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BOARD # 265: IUSE:HSI: A NetLogo-based Approach to Predictive Estimation of Student Performance and Corresponding Tutoring Demand within STEM Undergraduate Courses

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Dr. Joel Alejandro (Alex) Mejia is a Professor of Engineering Education in the Department of Engineering and Computing Education at the University of Cincinnati. His work examines the intersections of engineering, social justice, and critical pedagogies. He focuses on dismantling deficit ideologies in STEM, centering Latino/a/x student experiences—especially of those along the U.S.-Mexico border. His work draws on Chicana/o/x studies, raciolinguistics, and bilingual education to explore how language, race, and socialization shape engineering pathways and engineering practice. In 2025, Dr. Mejia received the Presidential Early Career Award for Scientists and Engineers (PECASE) Award for his contributions to engineering education.

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Hernández currently serves as a Professor of Chemistry and Dean of the College of Science at Texas A&M University-Corpus Christi. Prior to this role, he spent 24 years at the University of Central Florida, where he advanced through the academic ranks. During his tenure, he conducted interdisciplinary research in fundamental physical chemistry, nonlinear optics, and chirality, and also focused on scholarship of teaching and learning. He made a deliberate choice to transition to an administrative role in order to tackle the most pressing challenges in higher education.

He obtained his PhD in Chemistry from the Universidad Central de Venezuela (Venezuela) in collaboration with L'Université Franche Comté (France) in 1996. Following that, he worked as a postdoctoral research associate at the Venezuelan Institute for Scientific Research from 1996 to 1998, and as a Visiting Research Scientist at the College of Optics/CREOL (UCF) between 1998 and 2002. In 2002, he joined the Department of Chemistry at UCF as an Assistant Professor and advanced through the ranks to become a full professor. Throughout his career, Hernandez has authored over 100 articles in peer-reviewed journals and holds three US patents. He has also contributed to more than 100 national and international conferences (36 as an invited speaker) and has secured over five million dollars in external funding from various national agencies and private sector organizations (including NSF, DOE, DoD, Lockheed Martin, Kraft Food, and IAI) to support his research.

Throughout his career, Hernandez has been dedicated to imparting knowledge, developing critical thinking, and understanding how students from the new generation learn. He is also passionate about designing new strategies to support faculty, students, and staff in his academic community. Several years ago, Hernandez made a firm commitment to become an academic administrator to help others grow in their roles. With this goal in mind, he earned his MBA from UCF in 2018 and participated in several leadership programs at UCF, such as the Academic Leadership Academy and Provost Faculty Fellow, to gain a better understanding of academic administration. Over the last seven years, he has developed an exceptional interest in institutional academic affairs.

Dr. Ronald F. DeMara P.E., University of Central Florida

Ronald F. DeMara is Pegasus Professor in the Department of Electrical and Computer Engineering, and joint faculty member of Computer Science, at the University of Central Florida, where he has been a full-time faculty member since 1993. He has completed over 325 articles, 50 funded projects as PI or Co-PI, and 56 graduates as Ph.D. dissertation and/or M.S. thesis advisor. He was previously an Associate Engineer at IBM and a Visiting Research Scientist at NASA Ames, in total for four years, and has been a registered Professional Engineer since 1992. He has served ten terms as a Topical Editor or Associate Editor of various IEEE Transactions and in many IEEE/ACM/ASEE conferences including General Co-Chair of GLSVLSI-2023. He has received the Joseph M. Biedenbach Outstanding Engineering Educator Award from IEEE and is a Fellow of AAAS.

IUSE:HSI: A NetLogo-based Approach to Predictive Estimation of Student Performance and Corresponding Tutoring Demand within STEM Undergraduate Courses

Abstract

Tutoring support is vital to eliminate knowledge gaps and achieve learning outcomes, while attaining instructional scalability to large class sizes common in STEM courses. However, determining which courses require additional tutoring support is challenging due to the lack of formal quantitative measurement tools, thus hindering the ideal provision of Teaching Assistant (TA) allocation. Herein, we develop a NetLogo framework for an Agent-Based Model (ABM) designed to simulate student progress and performance in a required Electrical and Computer Engineering (ECE) undergraduate course. It predicts and quantifies course outcomes under varying amounts of tutoring support via TA office hours. The ABM incorporates key parameters such as learners' attainment in previous semesters, grading schemata, and tutoring impact to predict the corresponding number of at-risk students. Meanwhile, the technical approach utilizes a NetLogo-based implementation of the ABM, which realizes a flexible, modular, and observable design.

