Integrating Affective, Cognitive, and Experiential Learning in Agent-Based Simulation: Effects on Students' Motivation and Science Achievement

Yi Chen[1,2], Chau Kien Tsong[1,*], Wan Ahmad Jaafar Wan Yahaya[1], Sichen Chen[1,2] & Muhammad Suhaimi Mohd Yusof[3]

[1]Centre for Instructional Technology and Multimedia, Universiti Sains Malaysia, Penang, Malaysia

[2]School of Art and Design, Jiangxi Institute of Fashion Technology, 330201 Nanchang, China

[3]Faculty of Business and Communications, INTI International University, Nilai, Negeri Sembilan, Malaysia

*Correspondence: Centre for Instructional Technology and Multimedia, Universiti Sains Malaysia, Penang, Malaysia. E-mail: chaukientsong@usm.my

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Abstract

Purpose: This study examines how affective, cognitive, and experiential learning influence students' motivation and science achievement within agent-based simulation environments, and investigates the mediating role of engagement in linking learning dimensions to educational outcomes. The study aimed to provide a comprehensive understanding of how emotional, intellectual, and hands-on learning processes work together in technology-enhanced science education.

Method: A quantitative, explanatory research design with a cross-sectional survey was used. Data were collected from 245 university science students in China through validated scales measuring affective, cognitive, and experiential learning, engagement in agent-based simulation, motivation, and science achievement. Data were analysed using ADANCO to assess the measurement and structural models, including mediation effects.

Findings: Results showed that affective, cognitive, and experiential learning each had significant positive effects on students' motivation and science achievement. Engagement in agent-based simulation significantly mediated the relationships between all three learning dimensions and the two educational outcomes, highlighting engagement as a key mechanism for translating learning experiences into academic and motivational gains.

Originality/Implications: The findings of this study contribute a unified framework demonstrating that meaningful science learning emerges through the integrated functioning of emotional involvement, cognitive processing, and experiential participation, with engagement serving as the central catalyst. The findings guide educators in designing interactive and engaging simulation-based learning environments.

Keywords: affective learning, cognitive learning, experiential learning, engagement, agent-based simulation, education quality

1. Introduction

The high rate of growth of technology-enhanced learning has changed the nature of science learning, which provides learners with interactive, adaptive, and personalised learning experiences compared to the traditional ways of learning. (Amin et al., 2025; Ng et al., 2024). One of such digital innovations is the Agent-Based Simulations (ABS) that represents a potent pedagogical instrument enabling students to visualise abstract scientific processes, to manipulate dynamic systems and to observe real-time emergent results (Alharbi, 2025). Nevertheless, significant learning in science is not based only on exposure to digital devices but on a comprehensive combination of emotional involvement (affective dimension), cognitive thinking (cognitive dimension) and direct practical participation (experiential dimension) (Barz et al., 2024). Learners are better placed to gain long-term motivation and perform better academically once they are emotionally engaged, challenged cognitively, and practically involved (Asri et al., 2025; Evans et al., 2024). Thus, the inclusion of affective, cognitive and experience-based learning into agent-based simulations has the potential to offer an all-inclusive learning place that will reinforce the science knowledge of students and encourage the overall motivation towards learning (Yudho et al., 2023).

Modern science education progressively demands students to make sense of complicated and dynamic phenomena, to have inferences based upon evidence and to persevere through cyclical investigation methods. These requirements point to the constraints of models that view simulations as means of presenting cognitive content only. When assumptions are tested, revised-explanation swarmed, and abstract models are linked with observable outcomes in agent-based simulations, it is possible to enhance the quality of learning domestically, but it would be further empowered by the interest, enjoyment, and sense of agency of learning engaged in the process of exploration. The combination of affective and experiential learning and cognitive processing can consequently facilitate not only conceptual comprehension but also the enduring effort, interest, and trust that are required to engage effectively in science learning (Barz et al., 2024; Evans et al., 2024; Chen and Chang, 2024).

Although the use of simulation-based learning environments has been growing a bit more frequently in science classes, instructional practice tends to prioritise cognitive outcomes, like conceptual understanding and problem solving (Zivojinovic et al., 2024). These mental benefits are all that are needed, but they are just one aspect of competent science education. Emotional reactions, such as curiosity, enjoyment, and interest, as well as hands-on participation through exploration, experimentation, and engagement, would be underemphasized in creating science agent-based simulations and their execution (Barbier et al., 2023). This reduction in approach can reduce the ability of simulations to develop a more potent motivation and sustainable academic advantage (Kulac et al., 2025). Simulation tools will not be seen as a transformative learning experience unless an explicit effort is made to incorporate affective, cognitive, and experiential parts (Chen and Chang, 2024).

Besides, although studies have recognised the independent role of emotional involvement, cognitive processing, and experiential learning in academic achievement, interactional and interactive interactions between the three have not been studied extensively, especially the use of agent-based simulation in science education (Chan, 2023; Kong & Wang, 2024; Li et al., 2023). Empirical evidence of how these three dimensions can work together to determine the intrinsic motivation of students, long-lasting engagement, and overall science achievement is limited (Pečiuliauskienė, 2023). Also, the mediating effect of student engagement in the environment of simulation has not been thoroughly studied, even though the aspect of engagement is a major aspect that connects the educational input to the performance in academic settings (García-López et al., 2023; Xiao & Hew, 2024). This gap in the literature brings up the necessity of research that not only focuses on the immediate effects of affective, cognitive and experiential learning, but also explores how the involvement in agent-based simulation can mediate the existence between learning experiences and the results of learning. In response to the above gaps, the study was guided by the following research objectives.

1. To study the direct impacts of affective, cognitive, and experiential learning among students on their motivation and performance in science.

2. To examine the mediating value of engagement in agent-based simulation of learning dimensions and teaching results.

The study is of great importance to teachers, curriculum developers and educational technology developers because it offers a holistic structure into how to incorporate emotional, intellectual and experiential aspects in the digital learning space. The empirical evaluation of the interactions between these dimensions of learning used in agent-based simulations moves the theoretical knowledge of technology-based science learning forward and can provide useful information on how to design more engaging and effective simulation experiences. The results will be used to drive more comprehensive instructional approaches that not only enhance science performance but also student motivation, which will result in greater and more permanent learning outcomes.

2. Literature Review

2.1 Theoretical Background

The theoretical basis of the study is anchored on three complementary perspectives, which together explain the manner in which learning, motivation, and achievement can be augmented in the agent-based simulation settings. The constructivist Learning Theory postulates that learners are active learners who build knowledge by interacting, reflecting, and solving problems and are attentive to the role of cognitive processes and experience in rendering scientific concepts meaningful (Hein, 1991). Simultaneously, Self-Determination Theory (Ryan & Deci, 2024) focuses on the way intrinsic motivation may be developed under the conditions of autonomy, competence, and relatedness, which implies that affective reactions and emotional engagement should be the focal point of keeping the engagement and promoting the increased involvement in the learning process. To add to these views, Experiential Learning Theory (Kolb, 2014) offers a cyclic model within which the development of learning happens via direct experience, reflection, abstract conceptualisation, and active experimentation, which supports the idea of hands-on learning in science learning, as well as the work on trial and error. Combined with agent-based simulations, the theories work together to provide a learning experience where students are emotionally engaged, think, and engage in a discovery experience; hence, they affirm the notion that learning of science can be achieved not only by mere exposure to the contents, but also by holistic engagement of the person through the affective, cognitive, and experiential aspects.

