Modeling Introversion in the Classroom: An Agent-Based Approach

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ABSTRACT

Education remains a critical challenge for many countries, with ongoing research seeking to better understand the complex dynamics of learning and teaching. In this paper, we propose an agent-based model to simulate student behavior in the classroom, focusing on the role of introversion and stress in learning and engagement. Our framework models how these psychological factors interact with classroom conditions to shape student experiences. The model was evaluated by an expert and offers a simulation environment to explore the impact of different classroom dynamics on student learning outcomes.

KEYWORDS

Agent-based Model, Learning, Introversion

1 INTRODUCTION

Classroom learning is a complex process influenced by various psychological, social, and environmental factors. While much research has been devoted to improving teaching methodologies and optimizing learning environments, individual differences among students remain a critical yet often overlooked aspect. In particular, introverted students may experience unique challenges in classroom settings, where participation, interaction, and external stimuli can impact their learning process. Understanding how introversion and stress influence student engagement is essential for designing more inclusive educational strategies. To explore these dynamics, we develop an agent-based model (ABM) that simulates the behavior of introverted students in the classroom, offering insights into how different environmental factors affect their learning experiences.

Introversion denotes a tendency in individuals toward introspective and self-reflective behavior, distinguishing them from extroverts. This distinction is evident in their verbal interactions. All individuals manifest some degree of both introversion and extroversion, as we will show in our model, but it is also known that one trait tends to be predominant. Introverts are often stereotypically seen as shy, socially anxious, or quiet individuals. However, in reality, introversion is more accurately defined by a person's ability to recharge and find peace through solitude, in contrast to extroverts who rejuvenate and unwind through social engagement.

Agent-Based Models (ABMs) offer a powerful framework for simulating cognitive processes and learning behaviors by capturing the interactions between individual learners and their environment. Unlike traditional equation-based models, ABMs allow for the representation of heterogeneous student agents, each with distinct cognitive traits, emotional responses, and adaptive behaviors. This flexibility makes them particularly useful for modeling learning processes influenced by psychological factors such as introversion, stress, and motivation.

By encoding decision-making rules based on cognitive theories, ABMs can simulate how students engage with instructional materials, respond to peer interactions, and adapt to different teaching strategies. Additionally, ABMs enable researchers to explore emergent learning patterns that arise from individual differences and classroom dynamics, providing insights into how environmental factors shape cognitive development. Through simulation experiments, educators and policymakers can test interventions—such as modifying classroom layouts or adjusting participation requirements—to better accommodate diverse learning styles. Ultimately, ABMs serve as a bridge between cognitive science and educational research, offering a method for understanding and improving learning experiences.

The objective of this study is to create a cognitive model focusing on an agent symbolizing a student in the classroom, where characteristics such as introversion/extroversion, stress levels, and other influencing factors directly impact their ability to assimilate the information provided by the teacher. This initial work aims to provide a framework for a more elaborate simulation where the interactions among students and the teacher's style influence and alter the students' learning experiences.

The next section (Section 2) presents related works that inform and contextualize this study. Section 3 describes the methodology used to develop the conceptual framework. Section 3.3 provides a detailed explanation of the model itself, while Section 4 discusses the preliminary results and outlines directions for future research.

2 RELATED WORKS

To the best of our knowledge, this is one of the first attempts to use agent-based models to simulate students' reactions in the classroom based on their intrinsic traits. Nevertheless, several existing studies align with and support our claims in various ways.

The paper "A Framework of Negative Responses to Introversion at Work" [10] introduces a two-pathway model for understanding negative reactions to introversion in the workplace. It suggests that these responses arise from both stereotype-driven biases and behaviors inherently associated with introversion. The framework examines how introverted behaviors trigger social categorization and bias, emphasizing that such behaviors can be exhibited by anyone, regardless of personality type. Ultimately, this work lays the groundwork for future research by offering a structured approach to studying negative perceptions of introversion in professional settings. Inspired by this effort, we explore the possibility of extending this framework to the educational environment, examining how negative responses to introversion manifest in classroom dynamics.