The ABM is composed of three primary components: student agents which represent individual students along with their content proficiency, a course environment which encapsulates the grading scheme along with tutoring support parameters of the TAs available, and a feedback mechanism which enables the ABM to adjust its predictions based on the instructor's input. The technical results demonstrate that the ABM is capable of accurately predicting the number of students having significant risk of DFW, i.e. earning a course letter grade of D or F, or withdrawing (W). The results show that the ABM is robust and reliable in its predictions of DFW rate, whereas three out of four semester configurations analyzed indicated that the ABM's predicted values bordered the 95% confidence interval. When measuring accuracy, test runs included course enrollment ranging from 70 to 121 students, commensurate with actual course delivery enrollments. The NetLogo model was parameterized towards attaining the worthy objective of lowering the DFW rate. Furthermore, to assist administrative decision making, it computes the monetary cost of tutoring per supported student. This new metric, known as Remediation Cost Per Supported Student (RCSS), delivers a quantitative measurement of cost-effectiveness for a course staffing configuration when considering the number of tutors paid and the number of students who received remediation. The model's performance is evaluated through a series of experimental scenarios, which involve varying student enrollment, grading schemes, and teaching assistant support levels using a dataset of previous course offerings.

Keywords

Remediation, Tutoring, At-Risk Learners, Student Outcome Modeling, Canvas LMS

Introduction

The study of Agent-Based Models (ABMs) is a growing field in social sciences that provides valuable insights into complex systems and phenomena. ABMs have been successfully applied to various fields, including reconstructing ancient societies and analyzing modern social media platforms [1,2]. This paper introduces an innovative ABM to improve targeted tutoring remediation in mandatory undergraduate courses, specifically in Electrical and Computer Engineering (ECE) degree programs. The research revealed a direct correlation between courses that utilize remediation services and student outcomes, highlighting the critical role these services play in shaping academic success. The ABM leverages this insight to provide instructors and administrators with a predictive toolset that identifies the optimal number of assistants needed for specific courses. This approach takes a step further by providing data-driven support to ensure informed decisions about resource allocation and optimized student success.

As depicted in Fig. 1, the research involves developing an ABM to simulate a classroom environment with students and tutors for identifying optimal staffing. The ABM can be customized by adjusting various parameters such as student comprehension, number of tutors, topics covered, tutoring sessions, and number of students. Visual markers indicate student status within the model. The project aims to predict dropout and failure rates using real-world data from an undergraduate level ECE course. The research follows a three-stage process: (1) selecting a simulation tool (NetLogo), (2) collecting data and gathering essential rules, and (3) refining the model to make predictions within reason of actual data.

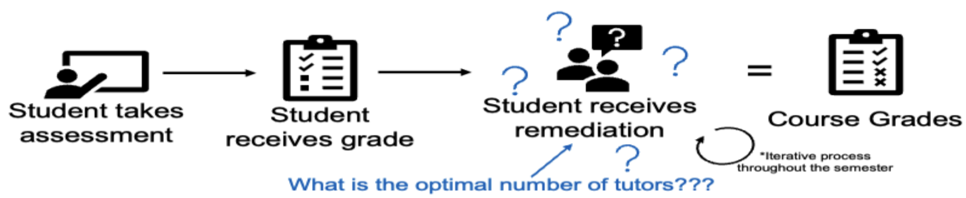

Fig. 1. Ideal Tutor Determination Process for an ECE course at a Large State University

Related Work

ABM development and application have been a fruitful area of research within recent years for providing explainable models that provide insightful measurements. Our model is built on the flow that considers an instructor implementing a remediation protocol that allows students to receive tutoring support and quiz rebuttal opportunity [3]. Through remediation approaches, STEM students can enhance their soft skills and benefit from individualized clarification sessions with the content remediation GTAs [3]. In addition, the emphasis on reducing DFW rates is not a novel numerical metric, as demonstrated by research integrating system data to illuminate the impact of adaptive instructional systems on students [4]. Various related works explore the balancing of cost, enrollment, and department requirements. Some methods use mathematical modeling and optimization techniques, while others rely on simpler mental models and / or retroactive observations to allocate and advocate for resources [5,6].