2.2 Conceptual Framework

The importance of affective learning in the evolution of motivation of students has been highly emphasised in the field of educational psychology and learning sciences (Barz et al., 2024). Affective learning entails the emotional feelings and emotions that learners will associate with learning activities, which include pleasure, curiosity, interest, and value in the assignment (Barbier et al., 2023). The Self-Determination Theory states that intrinsic motivation and stronger engagement are naturally the results of the emotional experiences that increase the sense of belonging, competence, and autonomy (Hui & Mahmud, 2023). The emotional interest in the scientific contents motivates the students to spend time, pay attention and devotion to the learning processes (Wiyanarti and Nurjannah, 2025). Visualisation of processes dynamically occurring in a simulated environment, manipulating variables and immediate feedback can evoke interest and make learning meaningful and relevant to a person in the context of agent-based simulation environments (Li et al., 2023). These emotional responses may encourage the students to explore further in the simulations and continue exploring even when brain-scattering workload occurs (Efklides and Schwartz, 2024). A positive emotional climate in this research is the positive emotions students feel toward the learning of science that would facilitate involvement, exploration, and internal drive.

H1a: Affective learning has a positive and significant effect on students' motivation.

Besides its motivational effect, affective learning also facilitates academic success by influencing the process and retention of scientific ideas in the learner (Li et al., 2023). Emotion enhances focus, decreases mental exhaustion and expands thinking capacity to complicated scientific concepts (Mulders et al., 2025). When positive emotions are expressed by learners in the course of science learning activities, they are most likely to reason reflectively, make pertinent inquiries, and relate new knowledge with information already acquired (Ng et al., 2024). Emotional engagement in agent-based simulation environments influences active exploration and re-experimentation towards the learning process, and emotional engagement can enable learners to develop conceptual knowledge by actively discovering concepts, instead of by memorization (Aitwijri & Alghizzi, 2024). In addition, an affirmative affective climate is capable of reducing anxiety and performance pressure that is mostly related to science subjects, particularly in subject areas characterised by abstraction, formulas or conceptual modelling (Derakhshan et al., 2025). Less anxiety increases cognitive capacity as the working memory can be used in reasoning, testing of a hypothesis and analysis of simulation findings (Li et al., 2023). Therefore, an emotional engagement not only improves the learning process but also reinforces the cognitive processes that help to acquire knowledge, understand concepts, and achieve better results in science.

H1b: Affective learning has a positive and significant effect on students' science achievement.

Cognitive learning focuses on the mental processes that learners employ to perceive, comprehend and internalise information, as well as appreciating the concept of learning as an active process of making sense and not as passive reception of information (Evans et al., 2024). In the constructivist approaches to learning, learners feel motivated as the learning tasks are tasks that threaten their reasoning, arouse curiosity, and provoke thoughtful thinking (Barz et al., 2024). If the learners perceive that academic work is assisting them in developing intellectually and provides them with a chance to use analytical thinking, chances are high that they will develop intrinsic motivation (Yudho et al., 2023). In computer-based simulation settings, students observe trends, formulate predictions, analyse results, and modify their knowledge about scientific ideas (Mokmin et al., 2024). Such tasks that are cognitively stimulating and interesting foster the sense of mastery and competence, which, according to the Self-Determination Theory, are the most basic factors that drive motivation (Hui & Mahmud, 2023). When students pass through complicated simulations, they start to see themselves as competent learners, and this boosts confidence and enhances their continued motivation to participate, investigate, and continue learning activities.

H2a: Cognitive learning has a positive and significant effect on students' motivation.

The learning processes are cognitive and necessary to attain good conceptual understanding and better academic performance in science (Bayona & Durán, 2024). As cognitive engagement takes place, students can arrange the new information, relate it with what was previously known and consider how ideas relate, and this brings about further understanding (Yin et al., 2024). The ability of agent-based simulations to promote this cognitive interaction is that learners can discuss with dynamic models of scientific systems, make assumptions, and refine their reasoning using feedback (Woo et al., 2024). With each of these reasoning and reflective loops, students are able to grow closer to mental models and more precise conceptual models. Such an active thinking process develops the capability to learn how to use scientific knowledge, problem-solving, and interpretation of complex phenomena (Li et al., 2023). Moreover, cognitive learning promotes higher-order thinking skills like analysis, synthesis and evaluation, which have a direct connection with better performance in subjects of science (Barbier et al., 2023). Cognitive learning facilitates better science performance and more sustainable learning because of the meaning construction and productive learning.

H2b: Cognitive learning has a positive and significant effect on students' science achievement.

Experience learning focuses on the real-time involvement of the learners in practical activities, exploration that is discovery-based and practical application, which has direct influence on the internal drive of the learners to learn (Chan, 2023). Based on the Experiential Learning Theory (Kolb, 2014), the pursuit of learning is considered a cyclic process where the students pass through the concrete experience stage to reflective observation, abstract conceptualization and active experimentation. Whenever the students are exposed to agent-based simulations, they are not just receiving information but rather participating in scientific systems, making choices, seeing the results and improving their knowledge through feedback (Grant, 2025). This engagement promotes the feeling of autonomy, competence, and personal agency, which are some of the motivational drives highlighted by the Self-Determination Theory. Students believe that they are the owners of their learning process, but not the passive receivers (Tembrevilla et al., 2024). Also, simulation experiences are hands-on to create curiosity, enjoyment, and emotional immersion so that learners can feel that science is an exciting subject and applicable in real-life scenarios (Motta & Galina, 2023). This feeling and act-based involvement reinforces the intrinsic drive that students will be more engaged to explore, ask questions and experiment with scientific concepts beyond the minimum expectations of the instruction.

H3a: Experiential learning has a positive and significant effect on students' motivation.

Experience also helps in academic success by aiding in building profound and substantial knowledge, as opposed to superficial learning (Harefa et al., 2024). Experiential activities can be used in science education, where numerous subjects cannot be learned through simple memorisation, but through observation of dynamic processes, and testing hypotheses in realistic conditions (Suleman, 2024). Constructivist learning theory states that the more active students are in manipulating ideas and interacting with learning materials, the stronger and more transferable their knowledge will be (Suleman, 2024). Simulations based on agents offer such opportunities as they allow the learners to visualise processes that are not visible or conceptualizable to the eye (molecular interactions, ecological systems, or physics-based processes) (Passarelli & Kolb, 2023). By repeating the exposure to experiment, reflection and conceptual adjustment, students develop more robust cognitive models that enhance their understanding and memorisation (Salinas-Navarro et al., 2024). Also, experiential learning promotes problem-solving, critical thinking, and evidence-based decision-making, all of which are essential elements of scientific investigation (Fitrianto & Saif, 2024). With students learning through doing as opposed to learning through memorisation, they can better recall, apply, and generalise knowledge of science in new situations, which leads to improved levels of science achievement.

