BREAKTHROUGH IN DYNAMICALLY ADAPTIVE TUTORING: AUTHORIT AUTHORING AND TUTORIT DELIVERY SYSTEMS

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INTRODUCTION

The demand for private tutors has never been stronger (see McRae, 2013, p. 7). Yet, costs are prohibitive for the majority. It is not surprising in this context that adaptive learning systems are gaining more and more attention. This article begins with a short introduction to two dominant categories of adaptive learning systems: Intelligent Tutoring Systems (ITS), which have been around since the late 1970s, and relatively new learning systems based on Learning Analytics, deriving largely from technical advances in BIG DATA pioneered by Google. The article then details a third approach to adaptive tutoring deriving from a long history of basic research in structural learning. This research started even earlier than instructional theories leading to ITS, but has only recently achieved the precision necessary to enable the development of highly efficient technologies for developing dynamically adaptive tutoring systems. Collectively, the AuthorIT authoring and TutorIT delivery systems offer the potential of a highly skilled tutor for every student in every content area at a cost most can afford.

TutorIT is a dynamically adaptive tutoring system that interacts with students as might a good human tutor. AuthorIT is an authoring platform that makes it possible for subject matters experts and instructional designers (SMEs) to create automated tutors that dynamically adapt to individual student needs as would a skilled human tutor. AuthorIT allows unprecedented precision at a fraction of traditional costs. Very recently patented technologies offer a broad range of authoring capabilities. Any educator can easily customize existing TutorIT tutorials. Those with a solid grasp of the subject matter and a reasonable degree of computer literacy can be taught to use AuthorIT to create dynamically adaptive TutorIT tutorials in their own areas of expertise. AuthorIT is first used to create arbitrarily precise representations of the knowledge to be acquired.

TutorIT takes as input knowledge representations created with AuthorIT in any given field. Patented technologies make it possible for TutorIT without programming to automatically pinpoint what any given student already knows at each point in time as well as the information the student needs to learn to progress . Based on automated continuing assessment, TutorIT delivers instruction specifically tailored to each individual, providing each student with precisely the information he or she needs to progress precisely when it is needed. TutorIT automatically meets the varied needs of student populations ranging from challenged to gifted.

TutorIT literally makes it possible to guarantee learning. Any student who enters a TutorIT tutorial (having mastered predefined prerequisites), and who completes the tutorial, will by definition have mastered the knowledge taught to the specified level of mastery. The empirical question is not whether a student will succeed, but rather how long it will take and to what extent the student will be motivated to complete any given tutorial.

ADAPTIVE LEARNING

The phrase "adaptive learning" has become extremely common in describing many types of online instruction. Most so-called adaptive learning systems, however, are adaptive in name only. Students are invariably given a pretest consisting of a set number of questions. Pretest results then are used to identify what each student knows (and does not know) on entry. Students are then assigned to one-size fits all instruction associated with each entry level.

Dynamically adaptive learning systems are very different. Such systems interact with individual students dynamically (that is, continuously) during the course of instruction. To date, the latter have fallen into two categories, both of which have critical limitations:

(1) **Intelligent Tutoring Systems** (ITS) are designed to dynamically adapt to individual student needs during the course of learning. This is good. Huge amounts of government money have been plowed into development of these systems, yet they remain extremely (usually prohibitively) costly and time consuming to build, test and refine. In addition, they require specialized knowledge engineers in each field working with experienced educators to identify what must be learned. Even so, the (cognitive task analysis) methods used are estimated by practitioners in the field to miss 70% of what needs to be learned for success (Clark, 2013). The only commercially available ITS are those marketed by Carnegie Learning, and these fail to automate the delivery of much needed content. So-called declarative knowledge is still taught using ordinary workbooks.

(2) **Learning Analytics** (LA) based learning systems adjust instruction based not on what any given individual needs to know but on correlations between data collected and stored in multiple data bases (so-called BIG DATA). Computer algorithms use these correlations to determine what instruction students are to receive. Unfortunately, correlations do not imply causality. LA systems may or may not help learning. But they are not tutoring systems. LA systems say nothing directly about what any given student needs to learn for success, and even less about when that information is needed. Consider an example from their sales literature stating "performance in math may be correlated to success in journalism". Even if this or anything similar were true, it would not mean teaching math is the key to success in journalism, or vice versa. Correlations show relationships. Just because one thing is related with another, however, does NOT mean that one causes the other.

Correlations say nothing about how to teach math, even less about what math should be taught to any given student at any given time.

According to Superintendent Phillip McCrae, another major concern is privacy. BIG DATA is being collected and disseminated to both schools and commercial firms without parental permission. Some believe this information will eventually be used or sold to make money for companies, investors or schools (e.g.,
McCrae, 2013, pp. 9-10). Knewton and Dreambox are just two of many commercial systems based on LA.

