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Comprehensive Multi-Agent Distributed Artificial Intelligence Framework in Higher Education

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Abstract
A framework of a multi-agent system will be designed to enhance teaching and learning processes in higher education, aligning with Sustainable Development Goal 4(SDG 4). It emphasizes the roles of various intelligent agents, such as Student Agents and Instructor Agents, which work collaboratively to improve learning outcomes and student engagement. The framework leverages artificial intelligence to address complex educational challenges while ensuring effective communication among agents. Additionally, it highlights the importance of data protection measures to mitigate risks associated with unauthorized access and algorithmic bias.

Keywords: Multi-Agent System (MAS), Distributed Artificial Intelligence (DAI), Student Agent (SA), Instructor Agent (IA), Administrator Agent (AA), Curriculum Developer Agent (CDA).

1 Introduction

The framework of a comprehensive multi agent distributed artificial intelligence (DAI) is considered an intelligent and comprehensive system consisting of a group of intelligent agents working cooperatively to confront complex problems in a specific environment. It is a group of agents working collectively, independently and in harmony, with each agent having a specific role, so that this system constitutes an intelligent and comprehensive framework for dealing with complex cases (De Ridder, 2025). According to Russell and Norvig (2021), they pointed out that an intelligent agent is an intelligent tool designed to operate in a specific environment, and based on its cognitive and sensory perception of this environment, it makes decisions to achieve optimal performance.

The tremendous development in the world of technology today benefits all fields, but brings challenges and risks. However, using artificial intelligence and its various tools in an appropriate manner has the ability to confront many problems in the field of higher education by developing teaching, learning methods, and achieving highly efficient outcomes, thus achieving the fourth goal of sustainable development (SDG 4) (Artificial Intelligence in Education, 2026). All sectors are witnessing many technological transformations in completing, developing work, and making decisions to confront problems, especially complex ones.

One of these sectors is the higher education, it has witnessed a tremendous transformation. Many universities and educational institutions have adopted artificial intelligence systems with multiple agents in order to keep pace with developments in different environments in order to develop the educational process and its outcomes, as well as in managing their work. The concept of the agent has become important in the field of uses of artificial intelligence in most sectors (Wooldridge & Jennings, 1995). One of these important sectors is higher education. One of the challenges that universities deal with as a result of development and competition is developing and improving learning outcomes, so universities resort to using multiple agent systems to contribute to this process (Alhafidh & Alhafidh, 2025). This type of system enhances learning outcomes, student engagements, and other elements in the educational process, leading to the development of higher education as a whole in the educational institution (Usm, 2025). In order to deal with the complexities in the field of higher education, we must implement an intelligent multi-agent system, not a simple system.

One of the problems we face in the higher education sector, is enhancing the learning outcomes for learners (students) and participation through customized educational methods and techniques through a multi-agent system. These agents are learners or students, lecturers or instructors, administrators, and those responsible for developing the curriculum. The challenge is to improve, provide and use available resources, control development, and follow appropriate and effective learning strategies in real time across different entities.

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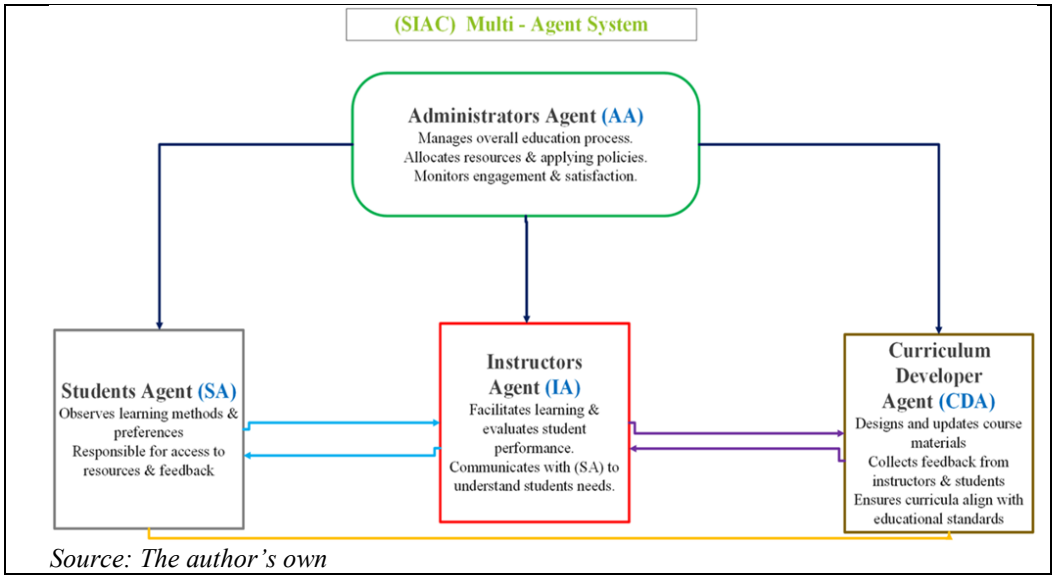
2 System Design

In order to design a system that is more effective, we must analyse and set the desired goals of the system, as well as the sub-goals for intelligent agents (Park & Sugumaran, 2004). The more appropriate the design is, the more effective the system's operation will be. The system name will be **SIAC** according to the names of the relevant agents.

