Automated Environment for Individually Optimized Learning Experiences

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***Abstract*— This is a work-in-progress paper that describes research involving the development and use of technology to create social real-time learning experiences. This technology can provide rapid feedback between students and instructors, enabling the ability to make real-time data-driven decisions to automatically inform and individualize instruction. This paper discusses research being conducted in the following five supporting major areas: 1) Learning Assessment and Tracing, 2) Learning Outcome and Concept Dependencies, 3) Pre-Learning Intervention, 4) In-Process Learning Intervention, and 5) Future Learning Intervention using a learning environment called SlideSpace that has served as a living laboratory for experiments into human interactions.**

Keywords—Automated learning assessment and tracing, learning concept dependencies, automated individualized instruction, closed-loop learning

I. Introduction

A. Background

Assessment plays an important role in the teaching and learning process and is a powerful tool for enhancing student achievement and facilitating instructor, curricula, and pedagogy development [1,2]. Innovative technologies have the potential to deliver better quality educational assessments that are more useful for teachers and that more readily benefit student learning [3]. The use of technology in classroom assessment enables advanced features such as rapid student feedback and computer-generated next steps that allow teachers to make real-time data-driven decisions to inform their instructional changes. In order to realize such insightful and sophisticated technology, attention to student-centered assessment and instructionally tractable assessments is highly recommended [4,5]. Technology offers much promise for supporting educators in making data-driven instructional modifications. For example, technology may help educators set realistic instructional goals that simultaneously consider a student's current proficiency set, specific conceptual knowledge, demographic characteristics, and learning attributes. Students' progress toward individual goals and normative benchmarks can be evaluated continuously and instructional modifications made if necessary.

While there are many available learning assessment tools, few provide tight integration with course curricula and pedagogy, and a vast array of student learning experiences. This level of integration is necessary to facilitate efficient and effective feedback for both students and instructors. In addition, the feedback needs to be timely, almost instantaneous in some use cases, and intuitive for use both by students and instructors. If such feedback is provided when learners need it, it can considerably improve the quality and speed of learning processes [6,7]. However, students report serious deficiencies in the amount and quality of feedback they receive [8,9]. Delivering real-time feedback at an individual level is often infeasible, considering the limited teaching resources and the varying nature of the students' profiles [9,10].

Recent technological advancements have caused a widespread uptake of various technologies in the field of education, e.g. Intelligent Tutoring Systems (ITS), which are intended to produce personalized feedback in an automated way [10]. A recent publication [11] completed an extensive review of automated feedback learning systems which searched over 75 million records, with 766 reviewed abstracts, 190 reviewed papers, and 109 thoroughly analyzed and classified. Deeva et al. [11] noted that existing automated feedback learning systems were challenged in the areas of need for expert intervention, adaptivity, personalization, and implementation accessibility. Each of the deficiency areas described below will be addressed by our research project.

B. Objectives

Our objectives for this project are threefold. First, to test mechanisms by which the value of continuous, near real-time interactions and feedback between students, teaching assistants, and instructors in STEM education can be made more contextually relevant, timely, automated and actionable, and the subsequent impact on individual learning outcomes, pedagogy, instructor continuous improvement, and the collective educational experience. Second, to test mechanisms using automated machine learning models to dynamically augment the experience of students to provide customization and drive improved individual performance outcomes. Third, this project will extend and disseminate a novel digital learning laboratory technology,

C. Overview

This project encompasses the following five major areas of research: 1) Learning Assessment and Tracing, 2) Learning Outcome and Concept Dependencies, 3) Pre-Learning

Intervention, 4) In-Process Learning Intervention, and 5) Future Learning Intervention. The first two are in learning assessment and tracing, and concept dependency mapping which are critical to provide evaluative feedback on the efficacy of the feedback systems, and determine where improvements can be made. The latter three areas of research focus on how to leverage this information to provide individualized educational assistance for students before they attempt to learn new material, while they are learning the material, and/or updating the curricula and pedagogy for future students.