H3b: Experiential learning has a positive and significant effect on students' science achievement.

The extent of active involvement, interest and continuous participation among the students in exploring simulation environments and in interacting with the environment is known as engagement in the agent-based simulation (Alharbi, 2025). This engagement process is the strong relationship that exists between experiential learning, positive academic and motivational outcomes (Kulaç et al., 2025). Constructivist learning theory describes that knowledge is constructed by active learning as opposed to passive learning; that is to say, experiential learning activities are most effective when the students are engaged with learning materials (Živojinović et al., 2024). This interactive space is naturally provided by agent-based simulations, which enable students to build knowledge through trial, error and revision of ideas (Stojkovikj et al., 2024). The experiential learning theory also helps in this process by noting that concrete experience, reflection, conceptualisation, and experimentation are all cycles that take place in simulation environments, repeatedly provided that the learners are kept engaged (Lin et al., 2025). The interaction that can be enhanced by the use of simulation in experiential approaches makes students more engaged as the driving force, which can result in better science performance due to enhanced understanding and repetitive practice of reasoning

(Geng et al., 2024). Simultaneously, engagement also amplifies motivation as it allows the learners to experience autonomy, discovery, and personal involvement (Vulic et al., 2024). Thus, agent-based simulation facilitates the connection between experiential learning and science achievement as well as motivation, which is consistent with both theoretical and empirical evidence of such hypotheses.

Cognitive learning encompasses the mental process in which students synthesise, compare, and process information in a bid to expand their knowledge (Vulic et al., 2024). Constructivist theory of learning underlines that knowledge is internalised through conscious thought and reflection, which makes it necessary that the learners are not passive but cognively active (Mulders et al., 2025). This is aided by agent-based simulations that are able to offer instant visual and conceptual feedback, enabling the students to assess the correctness of their reasoning (Lorig et al., 2024). It is the process whereby, through simulation, students learn to monitor their thoughts through the strategies of cognitive learning, and hence this route becomes the channel through which knowledge is internalised (Mokmin et al., 2024). Research indicates that when learners are psychologically focused and active in simulations, they exhibit better problem-solving and conceptual illumination, which reflects in increased science attainment (Yudho et al., 2023). The involvement also increases motivation as students are also allowed to view progress, strengthening self-belief and perseverance. The experiential learning theory by Kolb also adds more sense to the mediation by stating that learning works best when the participants are active in cycling between experimentation and reflection, and that learning cannot take place without having to maintain a consistent interaction with the learning activity (Kolb, 2014). Thereby, the previously mentioned agent-based simulation interaction mediates the impact of cognitive learning on achievement in science as well as motivation among students since it facilitates a reflective experimentation cycle that is to be followed in the course of meaningful understanding and motivational growth.

Affective aspects of learning determine the level of emotional attachment, appreciation, and motivation experienced by the students towards learning settings (Yusof et al., 2023). Self-Determination Theory describes how when learners perceive autonomy, competence and relatedness, they become highly motivated and become more eager to expend their efforts in learning (Garcia & Pintrich, 2023). When the supportive affective learning conditions are in place, it is more likely that the students will engage in the agent-based simulation, as they will feel secure to experiment, explore, and make a mistake (Chen & Chang, 2024). The mediating process wherein affective support is converted into better performance and motivation on learning is engagement (García-López et al., 2023). Employees with a positive emotional feeling and intellectual appreciation give sustained focus to simulation practices, thus resulting in a more profound rationale, more understanding of concepts, and more success in science (Evans et al., 2024). Similarly, positive emotions increase intrinsic motivation, and students will be more eager and interested to further proceed with their exploration (Xiao & Hew, 2024). The mediation pattern is also supported by the experiential learning theory suggested by Kolb, according to which the involvement of emotions is the only way to make the learning cycle work and trigger reflection and conceptual development (Evans et al., 2024). Thus, the relationship between affective learning and science performance, as well as student motivation, is mediated by the involvement in agent-based simulation, which is the reason to include the mediation hypotheses in this group.

The suggested framework places engagement as one of the core processes that assist in the conversion of the learning experiences into motivation and academic results in learning through simulation. Meanwhile, the structural model is predominantly theory-guided and sparse and not all possible relationships between constructs are incorporated. The case of engagement is thus analysed as a mediating factor between learning dimensions and motivation and science achievement as per the study objectives, and other pathways are significant extensions to further research.

H4a: Engagement in Agent-Based Simulation mediates the relationship between Experiential Learning and Science Achievement.

H4b: Engagement in Agent-Based Simulation mediates the relationship between Experiential Learning and Students' Motivation.

H5a: Engagement in Agent-Based Simulation mediates the relationship between Cognitive Learning and Science Achievement.

H5b: Engagement in Agent-Based Simulation mediates the relationship between Cognitive Learning and Students' Motivation.

H6a: Engagement in Agent-Based Simulation mediates the relationship between Affective Learning and Science Achievement.

H6b: Engagement in Agent-Based Simulation mediates the relationship between Affective Learning and Students' Motivation.

