development of the Pedagogical Ontology and didactical factors, which attend to interlink technology and pedagogy in a non-linear manner. Second, this paper engages into inquiry-based learning (IBL) as a common pedagogy for science education and looks at its adaption to the needs of the Pedagogical Ontology based on the comparison of multi-stage learning (MSL). Conclusively, the authors draw on the development of the Pedagogical Ontology as well as the adaptions of inquiry-based learning and multistage learning to discuss in how far these pedagogies needed to be adopted to fit to formalities of ontology writing. Moreover, it will be shown how student-centred approaches such as IBL and teacher-centred approaches such as MSL differ in regards to adaptions to technical frameworks. It will be reflected whether teacher-centred approaches or student-centred approaches are more compliant to technological formalities for artificial tutoring.

PEDAGOGICAL ONTOLOGY

The Pedagogical Ontology (PO) was developed at the intersection of Web-Didactics (WD) metadata (Meder, 2006), ontology writing language (OWL) and pedagogies such as IBL and MSL to interlink pedagogy and technology.

Schmoelz et al. (2013) show how the Pedagogical Ontology was conceptualized and how it may enable intelligent tutoring systems to recommend IBL pathways. Starting point is the Web-Didactics theorem, which provides a common set of pedagogical meta-data and, therefore, a suitable classification for learning pathways, activities and content. Based on different media types and knowledge types, which incorporate pedagogical functions, one can describe every possible way of communicating knowledge via media. Second, inquiry-based learning structures have been used to inform in which manner knowledge types and media types were supplemented and sequenced. Building relations between knowledge types that were derived from inquiry-based learning set the ground for formalizing so that IBL pathways become processable by machines. The last ingredient that completes the Pedagogical Ontology and caters sufficient formalization is the ontology writing language. "An ontology is an explicit specification of a conceptualization" (Gruber, 1993). Stated axioms and constrains for possible interpretations for defined terms of WD and IBL are merged into explicit specification via OWL. The Ontology writing language supports the integration of the WD classification hierarchy and specific constraints of IBL and, therefore, it was used to build a coherent and consistent specification, that provides sufficient formality to recommend IBL via INTUITEL. Main benefices of combining the Web-Didactics meta-data system with Ontology Writing is that together they build a framework to identify, sequence and recommend learning objects in a predefined manner and also brings the flexibility that predefined sequences can automatically be changed based on aggregated data of learner behaviour.

INQUIRY-BASED LEARNING AND ITS KNOWLEDGE TYPES

Inquiry-based learning is based on the idea that science education should closely relate to science practice, an idea advocated by Dewey (1964a, 1964b). “Participation in inquiry methods can provide students with the opportunity to achieve three interrelated learning objectives: the development of general inquiry abilities, the acquisition of specific investigation skills, and the understanding of science concepts and principles“ (Edelson, Gordin, & Pea, 1999). This approach allows learners to attend to scientific methods such as observation, experiment, and construction of knowledge. Therefore knowledge types of an IBL pathway should cater different steps of science practice such as posing questions, formulating hypothesis, conduction investigation, construction explanations and results.

Against this background, the following knowledge types have been supplemented and sequenced as presented by Schmoelz et al. (2013).

Table 1. Description of IBL and web-didactics meta-data for CIBL

Learning Phase	Learning Activity (LA)	Knowledge Type (KT)
Phase 1 Question Eliciting Activities	Exhibits Curiosity	Receptive: pique curiosity and/or Interactive: pique curiosity and/or Cooperation: pique curiosity
	INTUITEL possible scientific questions	Receptive: Orientation: Question
	Students chooses a question that guides the online lesson	Interactive: Assignment: Single Choice: Chose Question
Phase 2 Planning of Active Investigation	Student proposes preliminary explanations or hypothesis	Interactive: Assignment: Hand-in: propose hypothesis
	Example of preliminary explanations or hypothesis	Receptive: Explanation: Example: Hypothesis
	Propose possible scientific methods to engage the chosen question	Receptive: Orientation: Methods
	Student chooses a Method	Interactive: Assignment: Single Choice: Choose Method

Table 1. Description of IBL and web-didactics meta-data for CIBL (cont.)

Phase 3 Creation and Active Observation	Student Conducts Investigation and Gathers Evidence from Observation	Interactive: Assignment: Hand-In: Plan Investigation OR Interactive: Assignment: Simulation
	Example of evidence from the chosen method.	Receptive: Explanation: Example: Investigation
Phase 4 Discussion	Student provides explanation based on evidence	Interactive: Assignment: Hand-in: Provide Explanation
	Example of explanations from the chosen question	Receptive: Explanation: Example: Explanation
	Example of a different explanation from another method	Receptive: Explanation: Example: Further Explanation
Phase 5 Communication and Reflection	Student prepares presentation and communicates results	Interactive: Assignment: Hand-in: Present Evidence
	Example of presentation and possible communication of the results	Receptive: Explanation: Example: Present Evidence
	Student reflects on the differences between its own method, investigation, evidence and presentation and the examples given from INTUITEL	Interactive: Assignment: Hand-in: Reflect on Evidence

Table 1. shows the distinction between learning phases, learning activities and knowledge types to ensure that the core ideas of inquiry-based learning are engaged by a structure of activities. It can been seen that the knowledge types are mapped against the background of inquiry-based learning and correspond to the Web-Didactics theorem.

