Agent-Based Model for Optimal Remedial Staffing to Achieve Learning Outcomes within Cost Constraints

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Abstract

An *Agent-Based Model (ABM)* is developed to assist instructors in **optimizing the allocation of Teaching Assistants (TAs)** in STEM courses, with a focus on improving student outcomes. Parameters including students' understanding of course material, course enrollment, and the amount TA hours, the model estimates student success rates while highlighting effective tutoring strategies tailored to student needs. The ABM quantifies the number of students who are likely to pass a course based on a minimum threshold for comprehension. With the objective of **lowering the D-F-Withdraw (DFW) rate**, a new metric is introduced for identifying how cost effective a selected number of tutors would be at supporting the filling of knowledge gaps within the course and foundational to measuring **thresholds limits** for staffing purposes as shown in Figure 1.

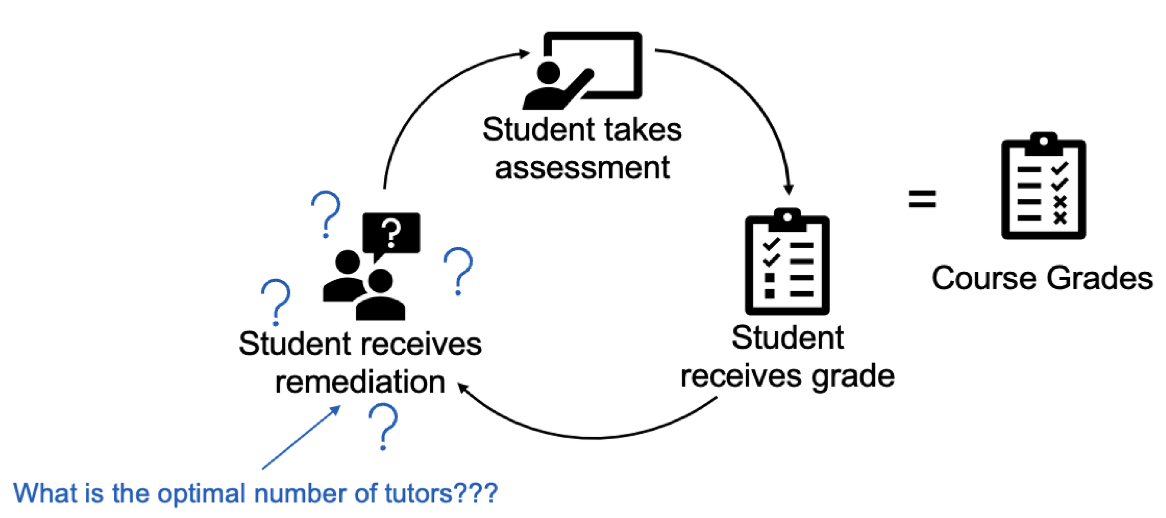

Figure 1: Traditional Remediation-Based Framework.

Introduction

Need for Quantifying Optimal TA Staffing
Automating of identifying optimal TA allocation within higher-ed courses

Approximate Cost Constraints
Identifying approximate financial cost per TAs necessary to support the filling of knowledge gaps presented in Figure 4

Agent-Based Model via NetLogo
Utilization of NetLogo provides a visual and easily append able model to be a general tool for various course configurations shown in Figure 2 and supported with Algorithm 1

Research Contributions

<u>*Predictive Modeling*</u>: The study develops an agent-based model (ABM) that successfully estimates the number of students at risk of failing or warning in a required ECE undergraduate course, offering a valuable tool for instructors to anticipate and mitigate student struggles. The estimations are presented in Figure 3 & listed within Table 5.

<u>*Teaching Assistant Effectiveness*</u>: The research demonstrates that increasing the number of teaching assistants can significantly reduce the number of DFW students and identifies an optimal threshold limit on TAs per course configuration (listed in Table 4), providing actionable insights for instructors to enhance support services.

<u>*Cost-Benefit Analysis*</u>: The study introduces a *Relative Cost-Student Support (RCSS)* metric to measure the cost-effectiveness of employing tutors, offering institutions a data-driven approach to allocate resources and invest in tutoring services that provide a clear financial benefit shown in Figure 4.