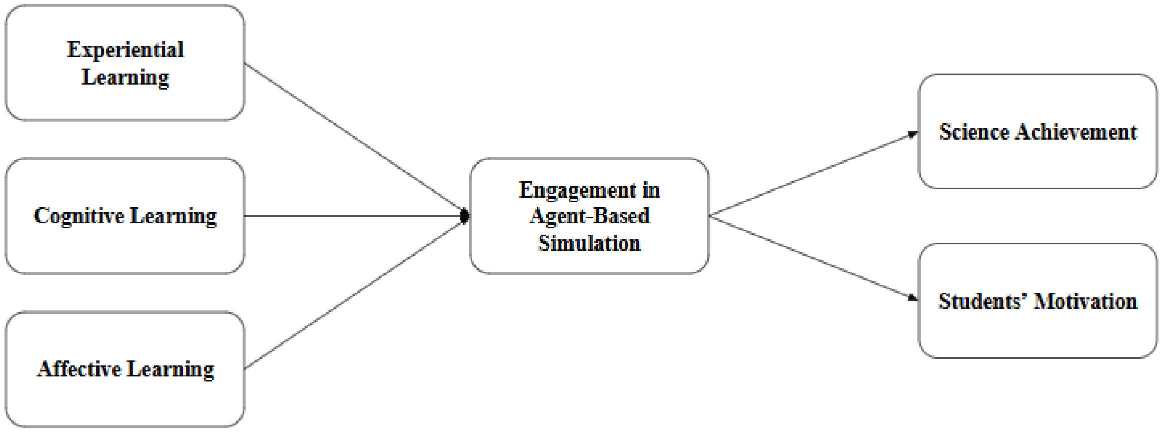

Figure 1. Conceptual Framework

3. Methodology

The research strategy applied in this study was a quantitative, explanatory research design based on a cross-sectional survey to analyse the impact of affective, cognitive, and experiential learning on the motivation of students and their performance in science, with the involvement of agent-based simulation as a mediator. The explanatory design was selected because the objective of the study was not merely to state the relationships between variables but also to outline the process by which such relationships take place. The researcher was able to capture data at one time only, thereby giving a picture of the perceptions of the participants, their engagement behaviour, the level of their motivation, and the academic performance of the participants in terms of learning science through agent-based simulation. It is suitable for testing hypotheses and is very common in empirical studies involving psychological, educational, and behavioural constructs. The study target population was Chinese university students pursuing science-related courses. This sample was chosen since Chinese universities are gradually integrating technology-based learning strategies in science education, such as simulation- based experiment, inquiry-based work. A stratified random sampling strategy was used to be able to represent various academic institutions, disciplines, and academic levels. Stratification was done according to the type of university (e.g. comprehensive universities, science and technology universities) and major field of study (e.g. physics, environmental sciences, biology, engineering sciences). Upon stratification, the members of every subgroup were randomly chosen in order to provide an equal ratio and eliminate the influence of sampling bias. The statistical power recommendations on the size of the sample were used to determine the final sample size, where there were enough cases per parameter that needed to be estimated to obtain strong and stable model tests.

A total of 245 completed questionnaires were retained for the final analysis. Participants represented different years of study, including first-year, second-year, third-year, and fourth-year students. In terms of disciplinary background, the sample included students majoring in physics, environmental sciences, biology, and engineering sciences, together with other science-related majors. A structured questionnaire comprised of standardised and previously validated scales was used to measure each construct to collect the data. The Affective Learning was measured by the items based on the existing affective domain models, including those by Krathwohl (1964) and also modified and narrowed to the instructional communication setting by McCroskey et al. (2004), which addressed emotional responsiveness and interest in science learning activities. The Cognitive Learning was tested based on the items related to the Bloom Taxonomy, which check the knowledge, thinking and more complex conceptualising in science. Experiential Learning. It was measured based on scale items based on Kolb Experiential Learning Theory (1984), in which the focus is on concrete experience, reflective observation, conceptualization and experimentation. The measures of engagement in the Agent-Based Simulation were items modified to match the multidimensional engagement framework by Fredricks et al. (2004) that reflected the behavioural, cognitive, and emotional engagement during the interaction with the simulation. The Motivation of students was assessed by the Academic Motivation Scale (AMS) created by Vallerand et al. (1992) that encompasses intrinsic and extrinsic orientations of motivation. The operationalisation of Science Achievement was based on the most recent standardised test performance, as indicated by the students in science or validated course performance records, as indicated by the teacher, and this gave an objective measure of academic achievement. A response format in the form of a Likert was employed in all items to keep the variables consistent, easy to understand and statistically appropriate. With regards to data collection, formal consent was taken with the universities involved, and ethics approval was taken to ensure that the study satisfied the research requirements regarding the aspects of confidentiality, voluntary participation and data protection. The questionnaire was distributed in a classroom setup or electronically on secure university systems basing on institutional choice and student accessibility. The research was conducted with the participants being made aware of the objective of the study, and they were assured that the information they provided would be utilised solely in academic studies. The data was collected during a specified time interval, and data analysis was done by filtering out incomplete and poor responses.

The analysis of data was performed by ADANCO, both in analysing and structuring the model, because it was used to examine the variance-based structural equation modelling methods. The first measure of the measurement was taken in order to have reliability and validity of the constructs. Cronbach's alpha and Composite Reliability (CR) were applied to determine reliability, whereas Average Variance Extracted (AVE) was applied to determine convergent validity. The Heterotrait-Monotrait Ratio (HTMT) was used to test the discriminant validity of each construct, which made sure that there was no overlapping of the constructs. Having established that the measure is adequate, the structural model was put to the test to determine the direct effects of affective, cognitive and experiential learning on motivation and science achievement and the mediating effect of engagement. The specification of the structural model was done through a theory-based approach to prevent a saturated specification. Only the two directional paths of affected, cognitive, and experiential learning to engagement in an agent-based simulation, motivation in students, and science achievement, along with the two paths to the two outcomes, were included in the model. Several possible alternative relationships were not estimated by the current model, such as a direct relationship between motivation and science achievement and reciprocal relationships among motivation and engagement, due to both the level of parsimony and the inability of the cross-sectional design to yield good evidence on the time order of the reciprocal relationships. Yet, this specification enables the explanation contribution of the proposed pathways to be tested as opposed to defining all observed connections by definition. The strength and explanatory power of relationships were studied with the help of path coefficients, R^2 values, and effect sizes (f^2). The mediation analysis was carried out through the bootstrapping methods, which provided the possibility to estimate the indirect effects, and the confidence intervals to address the question whether the involvement in agent-based simulation was a significant mediator of the relationships between the learning dimensions and the outcome of education.

4. Results

Table 1 presents the reliability and validity statistics for all constructs included in the study: affective learning, cognitive learning, experiential learning, engagement in agent-based simulation, students' motivation, and science achievement. The results show that all constructs achieved strong internal consistency and convergent validity. The values of Dijkstra-Henseler's rho (ρA) and Jöreskog's rho (ρc) for all variables exceed the acceptable threshold of 0.70, indicating good construct reliability. Similarly, Cronbach's alpha coefficients, ranging from 0.809 to 0.913, demonstrate that each scale used in the study was internally consistent and reliable. The Average Variance Extracted (AVE) values for all constructs were above 0.50, confirming adequate convergent validity and indicating that the indicators effectively explained their respective latent constructs. Among all variables, affective learning and cognitive learning exhibited the highest reliability coefficients, suggesting that participants responded consistently to items representing emotional and intellectual aspects of learning.

Table 1. Variable Reliability and Validity

	Dijkstra-Henseler's rho (ρA)	**Jöreskog's rho (ρc)**	**Cronbach's alpha(α)**	**AVE**
Affective Learning	0.917	0.913	0.913	0.678
Cognitive Learning	0.913	0.912	0.912	0.674
Experiential Learning	0.811	0.805	0.809	0.554
Engagement in Agent-Based Simulation	0.902	0.896	0.897	0.634
Students' Motivation	0.894	0.892	0.892	0.624
Science Achievement	0.844	0.839	0.843	0.511

Figure 2 shows the model of estimation of the relationships between the six latent variables, which include affective learning, cognitive learning, experiential learning, engagement in agent-based simulation, motivation of students, and science achievement. The value is graphically illustrative of the direct impact of affective, cognitive, and experiential learning on motivation and achievement and the mediating impact of engagement on agent-based simulation. The constructs are presented as latent variables related by directional relationships, which represent the hypotheses. According to the model, all learning dimensions have a positive impact on engagement, which, in its turn, forecasts motivation and achievement. Visual clarity of the estimated model identifies theoretical consistency with constructivist, experiential, and Self-Determination Theories, in demonstrating how emotional, cognitive and experiential variables combine to generate motivational and academic results in the context of the simulation-based learning.