How do TutorIT tutorials built with AuthorIT compare?

Newly patented methods based on the Structural Learning Theory (SLT) have been developed, tested and refined over several decades based on research at the University of Pennsylvania by Emeritus Professor Joseph M. Scandura, the author of over 200 scientific publications, including eight books, in cognitive psychology, software engineering, artificial intelligence, mathematics education and instructional design. Years of basic research in structural learning - make three things very clear:

a)   The more precisely one can identify what needs to be learned for success, the better job one can do of teaching it.
b)   What is learned is far more important than how it is learned.
c)   The timing of information is crucial. Information is wasted if given too soon. Given too late, it serves no educational purpose.

Unlike ITS and Learning Analytics, AuthorIT and TutorIT focus on what students must learn for success in any given domain. Whereas ITS based on biologically inspired ACT-R theories work from the bottom-up, AuthorIT and TutorIT based on the Structural Learning Theory (SLT) work from the top down (Scandura,
2013). Unlike ITS and LA systems, SLT and the AuthorIT and TutorIT systems based thereon are deterministic rather than statistical in nature (Scandura, 2013). They are designed to explain, predict and direct the behavior of individual students in specific educational situations. For a detailed updated description of the SLT, please see Scandura (2007,).

Unlike LA's use of BIG DATA, AuthorIT and TutorIT are designed to specify what every student must learn for success, how to determine what each student does and does not know at each point in time and when to provide precisely the information the student needs to progress. Rather than adjusting
instruction based on how difficult students on average find various tasks, or how they learn, SLT is concerned primarily with <u>what</u> must be learned for success. Information about student preferences and the like are strictly secondary. It is not a matter of collecting as much information about

students as possible, but rather identifying as efficiently as possible what each student needs to progress.

Why and How Do AuthorIT and TutorIT Work?

AuthorIT and TutorIT build on the Structural Learning Theory (SLT). SLT in turn builds on a long history of basic research (cf. Scandura, 1971, 2007) and is designed to answer to four basic questions:

1) What does it mean to know something, and how can one represent knowledge in a way that has behavioral (measurable) relevance?

2) How can one find out what individual students know and do not know about what is to be learned?

3) How do students use their existing knowledge to acquire new knowledge?

4) How does knowledge change over time as a result of interactions between individuals (e.g., teacher & student)?

SLT is backed by a substantial body of basic research and, over the years, has provided increasingly precise answers to each of these questions (cf. Scandura, 1971, 2007). Structural (cognitive task) Analysis (SA) in SLT plays an essential role in the process. SA provides a highly systematic way to identify what must be learned to master any given subject matter domain. SA starts with an overview -- with a high level abstract representation of both the problems to be solved and the solution methods to be learned. Both problems and solution methods are systematically refined into the increasingly elementary decisions and operations the learner must master for success. In its current form, SA provides a highly systematic way to refine each indefinitely. Problems can be represented in whatever degree of detail is desired. Solution methods can similarly be refined into all of the decisions and operations the learner must master for success. These representations provide a complete and arbitrarily precise

representation of what must be learned to master any given subject matter.

We have discovered that three basic refinement types are sufficient for refining problems and three for solution methods (e.g., Scandura, 2007, 2011). Moreover, each problem refinement corresponds to a unique method refinement and vice versa. Some refinements (category and component (AKA part of and isa) are well known. Traditional hierarchical analysis, however, always ends up with relationships that do not lend themselves to systematic refinement. The methods used in SA, on the other hand, guarantee that refinement can be continued indefinitely -- until contact is made with prerequisites assumed to be available to every member of any given student population.

SA also provides a systematic way to identify and represent the higher order knowledge so essential in problem solving and ill-defined learning (cf. Scandura, 1971, 2007). Specific reference here is given to higher order knowledge needed for success when there is more than one way to proceed and/or when new knowledge must be derived from existing knowledge (i.e., learned). SA is a

patented process that makes it possible to refine to-be-acquired knowledge systematically into arbitrarily elementary components (patent application approved in final form March 3, 2013).

Hierarchical knowledge representations play an essential role in SLT, and are referred to as SLT rules. SLT rules along with just three fundamental assumptions in SLT provide a deterministic account of individual student behavior. These assumptions include SLT's Universal Control Mechanism (UCM), along with a fixed processing capacity and a fixed processing speed for each individual. First and foremost, these assumptions are directed at and provide a rigorous foundation for explaining, predicting and guiding the behavior of individual students in specific situations at specific points in time (see Scandura, 2007, 2011 for details). In short, SLT focuses on what must be learned for success – as opposed to such incidentals as how difficult average students find various tasks, or how they learn.