The paper "An Agent-Based Model of School Tracking, Accountability, and Segregation" [12] employs agent-based modeling (ABM) to simulate the impact of school choice strategies and education system characteristics on socio-economic segregation in schools. The study examines two key factors: school tracking (the practice of separating students based on academic ability) and school accountability (the public availability of school quality information). The model represents schools and students as entities with state variables, positioned within a two-dimensional grid, and operates on a one-academic-year time step. Findings indicate that both school tracking and accountability mechanisms tend to amplify socio-economic segregation by intensifying competition for high-quality schools. Additionally, residential segregation emerges as a significant factor that further reinforces educational disparities, exacerbating the effects of existing policies. This study provides valuable insights that inspire our future work on extending the cognitive framework within a broader educational context, exploring its potential influence on decision-makers and educators in shaping school and university systems.

Gu and Blackmore, in their work entitled "A Systematic Review of Agent-Based Modelling and Simulation Applications in the Higher Education Domain" [6] examine the use of agent-based modeling and simulation (ABMS) in higher education (HE). The review identifies key dynamics addressed by existing ABMS applications, assesses their current state of development, and highlights opportunities for future research. The study categorizes models based on four dimensions: agents, relationships, users, and purpose, grouping them into six broad areas: university system, university collaboration, academic activities, application and enrollment, student performance, and teaching and learning. The findings indicate that academic activities have been a major focus for ABMS researchers, with university collaboration, academic activities, and student application and enrollment featuring the most validated models. Additionally, the review reveals that the adoption of ABMS in higher education has grown significantly since 2009. A critical observation is that many ABMS studies fail to validate their models against real-world systems, underscoring the need for more rigorous validation practices. In our work, we aim to ensure the robustness of our proposed model through thorough validation, contributing to the development of more reliable ABMS models for higher education. Furthermore, none of the studies reviewed specifically address the learning process of introverted students, highlighting a gap that our research seeks to fill.

Other studies have explored the connection between agent-based modeling (ABM) and education; however, they fall outside the scope of this study. For instance, [8] examines students' systems-thinking skills by presenting them with an ABM-based problem and evaluating their performance. As stated before, this work aims to create a cognitive model of students in class, and to simulate the interaction of many students and the lecturer in the same environment using ABMs. Now we turn to the model itself.

3 METHODS

In this section, we have two main objectives: first, to introduce the reader to the literature on introversion and education; and second, to present the cognitive model developed through multiple iterations and expert input. Notably, Dr. Crystal Bruxvoort actively participated in our discussions, highlighting potential misunderstandings and conceptual inaccuracies while providing guidance to ensure the development of a robust and well-founded model.

3.1 Introversion

Introversion is a preference for internal processing and solitude, rather than an inherent state of shyness or social anxiety [4]. It is a personality trait characterized by directing attention and deriving energy from the inner world (inner orientation), as opposed to focusing on the external world [2].

The studies by Jacobs and Condon et al. emphasize that introversion exists on a continuum rather than as a discrete category. This perspective suggests that individuals exhibit varying degrees of both introversion and extroversion [2, 7].

Common traits associated with introversion include analytical thinking, reservation, deliberation, caution, self-consciousness, introspection, and conscientiousness [11]. Additionally, introverts are often described as quiet and reticent, with a reflective nature and a preference for processing information internally [2].

Introverts recharge and gain strength from time spent alone, contrasting with extroverts who are energized by social interactions [4]. Introverts typically prefer less stimulation, such as being alone or with a small number of familiar people. They also tend to have fewer, but more meaningful, relationships [2, 7].

Some of the misconceptions about introversion are the misguiding ideas that introverts are cold, unfriendly, incompetent, or socially awkward [9].

It is important to note that introversion is distinct from shyness; while both introverted and shy individuals may exhibit quiet, reticent behavior, shyness is rooted in social anxiety and fear of negative evaluation, whereas introversion is a matter of preference. Additionally, cultural factors can influence behavior, with some cultures valuing collectivist values that may lead to behaviors similar to those seen in introverted individuals [1, 2].