2-1 The agents involved in this system (SIAC) and their roles will be as follows:

Student Agent (SA): It represents the single students and its role is to follow up and observe learning methods, performance and preferences, and is responsible for access to available resources and feedback.
Instructor Agent (IA): Assists and simplifies learning, measures student performance, modifies teaching strategies, and communicates with the student agent to understand the students' needs.
Administrator Agent (AA): The role of this agent is to manage the education process in general, determine the resources to be used, apply policies, and monitor the engagement process and the standards of satisfaction.
Curriculum Developer Agent (CDA): The role of this agent lies in building and developing curricula for programs according to the feedback received from students and instructors, and this agent guarantees consistency with educational and learning standards.

The following diagram illustrates the nature of the interaction and coordination between agents (AA, IA, SA, and CDA). It shows how agents interact with each other and how each of them contributes to enhancing the educational process through the agents' roles and cooperation.



Source: The author's own

2-2 Features (PEAS)

PEAS is considered an essential tool in the process of analyzing intelligent systems containing intelligent agents (GeeksforGeeks, 2025). It is considered important for classifying agents according to the main criteria, which are performance, environment, actuators, and sensing. The main elements of an agent are: Sensors, actuators, environment, performance measure (Jonwal, 2025).

Performance Measure: By focusing on measuring students' performance in terms of the extent of engagement, grades, as well as other measures such as suitability of the curriculum and levels of satisfaction.

Environment: Virtual applications for learning, real classrooms, and channels for communication and administrative dialogue.

Actuators: Should be interfaces for students and instructors to use, a mechanism for responses, and techniques for delivering appropriate content.

Sensors: Availability of data sources, student records and logs, response forms, learning analyses and interaction results.

The below diagram shows the PEAS by outlining the main elements and showing how these elements interact by each other's within the DAI system of higher education.

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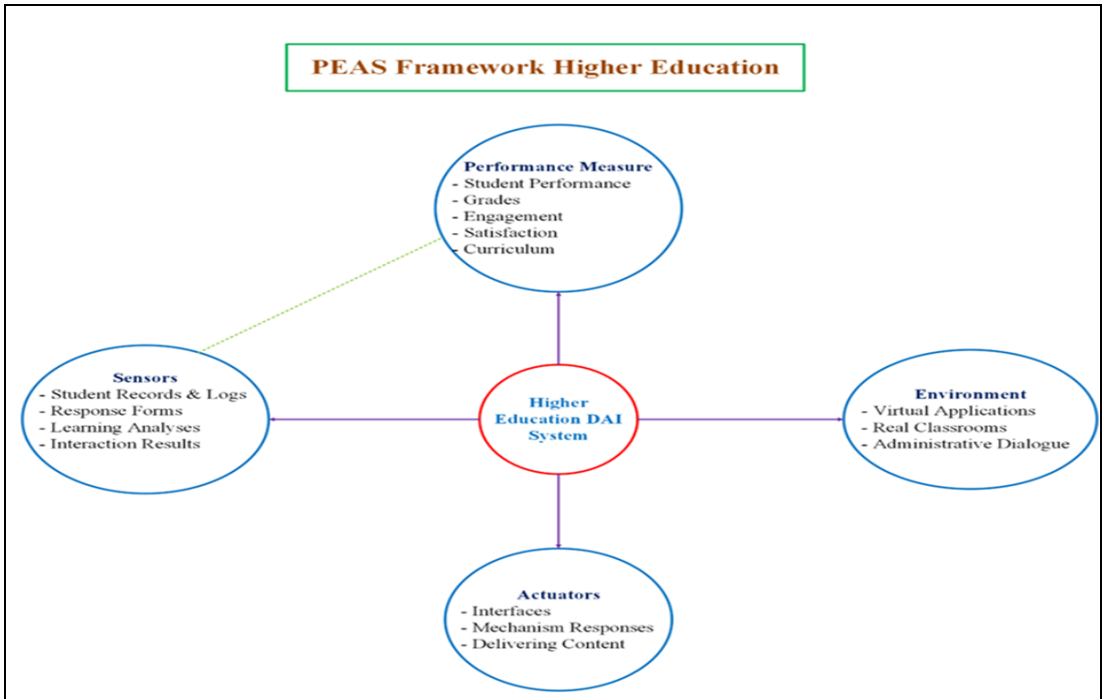

Source: The author's own

3 Communication and Coordination Strategy

Sending agent messages through specific protocols such as using the agent's communication language. Agent communication language (ACL) is considered one of the important tools in a multi-agent system, through which agents can communicate with each other to share information and knowledge (Soon et al., 2018).