II. Preliminary Research

To support our educational research, we designed and developed SlideSpace [12], a web-based digital learning environment providing numerous real-time communications, as a teaching and learning environment that supports a diverse community of educators and learners throughout their varying workflows. The system serves as a living laboratory that allows us to explore, experiment, and research new ideas in education, pedagogy, communication, and curriculum development. An essential aspect of a vibrant learning community is the presence of bi-directional interactions, individual growth, and feedback. Contributed artifacts may include curriculum, The system captures project reports, quizzes, notes, study guides, as well as anonymized data related to content creation, user interactions, content consumption/distribution, and study habits. To date, we have used this experimental data for statistical analysis to 1) understand how users interact with learning systems, curriculum, and each other - in live and time-shifted scenarios; 2) identify opportunities to develop enhanced features that improve the human experience and outcomes of our stakeholders; 3) to identify and test new mechanisms to make learning systems more accessible. We are entering our third year of development, and the system has been used in four undergraduate engineering courses in the Jacobs School of Engineering at UCSD, in 23 course sections, totaling more than 1400 students taught by five different faculty members.

III. Current Research

The description below provides an overview of the research, including questions, objectives, hypotheses, methods, measures and analysis in each of the five noted research areas.

A. RA1. Providing Learning Assessment and Tracing

For educational research, it is critical to determine each student's success in applying the desired learning outcomes, and trace this back to actions taken by the instructor and student [13]. To address this, we are developing the digital means by which instructors can instrument their courses facilitating tracing student educational outcome success with their performance artifacts and related educational experiences. This work involves the construction and mapping of course learning outcomes and analytical rubrics with each instructional section, student activities and additional materials that the students may access. If there are multiple means of measuring these, they can be coupled and their progression shown over time.

Questions: Can patterns of student performance on live-polls, quizzes, tests, projects, and other communications be used to determine whether curricular learning outcomes have been met? What meaningful types of analysis can be provided to the instructor to trace student success with the student's educational experiences? What meaningful suggestions can be provided to instructors regarding pedagogy based on analysis of students outcomes?

Objectives: Create and validate the digital means by which to support and validate course instrumentation tracing student educational outcome success with their performance artifacts and related educational experiences.

Hypothesis: We hypothesize that a hierarchy of educational outcomes at the level of degree, course, module, lecture, and section can be instantiated in SlideSpace to provide an outcome graph, with traceability to student created artifacts to determine outcome success, and to educational materials and student experiences to assist in analyzing their dependencies. We further hypothesize that foundational concepts can be assigned to each of these outcomes creating a concept dependency map to assist in the analysis of these dependencies. Finally, we hypothesize that both students and instructors will feel greater confidence in the learning process having an objective means to understand performance on these outcomes and the connection to the educational experience.

Method: A backward design by Wiggins and McTighe [14] is being used to align learning outcomes with evidence (assessment with measurement rubrics) and appropriate active teaching methods for implementation in SlideSpace. In parallel, a hierarchical set of course outcomes are being defined for Object-Oriented Programming (ECE17), Art of Product Engineering (ECE140), Software Foundations (ECE141), and instantiated in the existing SlideSpace course materials. Educational materials such as lectures, reference materials, etc. will be tagged with the support of each of these outcomes. Student created artifacts such as exams, projects, in classroom chats, etc. will be traced back to these outcomes. In addition, a new three course Cyber-Physical Social Systems sequence will develop its outcome hierarchy and course materials using the new SlideSpace framework. The SlideSpace infrastructure will be used to support the student grading process providing feedback to the outcomes and curricula tracing based on its success.

Measures & Analysis: The following metrics that will be used to measure efficiency and effectiveness. Time and accuracy will be recorded for the effort required to instantiate each learning outcome and educational material and artifact that tagged to it. Detected error rates will also be recorded. In addition to this quantitative data, qualitative feedback from the instructors will be recorded to improve the implementation and process. With respect to effectiveness, the automated analysis will be compared with the qualitative feedback from the instructors, teaching assistants, and students with respect to the accuracy and effectiveness of the results.

B. RA2. Supporting Learning Outcome and Concept Dependencies

Typically, there are dependencies in the key concepts that students bring to a course, along with dependencies related to learned material within a course. The weakness or nonexistence of these supporting concepts may jeopardize future dependent learning outcomes. Hence, it is critical to understand these relationships so that appropriate actions can be taken to support the desired educational outcomes. If we can identify each student's proficiency at applying key concepts, and the relationships between these concepts, we have the basis to provide individualized assistance to the student prior to and during an educational experience. In addition, this information can be used to inform and improve the construction of educational curricula and pedagogy at the class and individual level.