3.2 Introverted students and learning

Given the previously discussed traits of introversion, it is evident that introverted students may miss out on key aspects of their education, often due to misunderstandings and biases inherent in traditional educational settings.

For instance, introverted students may be penalized in classrooms that solely value verbal contributions, as their preferred methods of engagement, such as listening and quiet reflection, are often overlooked. They may miss opportunities to earn participation grades because they do not engage in the way that extroverted students do [4].

Educators also may fail to recognize and commend the observational and analytical strengths of introverted students, who may be too focused on trying to emulate extroverted behaviors. Besides that, introverts may find group activities unpleasant and difficult if they require constant "extrovert behaviors". They need assigned tasks within groups to feel comfortable [2].

Active learning environments may lack the quiet, reflective spaces that introverted students need to process information, potentially increasing anxiety and pressure to perform. The fast-paced nature of discussions can be particularly challenging, as introverts need more time to develop their ideas [2, 4].

Another problem that emerges in this context is when educators misinterpret quiet behaviors as indicators of lower intelligence or decreased learning potential. Teachers may not realize that silence can mean a student is thinking about the concepts being presented [2].

Introverted and shy students may have difficulty approaching faculty to seek clarification or assistance. They may need to be reassured that their need for quiet time is normal and academically advantageous. That is one important factor that our model will tackle, as explained in the next section.

3.3 A model for introversion

This study is ongoing and has undergone two phases so far. The first phase involved a literature review to identify key characteristics of introverts and relevant factors within the classroom environment. During this stage, numerous studies were selected, as presented in Table 1. The second phase focused on analyzing the interconnections between these characteristics. In this stage, we engaged in discussions to define each node and determine the most accurate representation of these elements while ensuring alignment with the literature. Expert consultations played a crucial role in refining our model and providing guidance throughout its development.

3.3.1 Model's attributes. The model is designed to represent the cognitive aspects of a student's interactions in the classroom. Specifically, it incorporates factors that explicitly influence a student's likelihood of engaging in the learning process. This can be exemplified by behaviors such as raising a hand to ask or answer questions, as well as a student's willingness to interact with peers during group activities.

Figure 1 illustrates the interconnections between inner nodes and their influences from external nodes. Each node represents a specific state, while the arrows depict the relationships between them. Red arrows indicate a negative influence from the origin to the target node, whereas blue arrows represent a positive influence. Table 1 provides a more detailed explanation of the nodes and the literature used to justify the modeling decisions made.

Specifically, the **Social Engagement** (*SocEng*) and **Teacher Engagement** ($TeaEng$) nodes represent, in a simplified manner, external stimuli from peers and the instructor, respectively. These states are not present in the Table 1 as they are not part of the internal cognitive model for the student. But they play a role as external inputs. For instance, if other students are highly participative (higher **Social Engagement**), an introverted student may experience increased pressure (stress) to engage. Similarly, **Teacher Engagement** can either encourage or discourage student participation, shaping a classroom environment that may facilitate or hinder a student's willingness to speak when prompted.

The observable reaction of the agent (the student) is captured by the **Engagement Level** (*EngL*) node. The value at this node determines the likelihood of the student increasing their participation in class. This is a reaction output for the student and represents their response after the internal processes are calculated. Therefore, this node is also not present in Table 1 as it is an output node and is used to fine-tune our model.

Our model can represent the full spectrum of introversion and extroversion. The **Introversion Level** (IL) node determines where a student falls on this continuum, with $IL = 1$ indicating a highly introverted student and $IL = 0$ representing a highly extroverted student. This is a stable value as we consider that the introversion trait is not prone to change in a short period of time.

Figure 1 provides how all nodes are related. Blue arrows mean a positive influence of the origin towards the destination node. Red arrows mean a negative influence. All arrows will have an attribute **weight**. The values for the weights will be adjusted as part of the fine-tuning phase.

Stress (St) and **Self-Efficacy (SEf)** present a self-loop arrow to account for the fact that these nodes' values influence their own state. That is, the more stress a person experiences, the more stressed that person tends to become. The same goes for confidence (self-efficacy).

