Data-Driven Hint Generation in Intelligent Tutoring Systems for Learning Microeconomics

Bui Trong Hieu and Bui Thi Kim Uyen

Abstract—Scientific inquiry skills is used in all educational areas. In the context of microeconomics, it is widely known that the development of scientific inquiry skills is central to the construction of ideas that enable understanding. Intelligent tutoring systems (ITSs) have been shown to be effective in supporting students’ domain-level learning through guided problem solving practice. ITSs provide personalized feedback (in the form of hints) to students and improve learning at effect sizes approaching that of human tutors. However, creating an ITS to adapt to individual students requires the involvement of experts to provide knowledge about both the academic domain and novice student behavior in that domain’s curriculum. Creating an ITS requires time, resources, and multidisciplinary skills. Because of the large possible range of problem solving behavior for any individual topic, the amount of expert involvement required to create an effective, adaptable tutoring system can be high, especially in open-ended problem solving domains. Data-driven ITSs have shown much promise in increasing effectiveness by analyzing past data in order to quickly generate hints to individual students. However, the fundamental long term goal was to develop “better, faster, and cheaper” ITSs. The main goal of this paper is to: 1) presents ITSs used in the microeconomics education; and 2) introduce data-driven ITSs for microeconomics education.

Index Terms—Data-Driven Hint Generation, Intelligent Tutoring Systems, Microeconomics, Scientific Inquiry Skills.

I. INTRODUCTION

Currently, education systems in the Asian region are undergoing extraordinary developments: a growing number of people are gaining access to formal and informal learning, curricula are diversifying, and educational institutions are experimenting with new and innovative forms of delivery. Despite this, Asian educational systems continue to confront four overarching challenges – namely, maintaining education quality, improving the relevance of curricula, improving on expenditure of financial resources, and balancing expansion with greater equity. One technological solution that has the potential to offer quality instruction to many students is the ITS. In recent years, an increasing number of researchers have shown interest in the development and/or deployment of ITSs for and in developing countries. In particular, ITSs are seen to have the potential to augment or support overstretched educational systems, thereby becoming instruments of equity, quality, and efficiency [1]. ITSs have been shown to be highly effective at increasing students’ performance and motivation [2]. For example, [3] claimed that the students using an ITS for economics could perform equally well as the students taking a traditional economics course, but required half as much time covering the materials.

II. BACKGROUND

A. Intelligent Tutoring Systems

It is a well-established fact that face-to-face and one-to-one human tutoring is the best tutoring field. However, it is extremely expensive in terms of both physical and human resources. ITSs are a natural solution that can be used to address this problem, as they are developed to give personalized feedback and help to students who are working on problems. The fact the ITSs are formed by three fields: Computer Science, Psychology, and Education, as illustrated in Fig. 1., in which, (i) Artificial Intelligence (AI) addresses how to reason about intelligence and thus learning, (ii) Psychology (Cognitive Science) addresses how people think and learn, and (iii) Education focuses on how to best support teaching/learning [4].

Fig. 1. The development of an Intelligent Tutoring System using methods and instruments from three different domains

According to [5], an Intelligent Tutoring System (ITS) is a computer system that provides immediate and customized instruction or feedback to learners. The classical architecture of an Intelligent Tutoring System includes the following four components (Fig. 2.) [6, 7, 8, 9].

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Bui Trong Hieu is with the Faculty of Information Technology, Ho Chi Minh City University of Transport, Ho Chi Minh City, Vietnam. (e-mail: hieu.bui@ut.edu.vn).
Bui Thi Kim Uyen is with the International Trade School, College of Foreign Economic Relations (Cofer) (e-mail:uyenbk2007@yahoo.com).

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This traditional view of ITSs is still very accepted by the ITS community. However, recent studies stress functionality over structure [6, 7, 8, 9], describing ITSs as having two main loops [10]: 1) the inner loop and 2) the outer loop (Fig. 3). The inner loop is responsible for providing personalized feedback, hints, and direct problem solving assistance to students. The inner loop also assesses students’ competence and registers it on the student model. Using the information that is obtained about the student, the outer loop performs task selection.