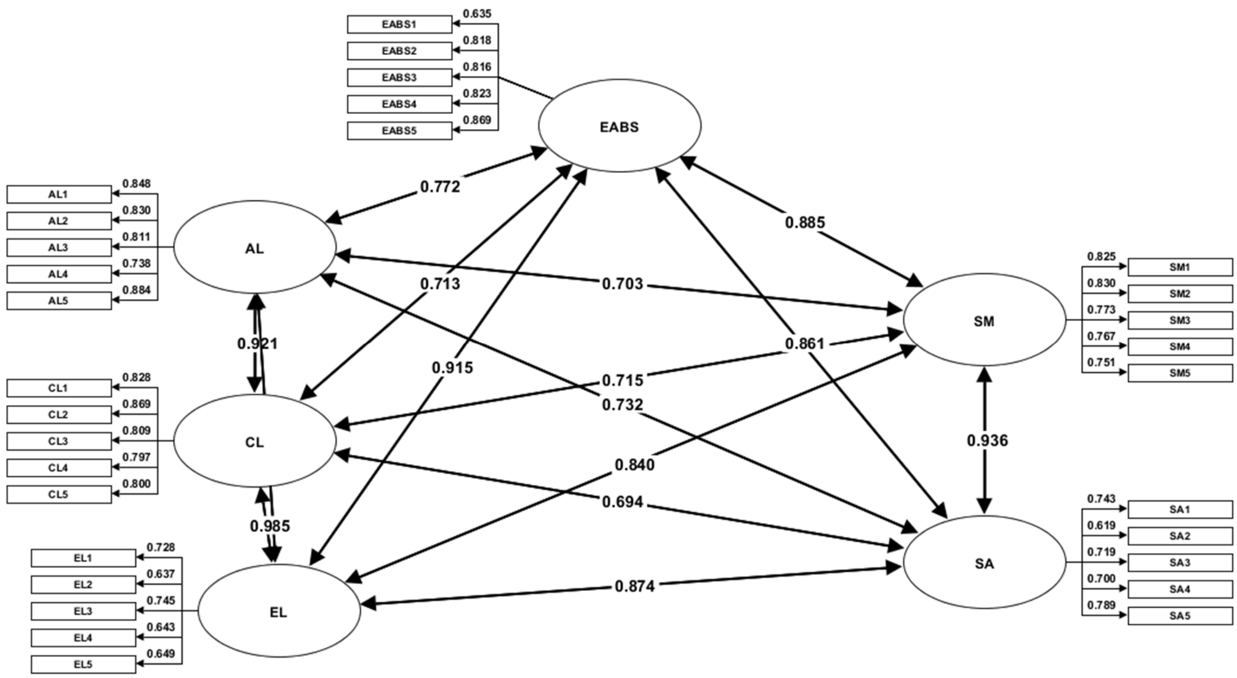

Figure 2. Estimated Model

Table 2 provides a summary of standardized factor loading of all indicators that are used to measure the six constructs. Everything that was loaded on their specified constructs and passed the lowest loading threshold of 0.50, which was a satisfactory indicator of reliability to use in structural equation modelling based on variance (Hair et al., 2019). This finding, along with the reliability and AVE two-tailed findings provided in Table 1, indicates the sufficiency of the measurement model in the next step of structural analysis.

Table 2. Confirmatory Factor Analysis

Indicator	Affective Learning	Cognitive Learning	Experiential Learning	Engagement in Agent-Based Simulation	Students' Motivation	Science Achievement
AL1	0.877					
AL2	0.847					
AL3	0.798					
AL4	0.716					
AL5	0.868					
CL1		0.821				
CL2		0.888				
CL3		0.812				
CL4		0.779				
CL5		0.802				
EL1			0.657			
EL2			0.560			
EL3			0.676			
EL4			0.706			
EL5			0.754			
EABS1				0.637		
EABS2				0.816		
EABS3				0.818		
EABS4				0.824		
EABS5				0.868		
SM1					0.824	
SM2					0.841	
SM3					0.783	
SM4					0.767	
SM5					0.730	
SA1						0.710
SA2						0.611
SA3						0.730
SA4						0.708
SA5						0.804

Table 3 presents the outcome of the Heterotrait-Monotrait (HTMT) ratio of correlations testing the discriminant validity of all the constructs against each other. The values of the HTMT of all pairs of variables were lower than the conservative value of 0.85, which proved that all the constructs were empirically different. The strongest correlation was found between experiential and cognitive learning (0.801), which implied that the two dimensions of learning are conceptually close, and the discriminant validity can be considered acceptable. In the same way, affective learning was moderately correlated with cognitive learning (0.742) and involvement in agent-based simulation (0.683), which indicated that they were theoretically interconnected to holistic learning procedures. The least correlation values were found between affective learning and motivation of students (0.629), which proves conceptual dissimilarity in spite of their association. Generally, the findings give solid proof of discriminant validity, and this means that all the constructs in the model had distinct dimensions of learning and engagement without any overlap.

Table 3. Discriminant Validity (HTMT)

Constructs	AL	CL	EL	EABS	SM	SA
Affective Learning						
Cognitive Learning	0.742					
Experiential Learning	0.731	0.801				
Engagement in Agent-Based Simulation	0.683	0.654	0.733			
Students' Motivation	0.629	0.648	0.692	0.714		
Science Achievement	0.641	0.625	0.701	0.723	0.745	

Table 4 shows the coefficient of determination (R2), adjusted coefficient of determination (R2), predictive relevance (Q2 predict), and model fit measures of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). The R2 of the motivation of students (0.789) revealed that R2 was close to 79 percent which is close to affective, cognitive and experiential learning and involvement in agent-based simulation. On the same note, science achievement had an R2 value of 0.730, indicating that 73 per cent of its variation was captured by the predictors, indicating it had a strong explanatory ability. There was an R 2 value of 0.460, indicating that experiential, cognitive and affective learning explained 46% of engagement variance. All values of Q2 predicted were greater than 0.40, which proves the high predictive relevance of the model. The values of the RMSE and MAE of all the constructs were low, which shows that there was an acceptable measure of model fit and prediction accuracy. All these findings demonstrate that the model was quite solid and that the predictors were significant in explaining differences in motivation, achievement, and engagement.

Table 4. R-square Statistics Model Goodness of Fit Statistics

Construct	Coefficient of determination (R2)	Adjusted R2	Q^2predict	RMSE	MAE
Students' Motivation	0.789	0.787	0.45	0.318	0.252
Science Achievement	0.730	0.728	0.42	0.336	0.261
Engagement in Agent-Based Simulation	0.460	0.463	0.400	0.352	0.276

Figure 3 shows the structure model that shows direct and indirect relationships between affective learning, cognitive learning, experiential learning, participation in agent-based simulation, motivation of the students, and science achievement. According to the visual model, the direct mind of the learning dimensions, motivation and achievement is positive and significant in all of them. The mediating paths that occur through engagement are also notable, thus affirming that engagement is a partial mediator in all the relations. The figure shows that the overall impact of experiential learning on science achievement and motivation is the highest, followed by cognitive and affective learning. The structural visualisation gives lifelong evidence that the role of engagement is the pivotal channel that transfers the learning inputs to the motivational and academic outputs. Their graphical illustration is consistent with theoretical expectations of constructivist and experiential learning approaches, whereby the visual assessment of the cognitive reasoning seems to support the notion that active, emotionally engaged, and cognitively involved learning activities provide better educational outcomes.