The mathematical framework for each of the nodes is explained in the next section. For more information on the characteristics of the nodes, refer to Table 1.

3.4 Temporal-causal model

The model will be calibrated using a synthetic dataset designed to align with expectations based on expert consultation and existing literature. Each node in the model will aggregate the influence from incoming arrows, reflecting the degree to which it is affected by other factors. Additionally, the arrows will be weighted to represent the strength of the connection between nodes, indicating the relative importance of each influence.

We consider a class to be a temporal event; therefore, our model incorporates a temporal-causal aspect [16].

The mathematical framework used in this study is based on previous work, where the equations are detailed and analyses demonstrate the consistency of the method [5]. In this paper, we focus on highlighting the key structural aspects of the nodes.

Each node in the model will receive an impact from each of the connections received (arrows in) equal to what is shown in Equation 1. In this case, O stands for the node of origin and D for the receiving node (destination). α_{OD} is the strength of the connection between the origin and the destination.

$$impact_{OD}(t) = \alpha_{OD} \times q_O(t) \tag{1}$$

The overall influence of all nodes in D, and affecting its value, is given by Equation 2.

$$\omega_D = \sum_{O \neq D} \alpha_{OD} \tag{2}$$

Considering that a node receives the impact of multiple nodes, we can account for the aggregated impact as shown in Equation 3.

$$aggimpact_D(t) = \sum_{O \neq D} impact_{OD}(t)/\omega_D \tag{3}$$

Therefore, the changes in the state of node D are derived as shown in Equation 4. The parameter γ_D represents the speed factor

Node	Abbr.	Description	References
Introversion Level	IL	Extraversion is one of the Big Five personality traits which will be used inversely for the introversion level.	Roccas et al. (2002) [13]
Combined Engagement	CombEng	The inner perception of the student of how his colleagues are responding to the learning technique used by the teacher.	Treur (2016) [16]
Self-Efficacy	SEf	Self-efficacy is linked to self-esteem and reflects a student's perception of their own potential to succeed in the course.	Tuovinen et al. (2020) [17]; Davidson et al. (2015) [3]
Stress	St	Student's stress level. It is linked to the introversion level and combined engagement, as factors that enhance the stress in classroom.	Shokrkon and Nicoladis (2021) [15]
Energy Level	EnL	The level of energy required for concentration and active engagement in the classroom.	Tuovinen et al. (2020) [17]
Cognitive Fatigue	CFa	Emotional exhaustion, leading to a reduced ability to process information presented by the teacher.	Tuovinen et al. (2020) [17]; Salmela-Aro et al. (2009) [14]
Dedication (Motivation)	Ded	Student's dedication to the course.	Tuovinen et al. (2020) [17]
Cognitive Engagement	CogEng	Active cognitive engagement in the class, including listening, critical thinking, and maintaining focus.	Dubee (2022) [4]
Behavioral Engagement	BehEng	Active engagement in classroom activities, including responding to instructions, answering questions, and participating in debates.	Dubee (2022) [4]
Absorption Capacity	AbsCap	The result of cognitive and behavioral engagement. It will be produced in the model by temporal-causal equations.	Treur (2016) [16]
Achievement (grade)	Ach	The student's academic performance in the course, represented by their current grade.	Tuovinen et al. (2020) [17]

Table 1: Inner states of the cognitive model.