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until tutoring is complete, repeat
   tutor selects a task;
   until task is complete, repeat
      Student executes a step;
      Tutor may present a hint;
      Tutor updates the student model;
      Tutor presents feedback on the step;
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Fig. 3. ITS Loops.

B. Data-Driven Intelligent Tutoring Systems

As mentioned by [11], data-driven ITS is a subfield of ITS where decision-making is based on the previous student’s work instead of a knowledge base built by experts or an author-mapped graph of all possible paths. Successful solutions from the past can be used to provide feedback and hints for students in the present, which circumvents the need to create an expert model. A data-driven tutoring system can be bootstrapped by experts providing missing data. The data-driven approach has proven to work well in combination with artificial intelligence and machine-learning techniques for learning an expert model by demonstration.

III. RELATED WORK

A. Intelligent Tutoring Systems for Learning Microeconomics

Smithtown [12] is an intelligent tutoring system designed to enhance an individual’s scientific inquiry skills as well as to provide an environment for learning principles of basic microeconomics. It was hypothesized that computer instruction on applying effective interrogative skills (e.g., changing one variable at a time while holding all else constant) would ultimately lead to the acquisition of the specific subject matter. Overall, the system performed as expected. Tutoring on scientific inquiry skills resulted in increased knowledge of microeconomics. The differentiating behaviors between more and less successful subjects were in agreement with specific behaviors relating to individual differences found in general studies on problem solving and concept formation. From an instructional perspective, the behaviors we have denoted can serve as a focal point for relevant intervention studies. From a design perspective, findings from these studies suggest modifications to intelligent tutoring systems so they may be more like the individualized teaching systems they have the potential to be.

The main goal of Smithtown is to enhance students’ general problem solving and inductive learning skills. It does this in the context of microeconomics, providing an environment that fosters learning the laws of supply and demand. Smithtown is a highly interactive program, allowing students to pose questions and conduct experiments within the computer environment, testing, and enriching their knowledge bases of functional relationships by manipulating various economic factors.

WEAR [13] is an ITS authoring tool for Algebra-related domains. The main objective of this tool is to be useful to teachers and students working in domains that make use of algebraic equations. Such domains could be chemistry, economics, medicine, physics etc. The tool takes input from a human instructor about a specific equation-related domain (e.g. economics). This input consists of knowledge about variables, units of measure, formulae and their relation. In [14], Introduction to Microeconomics courses were modified by asking students to read assigned sections of the textbook and view either videotaped lectures or PowerPoint lectures with sound before coming to class. The first part of each class session involved answering questions, which usually lead to a mini-lecture lasting no more than 10 minutes. If there were no questions, there would be no lecture. The rest of the class time was spent in an experiment, lab, or group work that investigated the topic at hand. Lage’s and Platt’s goal for inverting the classroom was to give students opportunities to learn economics according to their individual learning style. Students could learn course content by choosing between reading the textbook, watching a traditional lecture, or viewing PowerPoint with sound. They could also combine or repeat these content delivery methods according to their individual preferences. Hands-on activities inside the classroom added further diversity to the available teaching and learning styles. This study of 80 introductory economics students showed positive student attitudes toward the inverted classroom. In fact, the evidence showed that students would prefer to have an inverted classroom rather than a traditional lecture class. The study also evidenced increased faculty-student interactions and the development of student communication skills. Since the material in the course is presented in a number of different formats, it was shown that students’ learning preferences were better matched to course pedagogy.