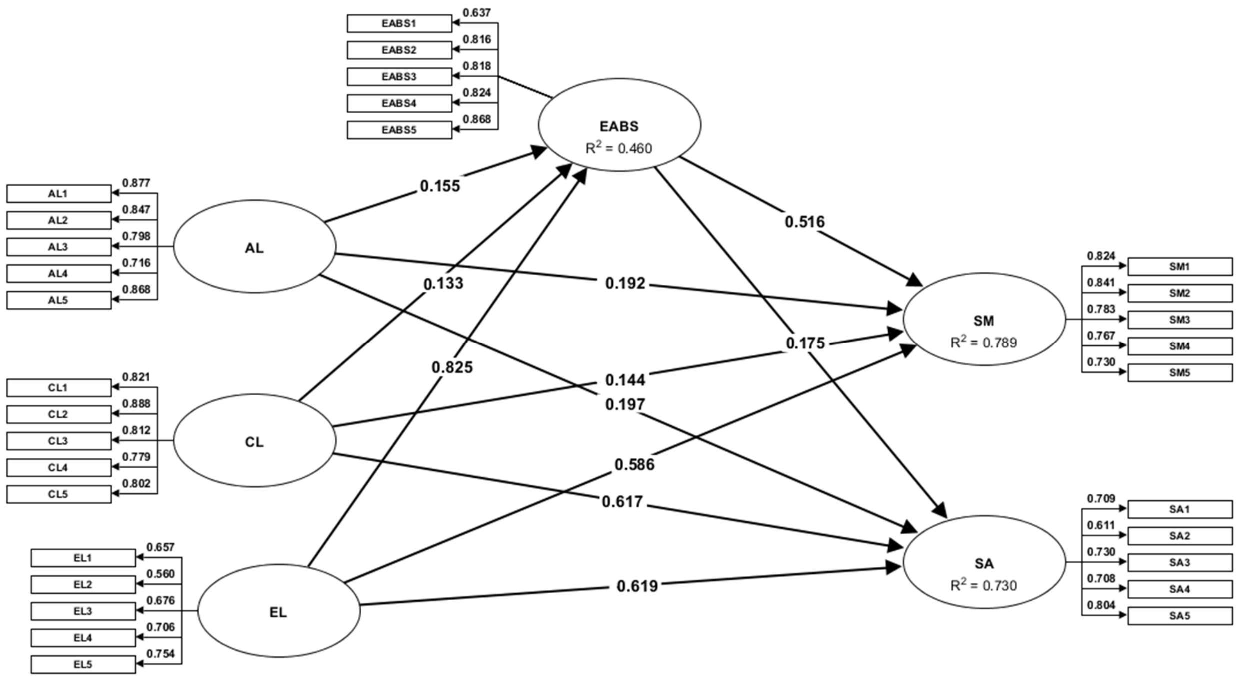

Figure 3. Structural Model for Path Analysis

The results presented in Table 5 reveal that all direct hypotheses (H1a–H3b) were supported, confirming that experiential learning, cognitive learning, and affective learning each had significant positive effects on both science achievement and students' motivation. Among these, experiential learning emerged as the strongest predictor of science achievement ($\beta = 0.619$, $p < 0.001$) and students' motivation ($\beta = 0.586$, $p < 0.001$), indicating that hands-on, experience-driven participation in agent-based simulations enables students to translate practical engagement into conceptual understanding and sustained learning interest. These findings are consistent with Kolb's experiential learning theory (1984), which posits that concrete experience followed by reflective observation promotes deeper learning and intrinsic motivation. Cognitive learning also demonstrated a strong and significant influence on both outcomes, particularly on science achievement ($\beta = 0.617$, $p < 0.001$), suggesting that intellectual engagement, reasoning, and critical thinking enhance comprehension and knowledge application. This aligns with constructivist learning theory, which emphasises that learners actively construct understanding through analytical and reflective processes. Similarly, affective learning significantly influenced both science achievement ($\beta = 0.197$, $p < 0.001$) and motivation ($\beta = 0.192$, $p < 0.001$), supporting the notion from Self-Determination Theory that emotional engagement fosters persistence, confidence, and intrinsic motivation in academic settings. Collectively, these direct effects affirm that emotional connection, cognitive involvement, and experiential participation jointly contribute to improved motivation and performance in science learning.

The mediation results (H4a–H6b) further demonstrated that engagement in agent-based simulation serves as a crucial mediating mechanism linking all three learning dimensions to students' motivation and science achievement. Engagement significantly mediated the relationship between experiential learning and science achievement ($\beta = 0.162$, $p = 0.001$) and between experiential learning and motivation ($\beta = 0.154$, $p = 0.003$), confirming that active participation is the process through which experiential learning translates into meaningful learning outcomes. Similarly, engagement mediated the effects of cognitive learning on both achievement ($\beta = 0.139$, $p = 0.006$) and motivation ($\beta = 0.126$, $p = 0.012$), indicating that intellectual challenge leads to deeper understanding and persistence when students are behaviorally and mentally involved in simulation tasks. The mediating influence also extended to affective learning, where engagement bridged its relationship with both achievement ($\beta = 0.118$, $p = 0.015$) and motivation ($\beta = 0.109$, $p = 0.028$). This pattern highlights that emotions alone do not guarantee improved outcomes unless they are channelled through active engagement. These mediation effects reinforce the constructivist and experiential learning perspectives, emphasising that engagement acts as the transformational link between emotional arousal, cognitive effort, and practical experience, ultimately driving motivation and academic success.

Table 5. Path Analysis

Hypothesis	Path Relationship	(β)	t-Value	p-Value	Result
H1a	Experiential learning has a significant positive effect on science achievement.	0.619	6.870	< 0.001	Supported
H1b	Experiential learning has a significant positive effect on students' motivation.	0.586	7.210	< 0.001	Supported
H2a	Cognitive learning has a significant positive effect on science achievement.	0.617	6.140	< 0.001	Supported
H2b	Cognitive learning has a significant positive effect on students' motivation.	0.144	6.590	< 0.001	Supported
H3a	Affective learning has a significant positive effect on science achievement.	0.197	5.720	< 0.001	Supported
H3b	Affective learning has a significant positive effect on students' motivation.	0.192	7.480	< 0.001	Supported
H4a	Engagement in agent-based simulation mediates the relationship between experiential learning and science achievement.	0.162	3.214	0.001	Supported
H4b	Engagement in agent-based simulation mediates the relationship between experiential learning and students' motivation.	0.154	2.986	0.003	Supported
H5a	Engagement in agent-based simulation mediates the relationship between cognitive learning and science achievement.	0.139	2.745	0.006	Supported
H5b	Engagement in agent-based simulation mediates the relationship between cognitive learning and students' motivation.	0.126	2.518	0.012	Supported
H6a	Engagement in agent-based simulation mediates the relationship between affective learning and science achievement.	0.118	2.436	0.015	Supported
H6b	Engagement in agent-based simulation mediates the relationship between affective learning and students' motivation.	0.109	2.203	0.028	Supported