Our model's user interface was inspired by the 'Learning Equity Interaction of teacher-pupil-environment' model developed by Dr. Elizabeth Randolph at RTI (Research Triangle Institute) international in 2022 [7]. Specifically, it revealed how teachers' responses to students' answers can influence future interactions and shape students' perceptions of their participation in the course [7,8]. The integration of the agent-based model (ABM) with micro-credentialing frameworks, that measure skills associated with questions [9], may enhance the process of recognizing and rewarding students.

Experiments

The model, as shown in Fig. 2, features a user-friendly interface that enables users to set an average passing comprehension rate percentage for students and specify the number of assessed topics (such as quizzes or tests). In the NetLogo simulation, each cell represents a single student enrolled in the course. The number of cells is proportional to the actual number of students, enabling users to specify the student population size using a slider. Although a two-dimensional grid may not perfectly represent a real-world course with an exact headcount of 70 students, the square grid model remains effective in exploring and visualizing student dynamics. A simulation with 81 students can still provide valuable insights into student behavior and interactions, even if the actual number is slightly higher or lower than the intended target. The model uses NetLogo plabel values to quantify the number of topics a student comprehends, with this value dynamically updating to reflect changes in course size as users add or remove students. The user interface is designed to keep inputs and outputs on the left side, with basic parameters for simulating course performance, while the dynamically changing course sizes are prominently displayed in the square heatmap simulation. The heatmap visualization depicted in Fig. 2 represents the course grading scheme, where green indicates low-risk students, yellow signifies medium-risk students, and red denotes high-risk DFW students.

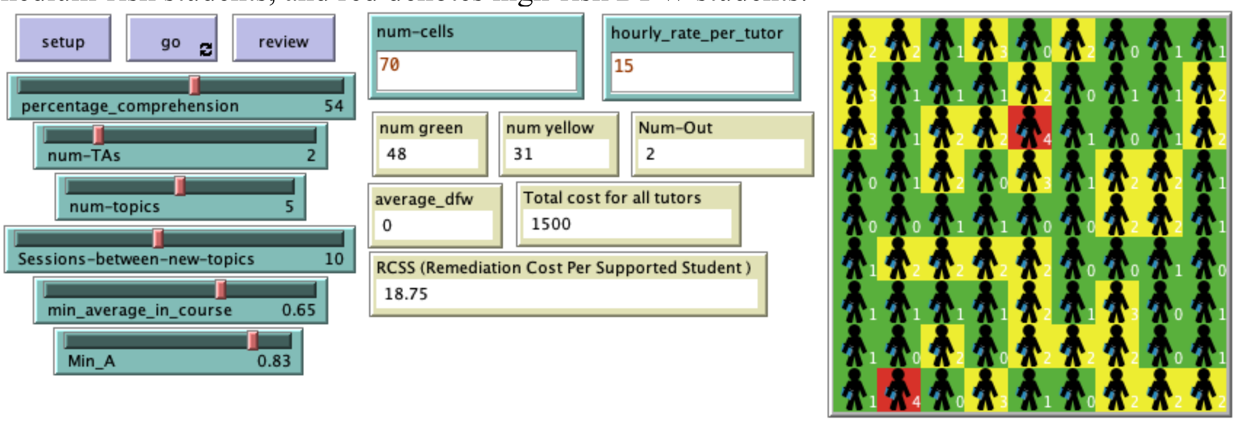

Fig. 2. User-Interface of the Model with Random Course Configuration to Display Heatmap Colors.

Statistical analysis was employed to confirm the correctness of the model's output. During the Spring 2022 semester, a total of 66 out of 70 students successfully completed the course via DFW estimation values. The model simulated 100 iterations and determined that approximately four students would fall into the DFW category, which is in line with the actual numbers observed during the Spring 2022 semester as depicted in Fig. 3. The model incorporates a slider titled "*min_average_in_course*" that enables the setting of the minimum grade average required to pass the course. In this case, a value of 0.65 was utilized, which is consistent with the grading scheme employed in a specific undergraduate ECE course offered through Canvas LMS.

