EXTENDED ABSTRACT

Researchers in the field of science education have been employing exploratory learning approach to scientific inquiry learning environments aiming at maximizing learners’ engagement and experience. Although many scientific inquiry learning environments have been developed, little attention has been given to employ a learner model to assess the temporally variable scientific inquiry skills and provision of tailored pedagogical support. Addressing the challenges is not trivial because the learning environment has to deal with a great deal of uncertainty inherent in capturing and inferring a learner’s interaction behaviour. In this light, the thesis focuses on developing a learner model for INQUIRY PROCESS (INQPRO), a scientific inquiry learning environment developed within this research work.

The first challenge addressed by this thesis is to determine the appropriate learner properties (features) for the static portion of INQPRO’s learner model. Extracting the required features and presenting them via Bayesian Networks could be difficult. The difficulty stemmed because INQPRO consists of six differently designed user interfaces. The uniqueness of activities contained within each interface has resulted in determining the observable and non observable nodes, as well as the causal relationships between these nodes became a challenging task. In addition to that, what interaction behaviour constitutes evidence to the learner model and when an observable node should be instantiated had also been a major challenge in this research work.

Having gathered a learner’s interaction behaviour, how should a learning environment effectively assess the mastery levels of scientific inquiry skills that
evolve across time is the second challenge addressed in this thesis. Existing learning environments that employed decision-theoretic approach, however, rely on either a static Decision Network (DN) or a Dynamic Decision Network (DDN). The DDN is constructed via repeating a static DN across time. Both approaches, however, have not been practically sound to INQPRO. Overcoming these challenges is not a trivial task. Considerations including the efficient way to construct a DDN, the overall size of DDN constructed, causal relationships between nodes, and many more must be well taken care of. This thesis investigates different proposed INQPRO’s dynamic learner model and their conditions so that modeling and intervening in the INQPRO learning environment could be optimum. Static nodes have been introduced to model the temporally variable scientific inquiry skills as oppose to merely depending on dynamic nodes proposed in other research work.

An iterative evaluation process was carried out aiming at (i) investigating the optimal static and dynamic portions of INQPRO’s learner model, (ii) determining what constitutes evidence and how nodes should be instantiated, and (iii) determine the optimal animated pedagogical agent interaction approach in order to avoid distraction to learners. A Two-phase empirical evaluation was conducted. The first phase of evaluation had been given focus to investigate the preliminary predictive accuracy of the first version of INQPRO’s learner model via simulated student technique as well as a field study with a domain expert and 30 learners. The findings of the evaluation provided insight into ways to improve the first version of INQPRO’s learner model. In the second phase of evaluation, raw log data gathered from the 30 learners were transformed to evaluate the proposed different versions of dynamic learner model. The preliminary outcomes, consisting of the optimal learner model and its condition, were reevaluated with two separate field studies consisting of a total of 6 domain experts and 102 human learners. In conclusion, results of the evaluations indicated that $\mathcal{M}_{D\mathcal{C}_3}$ is the optimal dynamic learner model. The optimal conditions for $\mathcal{M}_{D\mathcal{C}_3}$ are that variable instantiation approach must fix at $\mathcal{E}_y$ while the weight between two consecutive DNs should set at $C_y$. 
RESEARCH OBJECTIVES

The research work within this thesis aims at proposing and investigating a sound probabilistic approach particularly by employing the decision-theoretic approach to assess a learner’s scientific inquiry skills and provision of tailored pedagogical interventions. In specific, the research work presented in this thesis has the following objectives:

i. To determine the features needed in a static learner model to assess the mastery levels of two scientific inquiry skills (Hypothesis Formulation and Variable Identification) through learner’s exploratory behaviour.

ii. To determine the optimal dynamic learner model that provides probabilistic assessment of temporally variable scientific inquiry skills as well as generation of tailored pedagogical interventions.

iii. To determine the properties for integration of proposed static and dynamic learner model into INQPRO learning environment. These properties include what constitute evidence from a learner’s interaction behaviour, when the evidence should be instantiated to the network, when should the network be updated to retrieve the posterior probabilities, and how animated pedagogical agent should intervene to minimize distraction.

iv. To determine the optimal conditions via empirical evaluations of approaches for variable instantiation and weight assignment between two consecutive INQPRO’s interfaces for the proposed learner model.
THESIS CONTRIBUTIONS

i. Identification of learner properties and structure for static learner model.

ii. Identification of the design and conditions of dynamic learner model to provide assessment of temporally variable scientific inquiry skills.

iii. Identification of properties as preferred practices for integration of proposed learner model into scientific inquiry learning environment.

iv. Identification of properties for optimal agent intervention approach in scientific inquiry learning environment.
THESIS OUTLINE

The central question for the research is:

How can we develop a probabilistic learner model within a simulation-based scientific inquiry learning environment that assesses the temporally variable scientific inquiry skills (Hypothesis Generation and Identification Variable) and provision of tailored pedagogical support in timely manner, based on individual interaction with the learning environment?