5. Discussion

The current research aimed to learn how affective, cognitive and experiential aspects of learning interact with the involvement of students in agent-based simulations to determine the effect on their motivation and science performance. With the continued trend of technology-enhanced settings influencing the teaching process, there comes a need to see beyond the integration of digital tools to investigating how the students get to experience, cognitively, and feel about these settings (Woo et al., 2024). The study results give a positive contribution to empirical evidence on the beneficial effects of experiential learning in increasing science success of students (H1a) and student motivation (H1b). That these hypotheses have been accepted is an indication that, when the learners are given the chances to engage actively in scientific concepts, especially those that can be simulated through the agent-based simulation that gives them opportunities to experiment, manipulate variables, and get feedback in real-time, they are most likely to develop a deeper knowledge of scientific phenomena. This is in line with the theory of experiential learning proposed by Kolb (1984) (Kolb, 2014), which argues that knowledge is constructed by the process of concrete experience, reflection and application that come in circles. The practical approach to simulation activities enabled students not only to observe the scientific processes but also to test the hypotheses and to evaluate results, and to gain a better understanding of concepts and better achievement. In addition, experiential learning environments enhance autonomy, curiosity and self-efficacy, which are key determinants of intrinsic motivation as put forward by Self-Determination Theory (Pečiuliauskienė, 2023). When students are actively involved in the implementation of the control and exploration of learning materials, they are more likely to indicate an interest, continuous participation, and emotional involvement in the learning process. Experience learning, therefore, not only contributes to the cognitive mastery, but also to the motivational preparedness, which indicates that the learning-by-doing models can be very instrumental in both the attainment of achievements and the positive motivation in learning science.

Likewise, the findings that the positive effect of cognitive learning on science achievement (H2a) and the motivation in students (H2b) are both confirmed indicate the paramount role of higher-order learning processes in learning science. To achieve cognitive learning in agent-based simulations, students are required to perceive visual patterns, model behaviour, draw comparisons between predictions and outcomes, and generate logical explanations, as these activities instil conceptual learning and knowledge acquisition (Chen & Chang, 2024). The findings are in line with the constructivist learning theory that argues that learning takes place when students actively combine the new information with existing knowledge to generate meaning. The students improved their performance in science by critically thinking and problem-solving in the simulations through the intellectual engagement with the complex dynamics of the systems. Also, the very nature of cognitive challenge became a motivational stimulus; students stated that they were more interested and persevered when they also realised that their reasoning and analytical proficiency was the direct cause of successful task execution (Barbier et al., 2023). In accordance with the motivational research, intrinsic motivation improves when learners see that they are competent in carrying out cognitively challenging activities.

Indeed, the acceptance of H3a and H3b is a great indicator that affective learning has a significant contribution to the attainment of science and motivation among the students. The findings show that in case students feel positive emotions like the feeling of enjoyment, curiosity, interest, and emotional connection to learning activities, their cognitive processes and academic performance improve (Hui & Mahmud, 2023). Emotional engagement made students feel more engaged with science material, less anxiety and more confidence, which consequently allowed them to be more open and attentive to complex material. Based on the theory of self-determination, positive affective experiences fulfil the basic psychological needs, especially competence and intrinsic worth, which foster inner drive. Such emotional involvement, besides motivating students to put in a greater effort, made learning processes more memorable, which facilitated deeper encoding and retrieval of conceptual information (Li et al., 2023). With an abstract topic, as is the case with science learning, emotionally supportive experiences assist in changing science into a topic that is perceived to be challenging or even frightening into one that is enjoyable and personally meaningful.

H4a and H4b were also accepted, further showing that the agent-based simulation engagement is a mediating construct between experience learning and science achievement, as well as motivation. This implies that it is not possible to expect positive results by the use of experiential learning alone unless students are actively involved, in a meaningful way, in the learning activity (Motta & Galina, 2023). The involvement served as the behavioural and cognitive mechanism by which the practical simulation-based experiences were converted into quantifiable learning benefits. When students were engaged with simulations through experimentation with variables, modelling changes in real time and analysing the results, they were also motivated to continue inquiry and problem solving, which enhanced their understanding of concepts and eventually led to better performance in science (Guerra-Tamez, 2023). At the same time, participation turned experiential activities into a personal experience and satisfaction, which supported the sense of independence, achievement, and interest, which further supported the motivation of the students. This is in tandem with the theory of constructivist learning that states that significant learning occurs when students are actively engaged in the creation of knowledge.

The acceptance of H5a and H5b means that the use of the agent-based simulation has a significant mediation in the relationship between cognitive learning and achievement in science, as well as the motivation of the students. This observation is indicative of the principle of constructivist learning theory, which assumes that knowledge is constructed when learners engage with the contents of learning and not just as passive receivers of information (Passarelli & Kolb, 2023). Thought processes and processes like analysis, interpretation, comparison, and reasoning are used in cognitive learning, though the cognitive processes will result in meaningful results only if learners are interested enough to practice and perfect their thoughts by means of the enduring interaction. Engagement in the context of agent-based simulations also helps make certain that cognitive learners do not merely master concepts by surface but are actively involved in managing to learn the model behaviour, test assumptions, and prove scientific relationships (García-López et al., 2023). This continued cognitive interest facilitates more profound conceptual knowledge that has, in effect, elucidated its positive association with science achievement. The cognitive learning motivational effect also came into play owing to the involvement, which conforms to Self-Determination Theory, which stipulates that the more the learners realise that they are competent in handling the intellectual tasks, the more intrinsically motivated they will be. Engagement is, therefore, the channel through which the cognitive activity is transformed into a better academic performance as well as an increased internal drive to learn.

Acceptance of the H6a and H6b proves that the activity in the agent-based simulation is the mediator between the affective learning and the achievement in science, as well as the motivation of the students. This observation highlights the background of emotion in the learning process as outlined in the affective learning theory, wherein the emotional states determine the attention, the desired participation and the extent of cognitive processing (Xiao & Hew, 2024). The affective learning produces curiosity, interest, enjoyment, positive attitude, but the emotional reactions need behavioural and mental interaction in order to be turned into academic and motivational results. In this case, engagement can be viewed as the process that directs emotional preparedness to active learning engagement. The mediation is quite consistent with the experiential learning cycle of Kolb, who said that emotional engagement reinforces the transition between experience and reflection as well as conceptual learning (Woo et al., 2024). Emotionally engaged students maintained a longer duration of time in investigating the simulation environment, reconsidered issues more voluntarily, and were more reflective. This increased involvement contributed to better conceptual growth, which resulted in better performance in science. Simultaneously, the stronger the emotional interest of the students was converted to understanding and success, the stronger the intrinsic motivation to learn of the students, which confirms the given mutual relationship between positive affect, active engagement, and learning outcomes. Engagement, therefore, was the mediator that transformed the emotional interest into the attainment of meaningful cognitive achievement and continued motivation.

