Designing Pedagogical Agents Toward the Recommendation and Intervention Based on Students' Actions in an ITS

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***Abstract*—This full paper aims to present a model of the Pedagogical Agents architecture to assist in activities and tutorial interventions for mastering the resolution of first-degree polynomial equations. With the impact of the educational situation in various parts of the world due to the Covid-19 pandemic and the difficulties identified in the interaction between student and teacher, this research uses a multi-agent approach to improve the architecture of an Intelligent Tutoring System aiming to assist in the context of distance education. Exploratory research in the literature was carried out, aiming at the problem and situation, which implies the process of development of the technological artifact and from the elaboration of a product based on the gaps found. As pedagogical support, Vygotsky's social interaction theory for instructional support is used. The implementation of this proposal will result in the improvement of Tutoring Systems, allowing to guarantee conditions for the teacher and the student to carry out the teaching and learning process flexibly and intelligently, aiming at the construction of knowledge.**

***Index Terms*—Intelligent Tutoring Systems, Design Pedagogical Agents, Learning Algebra.**

I. Introduction

Over the years, several researchers have incorporated the technology of Pedagogical Agents (PA) in the modeling of Intelligent Tutoring Systems (ITS) e.g. [1]–[5], and the current projects, are focused on the identification of affective states to provide strategies for regulating emotion [6]. It is understood that the approach based on Pedagogical Agents is the application of a set of software agents that constitute a general architecture [7], as well as the inclusion of animated characters in the interface applied in an ITS [8].

The inclusion of PA in ITS has provided a new personalized learning experience for learners [6], [9], [10], and used in classrooms to support K-12, they can be highly effective [11]. In addition, they can be more effective if designed to work together with human teachers, expand their skills to their complementary strengths [12].

With the sudden changes in the teaching and learning process during the Covid-19 pandemic crisis, many teachers had to make an unexpected transition from face-to-face to remote education [13]. In the Science, Technology, Engineering, and Mathematics (STEM) programs, this means a change from face-to-face instruction to self-directed instruction model [14]. The use of technological solutions in response to the adaptation of the teaching and learning process mediated by technology has been adopted by educational institutions in response to the crisis [15].

The limitations faced by changing teaching and other already recurring ones, (i.e., basic computing skills, infrastructure, mobile computing, language and culture [16], it is possible to identify that many teachers encounter problems when creating and structuring exercises to be applied to the learners. Moreover, monitoring many learners in online classes has become a very expensive activity.

In the years leading up to the start of the pandemic, some studies already carried out with the ITS LEIA [17] and [18] point to this problem. Some other is that many students perform well and require exercises with a higher level of complexity because, for them this increases their confidence about the contents and subsequent evaluations.

Based on the problems of remote education and those outside the school (technology, culture, among others), this research proposes an approach based on Multi-agent Systems (MAS) to contribute to improving the adaptability of ITS about monitoring and sequencing of exercises for the initial teaching of Algebra for K-12 students. Some methodologies are used to define the proposal.

First, the approach is focused on the social interaction aspect [19], the didactic accompaniment of the various exercises is offered according to the level of knowledge of each learner. In addition, a set of techniques are explored aimed to control the learners' exercises for monitoring and sequencing the first-degree polynomial Algebra domain. For this, the proposal is based on the teaching model of Pillay, Wilss, and Boulton-Lewis [20].

In addition to this introductory section, this article is organized as follows. The section II presents the background and related works that justify the development of this proposal. The section III describes a summary of the project in progress and its functionalities that will be improved from this proposal. The sections IV and V describe the model and pedagogical agents that encompass the necessary improvements to adapt the current educational process. Finally, the section VI, describes the conclusion followed by future perspectives for further advances in the development of project.

II. Background and Related Works

According to [7], Pedagogical Agents are called pedagogical when linked to an environment where there is a society of agents that makes a teaching-learning system. In addition, they have a set of rules that determine their teaching objectives and plans to achieve them based on teaching strategies.

Lelouche [21], highlights that the agents' objective is to communicate with students to fulfill the tutoring functions so that it can be represented by the action/behavior of a student or another agent. The result of action defines the category of agents, as [21]:

- **Tutoring Agent**: interacts with the learner and performs tutoring functions, e.g., problem solver, domain presenter, domain aide, and exerciser, each responsible for an operational mode.
- **Service Agent**: performs functions e.g., problem selector, topic and question selector, and direct interaction with the learner is not possible.
- **Mixed Agent:** they are agents that can be activated in any way, depending on the situation. These are characterized as problem-solver and explanation provider.

The role of a PA can be associated with a level of abstraction, defined by the level of the entities on which it works [21]. In recent research, PA are presented as animated characters, responding to the learner through verbal and non-verbal combinations or emotions [7], [8]. At first, this research is focused on the construction of PA of the type *Service Agents*, seeking improvements in adapting self-directed learning [14] in tasks of mastery of early skills in the domain of Algebra.