B. Data-Driven Hint Generation in Intelligent Tutoring Systems for Learning Microeconomics

Using large sets of historical student data to generate hints is a recent development that has already produced some promising results. Due to lengthy development time for an ITS, several researchers have tried to generate hints
from past student data. Data-driven tutors reduce the necessary effort even further by mining educational data to generate feedback in the form of hints. They construct an implicit domain from solutions submitted by students. In most cases, feedback is still generated from the differences between the student’s program and a previously submitted solution. The use of data-driven methods to develop intelligent tutoring systems is just starting to be explored in the field [15]. Authors of data-driven systems argue that these approaches avoid the need for experts to spend time constructing complex domain models and can lead to additional insights that experts alone would not achieve [16]. In the other words, creation of adaptive educational programs is costly. This is, in part, because developing content for intelligent tutors requires multiple areas of expertise. Content experts and pedagogical experts must work with tutor developers to identify the skills students are applying and the associated feedback to deliver. The Fig. 4. below describes in brief what the model in data-driven ITSs for microeconomics education [17].

![Image](image1.png)

**Fig. 4.** The Data-driven hint generation in ITSs for microeconomics education.

Fig. 5 [4] uses a simple algebraic example showing a single attempt to solve the fraction addition problem of \(\frac{1}{4}+\frac{1}{6}\) (the start state), where the first action is to find the common denominator of 12, the second is to find the numerator for \(\frac{1}{4}\), the third is to find the numerator for \(\frac{1}{6}\), and the final step is to add the numerators. Each state, as illustrated here, represents enough information to reconstruct the tutor interface at a given step.

![Image](image2.png)

**Fig. 5.** An attempt sequence for a fraction addition problem. The nodes are states, and edges are actions the student takes to solve the problem.

Fig. 6 gives once more a simple example of an interaction network from a hypothetical algebra ITS. All students start in the same state (top) and attempt to achieve a goal state (bottom). Edge weight (thickness) corresponds to the frequency of students who took a given path. Multiple solution paths can lead to a given goal state, though some paths result in backtracking (right), indicative of a possible mistake.

A solution is represented as a path from the initial state to a goal state. A student requesting a hint is matched to a previously observed state and directed on a path to a goal state. [18] Hints can be generated from this data by searching the Interaction Network for users with the same solution path. Based on the previous users’ actions, a potential next step can be suggested. If no user has succeeded on that path before, we can suggest the current user try a different approach. In [19], Eagle has proposed both ordered and unordered matching functions. Ordered matches mean that the two matching states have exactly the same steps executed in the same order. Unordered matches mean that the two matching states have all the same parts, but may not have been done in the same order. The less restrictive the matching function, the more concise the interaction network, since it lowers the number of vertices in the network at the cost of having potentially less contextual information. Fig. 7. uses unordered matches from a single problem solved in a propositional logic tutor.

![Image](image3.png)

**Fig. 6.** A simple example of an interaction network from a hypothetical algebra ITS. All students start in the same state (top) and attempt to achieve a goal state (bottom). Edge weight (thickness) corresponds to the frequency of students who took a given path. Multiple solution paths can lead to a given goal state, though some paths result in backtracking (right), indicative of a possible mistake.

![Image](image4.png)

**Fig. 7.** An example interaction network. The vertices represent tutor states, edges represent actions that go from state to state, edge thickness is weighted by frequency, goal states are green, and vertices with high attrition rates have red bordes.
IV. CONCLUSION AND RECOMMENDATION

The main goal of this paper is to: 1) presents recent ITSs used in the microeconomics education; and 2) introduce data-driven ITSs for microeconomics education. Besides, this study has surveyed various research paper broadly based on the role of ITSs in microeconomics education field. In the context of data-driven ITSs for microeconomics education, despite the research efforts in recent years, however, generating data-driven hints is still having some problems. In summary, in this work, one gap the author identified that provide the motivation for future researches are listed below: data-driven ITSs for microeconomics education has been expanding as a subfield of ITSs over the past few years, with many different researchers creating new techniques to automatically generate hints. However, most of the systems have only been evaluated on collected student problem-solving traces, and the ones that are being tested on real students are implemented in online learning environments such as MOOCs (massive open online courses), not in individual classrooms. In the context of curriculum and real classroom in an ITS, this indicates that there is significant room for improvement in the field of data-driven ITS for microeconomics education.

REFERENCES


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