MULTI-STAGE LEARNING AND ITS KNOWLEDGE TYPES

Multi-stage learning is also known as “cognitive – associative – autonomous” or cognitive apprenticeship (Collins, Brown, & Newman, 1987). The multi-learning concept is based on the ancient Greek philosopher Aristotle, who structured the learning process in the phases of (1) sensuality and percipience, (2) wit and thinking, and (3) ambition and desire. Fitts and Posner (1987) used “cognitive – associative –

autonomous" in their theory of learning phases. As the learner moves through the phases, s/he is learning a new skill.

To have a general overview of the three stages, the following table describes each stage within the corresponding Learning Activities and Knowledge Types.

Table 2. Description of MSL and web-didactics meta-data for CMSL

Learning Phase (LP)	Learning Activity (LA)	Knowledge Type (KT)
Stage 1: Cognitive Stage	INTUITEL recommends learner orientation according to the topic INTUITEL recommends an explanation of the topic according to the relevance	Receptive: Orientation (this could be: Facts, History, News, Log, Overview, Knowledge Map or Abstract) Receptive: Explanation
Stage 2: Associative Stage	INTUITEL: Additional knowledge will be understandable by the example. Student follows in an interactive way because he is urged to write down the steps on his own.	Interactive: Explanation: Good Practice: Step by Step Interactive: Assignment: Hand-In
Stage 3: Autonomous Stage	INTUITEL recommends an assignment to student to make alone. Student hands in answers.	Interactive: Assignment: Hand-In

In the first phase called "cognitive" stage, the learner is trying to figure out, what exactly needs to be done and is developing a declarative understanding. That means, the learner is confronted with the topic. The second phase is the associative stage, in which the learner needs to associate in relation to his understandings in this field within exercises and assignments. In the third phase the learner is able to solve problems on an expert level, provided that the learner went through the first two stages.

This learning pathway is the most often used learning pathway in German-speaking countries and also known as "Frontalunterricht". It can be considered as a teacher-centred approach that is typically for a tradition where the principles of thinking are considered as an important background.

DISCUSSION AND CONCLUSION

MSL and IBL are concepts that have mainly been implemented within face-to-face teaching practices. As described in this paper, the INTUITEL project transfers MSL and IBL into online environments with artificial tutors via the Pedagogical Ontology. This transition from face-to-face tutoring to artificial tutoring, caused the concepts of MSL and IBL to lean towards structuring their pathways to the extent that they become suitable to computational processes and, therefore, computational multistage learning (CMSL) and computational inquiry-based learning (CIBL) was developed.

Conclusively, one can ask how CIBL and CMSL is expressed by INTUITEL and what are the core differences between IBL and CIBL as well as MSL and CMSL? In regards to the transition from IBL to CIBL it becomes obvious that open IBL cannot be implement because computers cannot react to semantically rich and individual research questions of students and guide them in their own thinking. This kind of mutual understanding requires great participation from both, student and teacher. Henceforth, the INTUITEL project works with the structured IBL pathway, in which the teacher offers a sum of optional research questions and the student can pick the one of personal interest. The intelligent tutoring system can follow up on the chosen research question, but it cannot read research questions that are novel to the machine. So, the transition from IBL to CIBL required a certain limitation of the student-centred notion to become feasible for computational formalities.

Looking at the transition from MSL to CMSL, one cannot detect a great difference due to the requirement of computational formalities. MSL works with low participation of students and can be described as a teacher-centred approach as artificial tutoring provide a great framework to deliver content, provide simulations and tasks for the students.

The authors want to remind that at this point of the research there is a fruitful discussion about the transition of face-to-face didactical models into computational didactical models. However, the implementation of an artificial tutoring system that can attend to the element of participation and dialogue in a human-to-human manner is yet to be established. Without the element of participation and dialogue one can ask how far INTUITEL reproduces traditional hierarchies of educational structures and knowledge. The participatory moment on the learners side increases the challenge for the transition from human-human to human-machine interaction within INTUITEL, mainly due to the fact that artificial tutoring cannot attend to semantically rich inputs from students and human ambiguities.

On one hand, it can be summarized that artificial tutoring can provide great outputs in regards to teacher-centred didactical models such as MSL. Against the background of students-centred models one can see that artificial tutoring is feasible if the element of semantically rich student input, which requires human understanding and empathy, is limited to the extent that it becomes processable by the machine. On the other hand, INTUITEL allows students to freely explore and choose various knowledge types and media types. So, students can learn based on their personal interests, speed, technical circumstances, level, etc. and, furthermore, INTUITEL can structure and recommend a vast variety of content based on these individual aspects, if the students look for greater guidance and structure in their learning process. In this manner the student-centred notion is fostered within INTUITEL, both for multistage learning and inquiry-based learning.

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