Chapter 1 begins with discussion on the challenges and motivation of the research work. It is then followed by highlighting the research objectives, and summary of thesis contributions.

Chapter 2 provides the theoretical framework of scientific inquiry learning, which includes defining the term, identifying the processes of scientific inquiry, highlight the challenges in employing scientific inquiry, the role of metacognition in fostering the acquisition of scientific inquiry skills, the adoption of exploratory learning approach to facilitate the acquisition of scientific inquiry skills. It then proceeds with the discussion on challenges to integrate exploratory learning approach to Intelligent Tutoring Systems (ITSs), a line of research that focuses on providing tailored pedagogical support to learners. Exploiting the exploratory learning approach in scientific inquiry learning environment, however, is not a straightforward task. Thus, this second part of this chapter highlights existing inference methods employed by researchers to overcome the challenges.

Chapter 3 focuses on decision-theoretic approach, the proposed reasoning mechanism employed in this thesis. It begins with the definitions for a Bayesian Network (BN) and a Decision Network (DN) as well as the necessary extensions to cater for the time changes. The chapter proceeds with presentation of how decision-
theoretic approach has been employed by researchers to handle the uncertainty issues in computer-based learning environments.

Chapter 4 presents an overview of INQPRO learning environment. The discussion begins with the instructional model, namely, Scientific Inquiry Learning model, which is employed for INQPRO. It then proceeds with the curriculum and subsequently, with the main components in INQPRO. This section starts with addressing all the interfaces and then with the learner model. Since the learner model is a crucial part of this research work, this chapter highlights the brief structure of the DN. Chapter 4 ends with the last component in INQPRO, namely, the animated pedagogical agent. This is the component that interacts proactively with the learners apart from the interfaces.

Chapter 5 discusses the preliminary version of the INQPRO’s learner model. It describes the high-level presentation of the structure of DNs within the INQPRO. The definition of evidence and the methodology for constructing CPT are discussed. The design and integration of DNs into the interfaces constitutes one of the key challenges in this research work. Finally, Chapter 5 describes the two different approaches (i.e., \( M_{\text{Combined}} \) and \( M_{\text{Separated}} \)) to construct the first version of DDN to model and intervene under uncertainty across time.

Chapter 6 discusses the first phase of the experimental evaluation (\( P_1 \)) that was conducted with the first version of the INQPRO. It begins with the discussion on utilizing the Simulated Learner technique to evaluate the individual DNs by domain experts. Chapter 6 also discusses the design and results of a study in which INQPRO was employed with \( M_{\text{Combined}} \) before being evaluated by human learners. The results given by \( M_{\text{Combined}} \) were presented to the domain experts for further elicitation of its behaviour. The last part of Chapter 6 discusses the limitations of the learner model, which have included the learner properties to model, the learner-agent interaction, and \( M_{\text{Combined}} \).

Chapter 7 discusses the improvements done to the first version of INQPRO’s learner model. The improvements done is firstly discussed and followed by three proposed
variations of DDN. Improvements done to the first version of learner model have included the structure of the DNs, the methodology for assigning prior probabilities, and inclusion of metacognition and time factor. The similarity and differences proposed INQPRO’s *dynamic* learner model, namely, $M_{DC_1}$, $M_{DC_2}$, and $M_{DC_4}$, are discussed.

Chapter 8 discusses the second phase of empirical evaluation ($P_2$). The chapter firstly discusses the transformation of raw interaction log (obtained via $P_1$) into data sets which could be fed into the three proposed alternative *dynamic* learner models. It then discusses the evaluation of $M_{DC_3}$ via two field studies, which had involved both human experts and learners.

Chapter 9 concludes the project and the directions of future research work that could be done.
PUBLICATIONS


REFERENCES


Appropriate Software Affordances. Annual Conference of the American Educational Researchers Association, April 16-17, Montreal, Canada.