Table 1: Spring 2022 Semester Gradebook Statistics for Base Model Selection

	Quiz 1	Quiz 2	Quiz 3	Midterm 1	Midterm 2	Final	Average
Minimum passing grade on quiz	17.5	17.5	17.5	70	70	70	
# above passing grade	49	49	46	36	32	22	
# of students in course	70	70	70	70	70	70	
Average # of student's above passing grade	70	70	65.714	51.429	45.714	31.429	55.7143
# students with passing grades	66						
The DFW value	4						
Average # of tutoring sessions/TA	12.25						

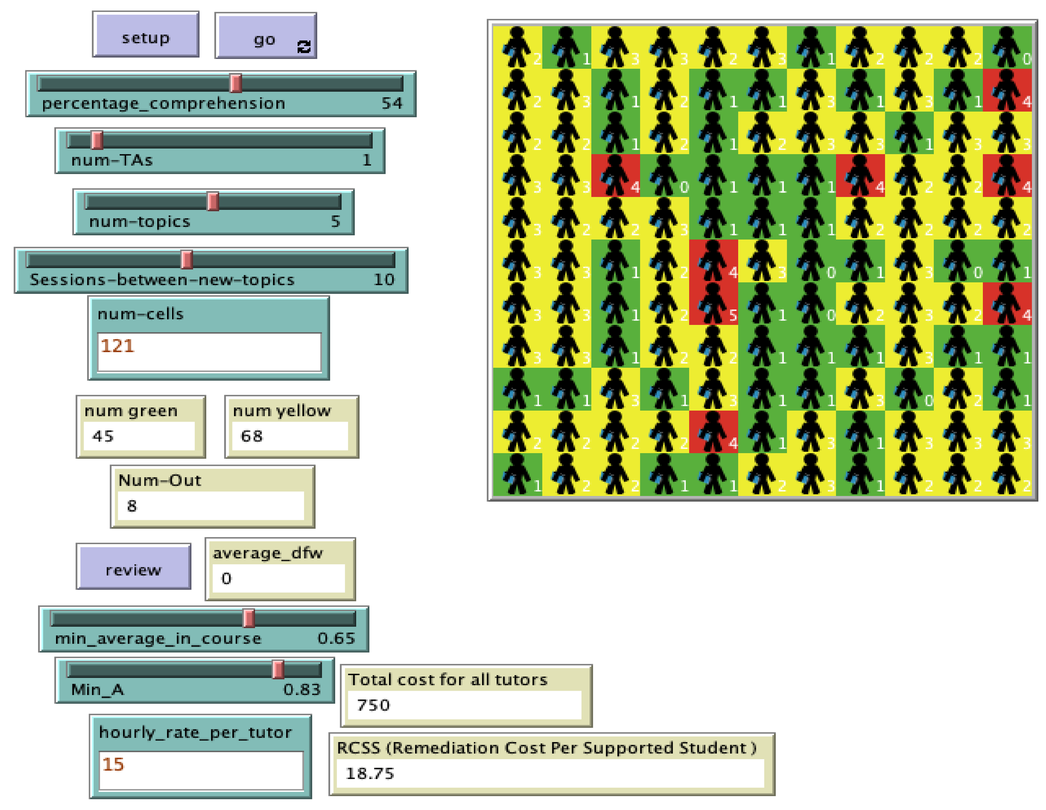

Figure 2: The Base-Model Using NetLogo

Table 2: Input Model Parameters

Input Variables	Description
num-cells	Number of students is dynamic to user preference
percentage_comprehension	The average satisfactory comprehension on quizzes in the course
num-TAs	User specified number of TAs to remediate knowledge gaps
num-topics	Number of major topic assessments, such as quizzes
Sessions-between-new-topics	Number of tutoring/ remediation sessions between major topic in course
min_average_in_course	Minimum percentage value to pass the course
Min_A	Minimum percentage in a course to receive an "A"
hourly_rate_per_tutor	Hourly dollar payrate for a teaching assistant (tutor)