Questions: Can learning outcome and concept dependencies be defined and mapped to provide a connection between each student's map of conceptual understanding? Can this mapping be used to suggest augmented curriculum to the instructor in order to address conceptual gaps?

Objective: Create and validate the digital means to describe proficiency at critical educational core concepts, map their interrelationships, and validate this through data collected during educational experiences.

Hypothesis: A set of key concepts can be identified as critical underpinnings to the desired learning outcomes in each course. These can be instantiated into SlideSpace and a graph can be created of their interrelationships. This information can be used by SlideSpace to automatically correlate student success with strengths and weaknesses in each student's underlying conceptual foundations.

Method: A hierarchy is being created for each course, module, lecture, section, and subsection learning outcome with a conceptual foundation. Once complete, student learning outcome results will be correlated with the measured and/or perceived strengths of their underlying conceptual application. Polled information will be used where there is inadequate measured information.

Measures & Analysis: The following metrics that will be used to measure efficiency and effectiveness. Time and accuracy will be recorded for the effort required to instantiate each new learning concept and provide the mapping with other concepts and learning outcomes. Detected error rates will also be recorded. In addition to this quantitative data, qualitative feedback from the instructors will be recorded to improve the implementation and process. Numerical analysis will be undertaken to validate the concept and outcomes mappings based on measured and estimated student capabilities and results.

C. RA3. Supporting Pre-Learning Intervention

If we can identify a student's conceptual understanding of foundational concepts, then specific, targeted educational materials can be offered to provide additional appropriate scaffolding for their future learning of concepts upon which these are dependent before they attempt to learn new material. As in RA2, we are developing the conceptual mappings for both existing courses and a new three course sequence. In addition, we are creating a map of the dependencies in the conceptual capabilities within and between the three courses. Based on this information, students can automatically be presented with appropriate scaffolding material based on their learning history.

Questions: How can the application of each student's proficiency in supporting foundational concepts be used to improve their learning in subsequent dependent outcomes? Based on user interactions and existing performance indicators, can we automatically identify and recommend supplemental resources to improve performance outcomes, and measure these changes in performance metrics over time?

Objective: Create and validate the digital means to automatically identify and provide individualized recommendation of preparatory supplemental educational resources to students to assist them in achieving desired course outcomes, based on digital concept maps and student prior-performance data.

Hypothesis: Mappings of concept dependencies coupled with prior evidence of a student's conceptual capabilities can be coupled using digital techniques to automatically provide proactive instruction that can improve student performance on selected academic outcomes.

Method: Capability is being created in SlideSpace to utilize the student outcome success and educational material tracing developed in RA1, in conjunction with the concept maps that were developed in RA2 to determine which students would benefit from remedial work on baseline concepts. A set of appropriate scaffolding educational materials will be identified and added to the SlideSpace database. These will be coupled to provide an automated means of providing the appropriate educational assistance on an individualized basis to students. Comparisons will be made on student success for those who accessed and did not access this material. Student feedback will also be solicited. Student success rates and feedback will be analyzed to determine the efficacy of these efforts.

Measures & Analysis: Both quantitative and qualitative metrics and analysis will be used to validate this hypothesis. First, each instance of a student being identified as being appropriate for additional educational support will be peer reviewed by an instructor and evaluated on a five point Likert scale. The appropriateness of the selected scaffolding material will likewise be reviewed and evaluated. The subsequent success of students who used these materials will be compared with similar students who did not, and their relative success will be compared using the course rubrics in the selected outcome area. Finally, student feedback will be solicited to evaluate the success of the intervention. The results will be analyzed and reviewed for statistical significance.

D. RA4. Supporting In-Process Learning Intervention

The outcome tracing and concept maps that were developed in RA1 and RA2 can be used to determine how students are perceiving instructional information in real time. This can be accomplished, for example, by having the students "take notes" in SlideSpace by annotating what they consider to be important information and what needs additional clarification. Other forms of feedback collected include class discussion comments, problem sets and formative assessments. Another source of information is related to the materials that the students access and how long, and in which order they access it. Recommendations can be made to students based on this information as machine learning can be used to identify student archetypes and provide predictive information on how to further students' information processing. All of this can be correlated to the learning outcomes and learning results can be noted based on final student outcomes.