Use coordination tools such as contract networks to identify resources as well as auction techniques for scheduling. By using this type of network, the agent has a role such as a manager or a bidder, where the agent determines the ability that must be available in order to carry out the required tasks (Hsieh, 2006).

4 Planning and Decision-Making Methodes

Applying blended planning mechanisms using rule-based systems and machine learning systems in order to reach the best outcomes.

Enhancing the learning of agents in order for them to create effective strategies so that these strategies are adopted in real times.

5 Evaluation the Performance of the (SIAC) System:

The following standards will be used to measure the system performance:
Speed: By measuring the speed of response from the time of students' inquiry to the time of response.
Accuracy: Measuring the validity of the responses and recommendations provided by agents to beneficiary entities in line with the planned standards.
Resilience: Measuring the system's ability to adapt in cases of malfunctions or failure.
Test Bed or Simulation Techniques:
Test Bed benefits those in charge of the system and the beneficiaries by sharing the system's workflow, observations, feedback, and setting priorities in order to enable the system to work effectively to reach the desired results (What Is a Testbed? < SURA, 2022).

Using specific simulation models to model the interactions resulting from agents in order to identify the behaviour of the system in the event of different scenarios. Simulation models such as NetLogo or

AnyLogic models. NetLogo: It is a simulation platform used for agent-based modelling in science (NetLogo Home, n.d.). AnyLogic: This type of model helps managers and analysts gain a deep understanding of operations and thus enables them to improve existing systems to arrive at solutions to complex problems (The AnyLogic Company, n.d.).

Pilot and experimental studies in some selected educational organizations in order to collect data and improve the actions of agents

6 Risk, Security, and Ethical Factors

Like any other system, the system proposed here related to the field of higher education is expected to face several different risks of a technical, security and ethical nature that may affect its operations and effectiveness. The following are the most important risks that this system may face and the guarantees and safeguards to avoid such risks:

6-1 Technical Weaknesses:

A failure in Synchronization: There may be between agents due to poor and inconsistent coordination leading to conflicting results.
Manipulation of Data: There is a risk of unauthorized parties accessing student data, changing it, manipulate with it, or using it for other purposes without permission.
Protecting and Encrypting Data: By applying strict restrictions on access to data, especially private data, to avoid unauthorized parties from accessing the data. This is why encryption tools are used to protect data. These encryption tools are considered a safe way to ensure that data is protected and not hacked by unauthorized parties (Ullah et al., 2022). By applying these technologies, data will be protected and breaches will be prevented.

6-2 Ethical Factors:

As a result of the increasing use of artificial intelligence tools in higher education, it is necessary to have ethical foundations and standards that enable all entities in higher education, including students, instructors, and administration, to carry out their tasks objectively and reliably.

Bias: There may be a bias in the system's work if the algorithms are designed in a biased manner, and thus the results may be biased toward one party over the other. Therefore, bias may result in the process of evaluating students or allocating and identifying resources. Therefore, failure to mitigate bias leads to failure to reach ideal and valuable solutions ("The 5 Biggest Biases That Affect Decision-Making," 2025).

Deficiency of ttransparency: Difficulty in understanding and clarity in decision-making processes by agents may lead to wrong decisions.

Mechanisms to Mitigate Bias: In order to reduce and avoid bias, there must be a process of auditing and monitoring the algorithms in order to achieve fairness and transparency, as well as those who carry out the process of designing the algorithms. Bias checking and audits is the process of verifying that the predictions and decisions of agents are fair and unbiased (FairNow, 2024).

7 A future Outlook

Artificial intelligence has a major role in higher education in the future, by bringing about fundamental changes that will contribute very significantly to enhancing and managing the educational and teaching process, through acquiring personal learning experiences, developing student engagement, management effectiveness, relying on data in making decisions, and developing research methods (Dev, n.d.).

In the upcoming 5 to 10 years, there is a very high possibility of development in artificial intelligence systems, especially those with multiple agents, through:

Adopting sophisticated and advanced artificial intelligence systems, by using advanced techniques in deep learning to enhance student performance using predictive analytical methods. Using real global data by taking advantage of big data in global learning systems in order to develop and adopt new learning methods.

8 Conclusion

A comprehensive multi-agent DAI framework for higher education comprises several intelligent agents working collaboratively to address complex educational challenges. These agents, including Student Agent (SA), Instructor Agent (IA), Administrator Agent (AA), and Curriculum Developer Agent (CDA), perform specific roles to enhance learning outcomes and student engagement through specialized teaching methods. However, implementing such systems faces challenges, including technical vulnerabilities, data manipulation risks, and ethical concerns related to bias and transparency in decision-making processes. Enhancing the learning of agents in order for them to create effective strategies so that these strategies are adopted in real times. By applying strict restrictions on access to data, especially private data, to avoid unauthorized parties from accessing the data to ensure fairness in decision-making.

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