Table 3: Output Model Parameters

Output Variables	Description
num-green	Number of students that fully comprehended all topics
num-yellow	Number of students that do not fully comprehend all topics but also pass the course
num-out	Number of students that did not get the minimum average required in the course
average_dfw	Average "num_out" value over 100 runs of the simulation
total_monatary_cost	The total cost to pay all the tutors for all the hours worked
RCSS (Remediation Cost Per Supported Student)	total_monatary_cost over the total number of remediated students

Experimental Setup

Course Selection: The research focuses on a required ECE undergraduate course, which is identified as having high DFW rates, making it an ideal candidate for testing the effectiveness of teaching assistant support.

Model Parameters: The ABM considers various parameters such as student population, instructor teaching style, and grading scheme to simulate the learning process and predict student outcomes. Which can be realized in Table 1 and parameters listed in Table 2, & 3

Simulation and Evaluation: The model is applied to a four-semester period listed in Table 5, with three out of four semesters' DFW student numbers being successfully predicted within a magnitude of one, allowing for a comprehensive evaluation of its predictive capabilities.

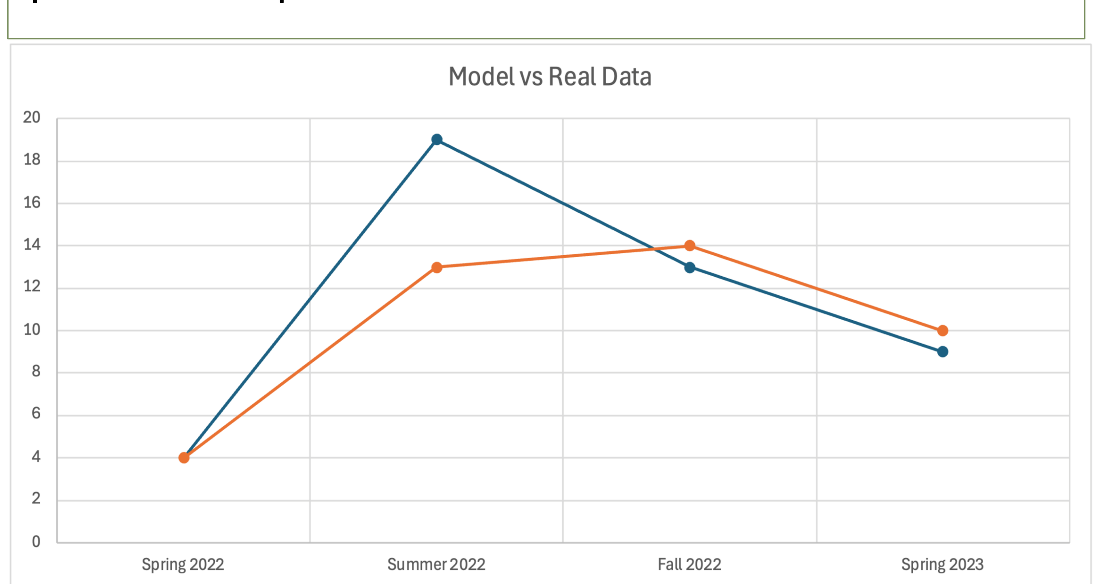

Figure 3: Model Predictions Compared to Real Values

Algorithm 1: Model Flow Pseudo Code for the "go" Procedure

*"**go**" procedure:*
  ***Repeat** for **number of topics** there are in the course:*
    ***Repeat** for the **number of tutoring sessions**:*
      *Tutors **Remediate** students*
    ***Randomly select** and **increase** (100 - percentage_comprehension) **%** of patches **plabel** value. To Indicate they **did not receive** the minimum letter grade on the given quiz to demonstrate competency on the topic.*
      ***Update** the cell **colors** accordingly*
  ***Count** # of red, green, and yellow cells*

Table 4: Input Parameters to Review Legitimacy of the 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