Patented methods used in the construction of AuthorIT and TutorIT build directly on SLT. Given any to-be- learned problem domain, AuthorIT both makes it possible and systematically guides authors in creating the necessary knowledge representations. Application is direct and highly efficient. To-be-acquired-knowledge can systematically and precisely be refined into arbitrarily elementary components.

These patented methods go further. Given hierarchical knowledge representations, TutorIT is able to make all pedagogical decisions - what to test, what to teach and when - all automatically. Instruction in TutorIT is based on what each individual student does and does not know at each point in time about what must be learned for success. Relationships between elements in these hierarchies play a central role in determining pedagogical decisions as to what is taught, when and under what conditions. Decision making does not have to be programmed. All such decisions are based on the hierarchical structure of the knowledge representations, completely independently of content semantics.

It is especially important to emphasize two things:
1.   AuthorIT makes it possible for subject matter experts to represent hierarchically what every student needs to learn to master any given content domain.
2.   These knowledge representations in turn provide a full and sufficient foundation for all TutorIT decision making.

In short, TutorIT decision making goes far beyond the correlations and average statistics used in Learning Analytics where the focus is on how students behave on average, not on what they actually need to learn to achieve defined levels of mastery. These patented methods also go far

beyond traditional ITS. Traditional ITS development requires broad and high degrees of expertise, extensive experimentation
and expensive revision. AuthorIT makes it possible for subject matter experts with a modicum of training to develop dynamically adaptive tutoring systems in their own areas of expertise. Eliminating the need to program pedagogical decision making dramatically reduces development costs. The near term prospect of making dynamically adaptive tutoring systems available to every student is very real.

POTENTIALLY EVEN BETTER THAN A HUMAN TUTOR
Ideally, an automated tutoring system should make the kinds of decisions that a knowledgeable human tutor would make. Good human tutors start with a deep understanding of what they believe students must learn to be successful in any given domain. The test items they use and the instruction (guidance) they provide is based on their assessment of what any given student does and does not know relative to what the tutor believes should/must be learned for success.

TutorIT makes diagnostic and tutoring decisions in the same way. Subject Matter Experts (SME) identify the knowledge that must be learned to successfully master any given particular subject. As detailed above, AuthorIT's patented technologies are used to systematically represent the knowledge to be acquired – all operations and all decisions -- in arbitrarily precise hierarchies. TutorIT then uses these hierarchies to deliver individualized instruction based on each student's specific needs.

In 1984, Benjamin Bloom showed that human tutored students may perform as much as two standard deviations (two sigmas – 98%) better than those taught in traditional classroom settings. His so-called "Two Sigma" goal has been an elusive, unachieved challenge to educators for more than a quarter of a century. To date, no LA system has come close and no ITS has achieved Bloom's ambitious goal.

It is too soon to know definitively because it is so new. Nonetheless, TutorIT is in fact a true tutoring system, able to "think" and "act" as a good human tutor might, asking the right questions and providing precisely the information the student needs to master any given content at each point in time. Since the way forward is intrinsic in the way knowledge is represented by a subject matter expert, TutorIT will make the right pedagogical decisions every time -- arguably better than even a human tutor, who may not always know exactly what to do next. Given the proven ease with which TutorIT tutorials can be revised and refined, TutorIT has the potential over time to achieve Bloom's long sought but never achieved goal. **EASY TO USE**

PLATFORM
All TutorIT tutorials are built with the AuthorIT authoring platform. AuthorIT is designed to work with all subject matters and is available as three easy to use increasingly powerful authoring systems:

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Customizer makes it possible for essentially any educator (teacher, curriculum supervisor or editor) to quickly and easily customize any existing TutorIT tutorial to reflect one's own preferences regarding wording of questions, instruction and/or positive or corrective feedback. These enhancements can easily be made by minimally trained editors in a matter of minutes. Customizer also can be used to add,

replace or customize voice (in multiple languages) and/or supporting media, ranging from simple pictures and videos to dynamic Flash files.

EZauthor greatly simplifies the task of creating adaptive tutoring systems for broad ranges of content, including multiple choice items as in test preparation, learning a foreign language, etc. -- wherever the content includes broad ranges of relatively unstructured test items (as is common in learning analytics).

AuthorIT is the most powerful authoring system, used to create dynamically adaptive tutoring systems in essentially any area. AuthorIT dramatically simplifies the task of creating even the most complex dynamically adaptive tutoring (not just adaptive learning) systems. In each case, AuthorIT makes it possible to create arbitrarily complete and precise representations of the knowledge needed for success.

In all three cases, TutorIT then takes the knowledge representations created as input. TutorIT then makes ALL diagnostic and tutoring decisions (what to test, what to teach and when) automatically. Automated one-on-one tutoring for every single student combined with the emotional support only human teachers can provide has the potential to truly revolutionize education in this country and beyond.

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