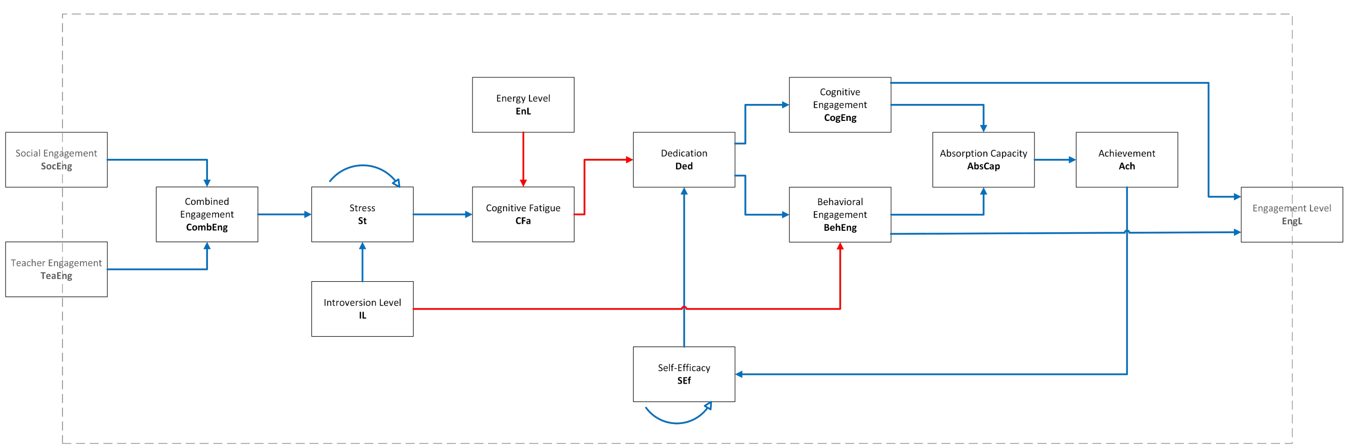

Figure 1: Cognitive model illustrating the relationship between introversion characteristics and student engagement in the classroom.

of these changes and will be fine-tuned during the model refinement process.

$$\Delta q_D(t + \Delta t) = q_D(t) + \gamma_D[aggimpact_D(t) - q_D(t)]\Delta t \quad (4)$$

Each node will consist of a state value within the interval $[0, 1]$. The edges will assume values between $[-1, 1]$, to represent their negative effect as well as the positive effect.

The model will be fine-tuned using a simulated annealing approach [18], given the high dimensionality of the problem, specifically the number of parameters involved.

Simulated annealing is a probabilistic optimization algorithm inspired by the annealing process in metallurgy, where materials are heated and then slowly cooled to remove defects and reach a low-energy state. In optimization, it seeks to find a near-optimal solution to complex problems by exploring the solution space while avoiding local minima. The algorithm starts with an initial solution and a high "temperature" parameter, which controls the likelihood of accepting worse solutions in the early stages to escape local optima. As the algorithm progresses, the temperature gradually decreases according to a cooling schedule, reducing the probability of accepting inferior solutions. Key parameters include the **initial temperature**, the **cooling rate** (often a constant factor like 0.9 or 0.99), the **number of iterations per temperature step**, and a **stopping condition**, such as a minimum temperature or a maximum number of iterations. These parameters must be carefully tuned to balance exploration and convergence to a high-quality solution [18].

The next phase of this project includes creating the synthetic database and the fine-tuning of the model.

In this section, we have outlined the key concepts underpinning the proposed cognitive model for introversion in the classroom. Next, we present the current results and final conclusions.

4 DISCUSSION AND EXPECTED RESULTS

This paper presents the initial phases in the development of a cognitive model to simulate the reactions of introverted students in a learning environment. To the best of our knowledge, this is a novel contribution, as we have not identified any existing studies addressing this specific problem.

We reviewed relevant literature highlighting the characteristics of introverted individuals, as well as the biases and misunderstandings that often hinder their participation in social interaction-dependent environments such as classrooms. Additionally, we detailed the structure of our model, grounding our decisions in both the literature and expert consultation to ensure a solid and promising framework.

The next phase of this research involves refining the model by implementing it computationally and fine-tuning its parameters using a synthetic dataset. The model will be validated through expert review to ensure it accurately reflects real-world dynamics. Once validated, we will use the model to simulate diverse classroom environments and explore the impact of various teaching techniques on introverted students' engagement and learning experiences.

In conclusion, this study marks an important step toward understanding and modeling the classroom experiences of introverted students through a cognitive agent-based approach. Its potential applications extend beyond theoretical exploration—offering valuable insights for educators and policymakers aiming to create more inclusive and effective learning strategies.

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