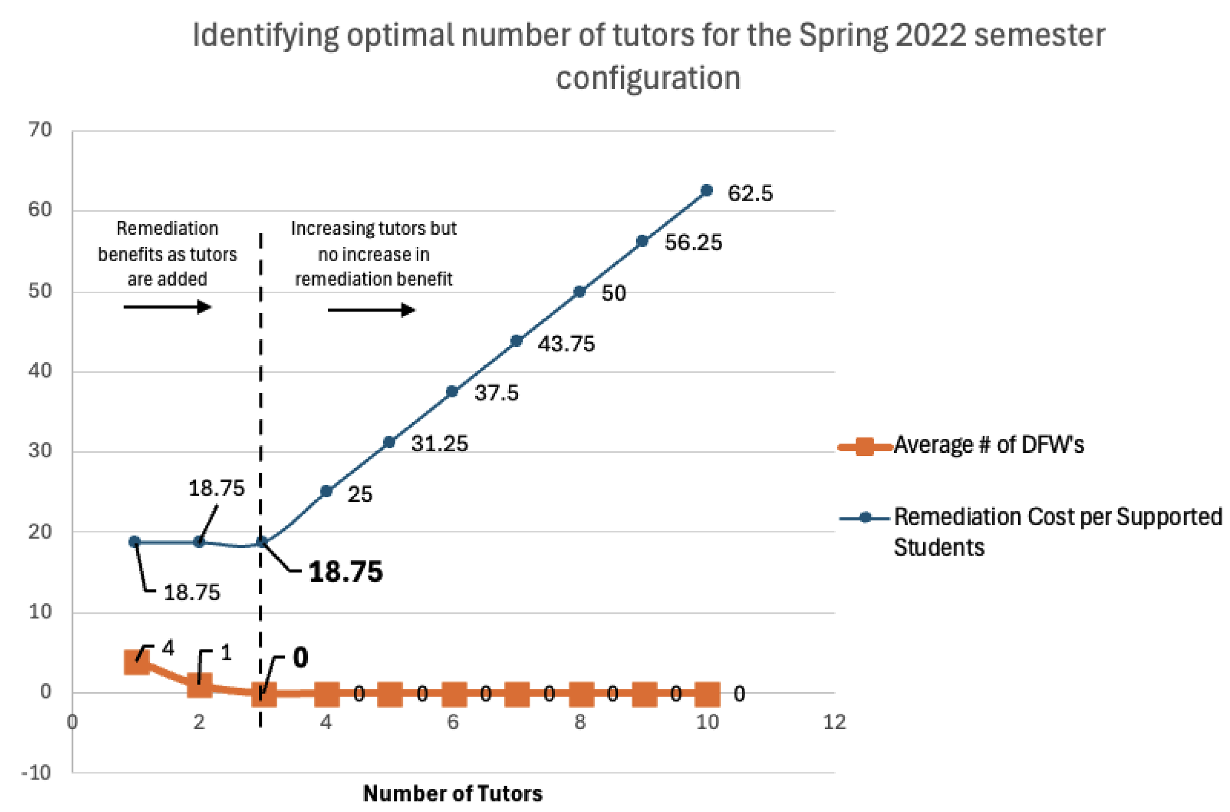

Figure 4: Identifying the Ideal Number of Tutors for the Spring 2022 Semester for the EEL3801 Computer Organization course at large state university in USA

Table 5: Statistical Analysis on the Four Observed Semesters

Semester	Confidence Interval at 95% DFW		Actual Value
	lower-bound	upper-bound	
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

Conclusions

Predictive Power
The agent-based model developed in this study demonstrates predictive power in forecasting student outcomes, providing instructors with a valuable tool to anticipate and mitigate student struggles.

Tutoring Services Effectiveness
The research highlights the effectiveness of tutoring services in reducing DFW rates and improving student outcomes, offering institutions a data-driven approach to allocate resources and invest in support services.

Future Research Directions
Future work is suggested to explore threshold limits on teaching assistants, cost-effectiveness analysis of different tutoring models, and quantifying student, instructor, and tutor behaviors to further enhance the predictive capabilities of the ABM.

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