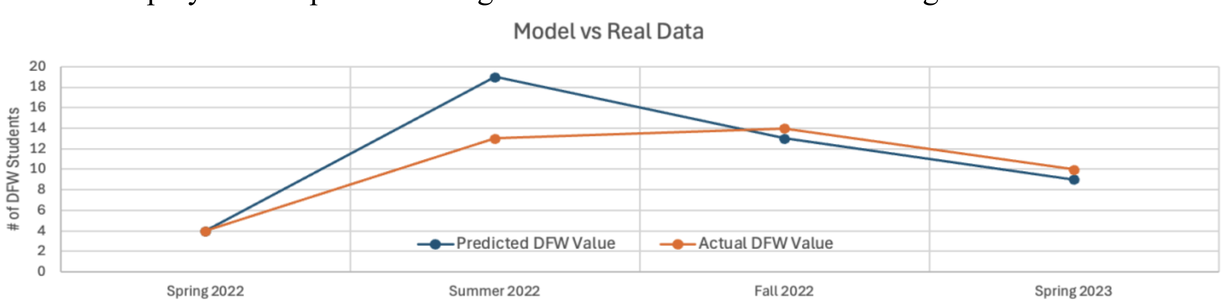

Fig. 3. Model Predictions Compared to Real Values.

The model was evaluated against real DFW values observed in four independent semesters listed in Table 1. The model parameters were tuned to align with the parameters obtained from each semester, resulting in similar performance across all semesters.

Table 1. Parameters to Validate Model

Input Parameters	Spring 2022	Summer 2022	Fall 2022	Spring 2023
num-cells	70	72	122	121
Percentage_ comprehension	55	40	49	54
num-TAs	1	2	3	3
num-topics	5	5	5	5
Sessions-between_ new_topics	12	4	5	5

Table 2. Statistical Analysis: Four Semesters

Semester	C.I. at 95% DFW		Actual Value
	Lower	Upper	
Spring 2022	3.908	4.532	4
Summer 2022	18.807	19.873	13
Fall 2022	12.356	13.364	14
Spring 2023	8.881	9.768	10

The model was statistically evaluated using a 95% confidence interval to support the average values presented in Table 2 and Fig. 3. The confidence interval's upper and lower bounds were incorporated into the model, with users able to view these values when selecting the "review" button. The collected data for three of the four semesters either fell within or were relatively close to the actual values, with the Summer 2022 semester presenting the largest variance. A closer examination of this variance suggests that it may be attributed to various factors, such as inaccurate documentation of total tutoring sessions or unmeasured statistically significant information diffusion rates among students. As previously stated, ABMs offer valuable insights into social structures but are not designed for precise predictions, due to their inherent assumptions and simplifications.

Identifying Optimal Staffing Configuration

As part of the tool for assisting administrative decision making, an added feature of the model is the automatic calculation of the monetary cost per supported student. The introduction of the new metric known as *Remediation Cost Per Supported Student (RCSS)* is defined by measuring the ratio of the total cost to pay all the tutors over the number of students that received remediation. This metric delivers a quantitative measurement of how cost effective a course staffing configuration between number of tutors paid and the number of student's that received remediation. By selecting the combination of tutors and DFW rates that minimizes both *RCSS* and the number of DFWs, administrators can identify the most efficient allocation. For instance, in Spring 2022, employing three tutors attains the most cost-effective remediation strategy, whereas it resulted in the lowest *RCSS* while still maximizing tutor coverage in the ECE course. Increasing the number of tutors directly benefits students seeking remediation; however, exceeding a threshold leads to unnecessary spending.

Conclusion

Given four semesters of a required ECE undergraduate course, the model was able to estimate three of the four semesters' number of students in the DFW category within the magnitude of one. The observational support provided by the base-model served as a starting point for using the model as a predictive tool. Note that this research was specifically applied to an ECE course utilizing a remediation protocol due to limitations in acquiring various instructor gradebooks, which would be required to verify the applicability of these findings in other courses. The primary purpose was to advocate for the crucial role of teaching assistants (TAs) in filling knowledge gaps as course size fluctuates. To test this hypothesis, two experiments were conducted: one that compared student numbers and TA allocation, and another that examined the relationship between student comprehension and TA dependency. The results showed that increasing student numbers requires more TAs, while higher student competency reduces the need for TAs. However, each course configuration can have unique needs, making the model's input parameters customizable to accommodate varying course expectations. The presented model represents the statistical confidence compared to real-world values, with additional experiments providing insights on parameter interactions. Via introduction of the *RCSS,* a quantitative metric is presented for displaying how cost effective the selected number of tutors were at supporting the filling of knowledge gaps within the course.

Acknowledgments

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