Questions: For students, how can more timely and contextually relevant feedback lead to better performance? How can this information be most effectively captured interactively in the digital classroom experience? Based on user interactions and existing performance indicators, can we automatically identify and recommend supplemental resources to improve performance outcomes, and measure these changes in performance metrics over time?

Objective: Create and validate the digital means to provide Individualized real-time information for students to enhance their in-process educational experience.

Hypotheses: Mappings of concept dependencies coupled with traceability between learning outcomes and a student's educational experiences in a course can be used by ML and other digital techniques to automatically provide individualized in-process feedback and instruction that can improve student performance on selected academic outcomes.

Method: Capability is being created in SlideSpace to utilize the student outcome success and educational material tracing developed in RA1, the concept maps that were developed in RA2, and each student's actions in the course to determine what additional assistance can be provided to them to achieve selected educational outcomes. In particular, analysis of student's digital behaviors (assignment, quiz, and project results, chat questions and responses, note taking, etc.) and objective results from prior classes will be analyzed and used to develop student archetypes that can be used to assist in the determination of the need for educational interventions. A set of appropriate scaffolding educational materials will be identified and added to the SlideSpace database in addition to potential tutoring services (in addition to those developed in RA3). These will be coupled to provide an automated means of providing the appropriate educational assistance on an individualized basis to students. Comparisons will be made on student success for those who accessed and did not access this material. Student feedback will also be solicited. Student success rates and feedback will be analyzed to determine the efficacy of these efforts.

Measures & Analysis: Much of the same measures and analysis used for RA3 will be used here. Some additional analysis work will be done in the identification and validation of student archetypes with respect to conceptual learning and digital educational behaviors.

E. RQ5. Support Future Learning Intervention

After a course is completed, an assessment of student learning outcomes will be collected and analyzed. Performance will be reviewed to determine where the curriculum and pedagogy should be improved. Updates will be made and the subsequent results from future classes will be compared with these prior results to determine the efficacy of the changes. We will create and compare performance-related "heat maps" from prior years to determine how to improve courses in the future to best understand the trajectory of the course's effectiveness. We plan to analyze and correlate curriculum development costs, versus content utilization and student feedback.

Questions: How can instructors use maps of conceptual information, student performance, and curricula tracing to improve course curricula and pedagogical methods? Can curriculum development teams use this data to identify gaps in the curriculum within a program of study?

Objective: Create and validate the digital means to assist instructors in the creation and improvement of course curricula and pedagogy.

Hypotheses: Mappings of concept dependencies coupled with traceability between learning outcomes and a student's educational experiences in a course can be used by ML and other digital techniques to assist instructors in improving course materials that can improve student performance on selected academic outcomes.

Method: This builds upon RA4 using the same methodology and analysis techniques. However, rather than using the analytic results for in-process education interventions, this information will be used to identify structural and functional weaknesses in the curriculum and pedagogy. SlideSpace will be updated to include data analysis tools that will highlight specific areas of improvement and how they might be improved with respect to adding additional materials, changing sequences, or student activities. Comparisons will be made on student success before and after the changes in the course curricula and pedagogy. Student feedback will also be solicited. Student success rates and feedback will be analyzed to determine efficacy.

Measures & Analysis: Both quantitative and qualitative metrics and analysis will be used to validate this hypothesis. First, each instance of the identified curriculum and pedagogy weakness area identified as being appropriate for improvement will be reviewed by instructors and evaluated on a five point Likert scale. Tool use ease and efficiency will be measured through time studies and instructor feedback. The subsequent success of students who used these materials will be compared with similar students who did not, and their relative success will be compared using the course rubrics in the selected objective area. Finally, student feedback will be solicited to evaluate the new materials.

IV. CONCLUSION

This project will be using an agile, interactive value-driven approach in which a learning laboratory will be created using SlideSpace as a digital platform. Work has already begun in the design of the SlideSpace features described in RA1: Providing Learning Assessment and Tracing. Development work will initiate in the summer of 2022. The design of features used in RA2: Supporting Learning Outcome and Concept Dependencies will begin in late summer and fall of 2022. This will be an incremental development such that the feature sets of RA1-2 and RA3-5 will be rolled out through much of the 2022-2023 academic year, providing preliminary results that will direct feature further development for the subsequent two years of this three-year research project.

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