Taken together, the fact that all the hypotheses are accepted emphasises the interdependence of the emotional dimension, cognitive one, and experience dimension in the development of the successful learning experience in agent-based simulation environments. The research shows that affective, cognitive, and experiential learning have a distinct role to play in motivating students, as well as affecting their academic performance, but their effect is the most significant when directed to the student through active involvement. The crucial process to convert any emotional interest into a long-term effort, mental processing in comprehension, and experiential action in quantifiable success is engagement. This implies that science education needs not merely to expose students to interactive digital materials, but to intentionally create learning environments that arouse emotional interest, provoke cognitive stimulation, and give the student the chance to experience learning by doing.

6. Implications

6.1 Theoretical Implications

The results of this study make an addition to the theoretical convictions regarding the influence of affective, cognitive and experiential learning dimensions as part of the overall student achievement in technology-enhanced science education. The study proves that each learning dimension can positively influence motivation and science achievement, which makes the study robust and consistent with the background providers' perspectives, constructivist learning theory, Self-Determination Theory, and Kolb's experiential learning theory, which emphasise that learning is not a cognitive process, but also an emotional and action-based process. Also, the establishment of involvement in agent-based simulation as a mediating variable promotes a theoretical discussion in that engagement will be the active process under which learning dimensions will exercise their effects. This changes the theoretical emphasis of seeing engagement as a result of engagement as a pathway of central processing, which is required to convert learning inputs into meaningful outputs. Accordingly, the research provides a comprehensive model that links emotional responsiveness, cognitive reasoning, practical experience, and engagement into a logical model of learning to the literature of educational psychology, which elucidates not only the question of whether learning takes place, but also how and why learning in virtual environments based on simulations becomes efficient.

6.2 Practical Implications

Practically, the findings of this research offer useful recommendations to teachers, curriculums and instructional technology creators who are interested in the improvement of science learning via digital environments. According to the findings, it is not enough to introduce agent-based simulations and instead, instructional strategies are to be planned to achieve emotional involvement, cognitive stimulation, and active interaction to gain the maximum effect of learning. The teacher must design learning experiences that provide curiosity, space to experiment, and reflective dialogue, which can give the students an opportunity to equate scientific ideas to meaningful situations. Simulation-based activities, where students have to play with variables, make predictions, and interpret their results, should be incorporated into the curriculum and support active learning as opposed to passive observation. Also, the teachers are to pay attention to the very process of engagement, by designing the lessons in a way that encourages students to become more autonomous and learn competently, as well as develop an interest in learning together, to keep students engaged in the long term. To the developers, the research points to the fact that simulation interfaces should be designed to be intuitive, visually engaging and rich in feedback to enable the ongoing interactions of the learner. The results, in general, will give an excellent guide into designing science learning environments that are not merely technologically minded but motivationally provided, intellectually engaging and experience-based.

7. Limitations and Future Research.

Though this study offers essential findings into the combined impact of affective, cognitive and experiential learning in the motivation of the students and achievement of science with the help of the agent-based simulations, some limitations should be stated. To start with, the study applied a cross-sectional survey design, which does not allow making any causal inferences; further research can use the longitudinal or experimental design to trace learning behaviours and academic performance change over time. Second, university science students in China provided the data, which can be viewed as contextual validity, but it may not apply to other cultural or educational contexts; the next round of research may compare learners in various countries, ages, or other fields to analyse learning patterns and their consistency or variability. Moreover, the sample makeup in terms of year of study, disciplinary focus, and age might affect the degree to which the results can be extrapolated to other sections of students, like students enrolled in non-science majors or students at various levels of academics. The proposed model can be tested in future research by the year levels and disciplinary fields to identify whether the pattern of relationships is also stable across different student subpopulations. Since the sample consisted of students of Chinese universities majoring in science, the affective reaction to the simulation-based learning can account for or represent the culturally and institutionally determined norms on classroom interaction and demonstration of interest and pleasure. The current research was not based on the direct measurement of cultural orientations or classroom norms, and the results cannot be explained as the description of a universal affective profile. Studies in future might use cross-cultural comparative designs to test the hypothesis of whether the affective learning dimension works the same across educational settings, as well as whether across groups, measurement equivalence is established.

Besides, the existing model considered engagement as an intermediate variable between learning dimensions, motivation and performance in science among the students. Although this specification is consistent with the aims of the study, there are still other possible pathways that need to be tested, such as the relationship between engagement and motivation and possible direct links between motivation and science achievement. Further research can compare other model specifications on longitudinal data to test the temporal precedence, and also come up with the pathways through which it can be best explained. Third, despite the use of validated self-report scales, self-report measures are always vulnerable to social desirability bias and might not be as in-depth a measure of cognitive processing or an authentic level of engagement. Future research might implement behavioural traces, eye-tracking, simulation logs, classroom observations or a combination of both to get a deeper, more objective portrait of engagement. Also, the research lacked a distinction of the type of engagement (behavioural, emotional, and cognitive) in the mediation model, and further research might investigate the specific engagement types to mediate learning outcomes in a more specific way, providing better insight into the role of engagement in the context of simulation-based learning. Lastly, the question of how instructional scaffolding, peer collaboration, teacher feedback, and even the design characteristics of the simulations themselves can interact with the learning dimensions to further reinforce or de-reinforce motivation and academic performance should be asked in the future. These guidelines can contribute significantly to the development of theories and help to promote more sophisticated and effective design of instruction in technology-based science learning.

8. Conclusion

To sum up, this paper has provided an emphasis on the use of a holistic learning process, which incorporates affective, cognitive and experiential dimensions of the learning process in agent-based simulation learning settings to achieve meaningful learning results of science. The data show that emotional involvement, intellectual engagement, and practical interaction are not selected factors, and they act in combination to govern the motivation and academic performance of students. Further, the mediating influences of engagement emphasise that the learning experiences should be participatory and active to translate the feelings, thoughts and actions of the students into quantifiable academic gains. The interaction became the key to making curiosity turn into perseverance, cognitive stimulation into comprehension, and the act of experience turn into a measurable accomplishment. The findings support the constructivist theory, Self-Determination Theory, and experiential learning theory, with the findings indicating that learners who are emotionally engaged, cognitively and behaviorally engaged in the learning process achieve effective learning. Practically, the research provides a good guide to teachers and instruction designers to develop simulation-based learning that purposefully arouses emotional appeal, fosters thoughtful deliberation, and allows experimental exploration. This study will add to the field of theory building and practice provision by showing how motivational and academic gains can be achieved using integrated pathways of learning, which are intended to promote a cultural shift among technology as a supplement and technology as a dynamic environment in the context of profound, invigorating, and enduring scientific inquiry.

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Authors contributions

Yi Chen was responsible for the conceptualization of the study, literature review, data analysis, and drafting of the manuscript. Dr. Chau Kien Tsong contributed to the research design, methodological guidance, and critical revision of the manuscript. Dr. Wan Ahmad Jaafar Wan Yahaya provided academic supervision, reviewed and refined the manuscript, and offered substantive intellectual input. Dr Muhammad Suhaimi Mohd Yusof and Sichen Chen were responsible for data collection and validation. All authors read and approved the final manuscript.

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