There is a variety of research that uses PA in an interesting way and with pedagogical behaviors and teaching tactics related to the approaches used by this research. SITS [1], uses the Multi-agent architecture to measurement at the user's knowledge level and recommend guidelines for developing a flowchart in the programming domain. The authors addressed the strategy of drag and drop in the fields of the flowchart so that the learner can have access to the particular concepts in the domain.

TECH8 [2] has an intelligent agent that automatically analyzes the learner's learning trajectory and alerts you of the most frequent errors during learning while later recommending pedagogical actions to improve (skip discipline, finish the formative assessment or new material).

The project TUCUMÃ [3] uses several agents who are responsible for monitoring the activities of the students, informing them that are pending or lack of participation for a 3D virtual tutor who assists with doubts about the discipline through a dialogue, where the student will hear the answers.

MELITS [4] was developed to recommend teaching-learning materials through the case-based methodology. A diffuse algorithm was used to estimate the levels of cognitive skills of the learner user. The proposal aims to avoid the need to define a set of complex rules for recommending learning objects.

WITS [5] was developed for introductory computer education. ITS contains agents responsible for managing course content, interface, and feedback. The prototype integrates concepts of personalization and learning theory to recommend learning objects appropriate to the level of knowledge of the learner. User reviews have been shown to meet personalized learning needs.

As highlighted earlier in the introduction to this article, the difficulties caused by changes in the educational process caused by the Covid-19 pandemic, there is a difficulty for teachers when it comes to creating and structuring practical exercises to be applied to learners. None of the works mentioned above took into account the teacher's task as a mediator in the remote teaching process, which justifies the development of the *Domain Agent* for this research helping in the organization of knowledge and leveling the degree of difficulty of the equations.

In general, the developed PA have the differential of highlighting and assisting the teacher's perspective as an ITS user. We highlight the adequacy of exercises based on the polynomial equation of first-degree considering abilities and difficulty of the learners during the solution of the activities.

III. An overview of the Project

The proposal is an extension of an ITS LEIA [17] to support the development of introductory knowledge of Algebra. ITS allows students to interact (step-based) individually to understand the dynamics of the equation-solving process. Moreover, the teacher works and inserts the content in system, which then the ITS itself makes available to the learners to carry out the practical activity of the supervised solution.

Currently, there are three PA that make up the ITS architecture, namely:

- **Data Agent**: is responsible for maintaining the student model; record the learner's action history. In addition, it is responsible for managing the system's mentoring cycle.
- **Expert Module**: analyzes the solutions of the users' equations (divide, add similar terms, sum) in each step until it finds the unknown value of x. Provide comments on the outcome of each step. In addition, it has Natural Language Processing support to facilitate communication between learner and system.
- **Analytics Agent**: is responsible for providing student performance reports to the teacher. The agent informs about the number of equations and the steps worked by each student, in addition to the creation of a Timeline informing the interaction time with each of the activities.

The ITS LEIA [17] was developed under the pedagogical perspective of Lev Vygotsky's social interactionist theory. Such architecture specifies the pedagogical agents exercising some functions (mediation, diagnosis, support) to which Vygotsky [19], suggests that the social environment and particular language provide the means to acquire knowledge in the process of mediation. Thus, our approach assumes that new knowledge and skills vary in their proximity (Zone of Proximal Development) to the current ones that the apprentice has.

Despite the positive impact of ITS LEIA in research [17] and [18] in teaching Algebra content, the authors recognize some limitations. First, the mathematical problems and the sequence of instruction are predetermined, unable to adapt to the needs based on the mathematical skills of each learner. Moreover, there is a concern regarding the help of the teacher in the construction of the equations to be made available for self-directed learning by the students.

In order to develop a teaching environment with improvements in adaptability and to contribute to minimizing the challenges of the Covid-19 pandemic, the proposal aims to ensure that ITS helps the teacher in promoting the teaching and learning experience carried out at a distance. Thus, ITS can act as an assistant in the diagnostic tasks of learners and can promote activities consistent with the level of learning.

In this way, a set of PA is proposed with the intention of helping K-12 students with practical questions involving polynomial equations of the first-degree. The proposal aims to improvements in the adaptation and sequential interaction of activities.

The proposal addresses the Multi-agent architecture, which has an advantage over traditional architectures because it presents greater flexibility of the elements that make up the system (e.g., a module = an agent) and, in addition, allows the insertion of new agents with new features.

IV. Designing of the Proposed Pedagogical Agents

The architecture shown in Figure 3, contains all the agents covered in the description of this research. The *Data Agent, Expert Module* and *Analytics Agent* mentioned in Section III, and the other three Pedagogical Agents: *Domain Agent, Learner Agent* and *Tutor Agent* that were designed as a proposal for inclusion in the system and that will be described in the next sections.

A. Domain Agent

At first, the proposal aims to increase the power of the ITS LEIA and facilitate the teacher's work to sort the questions according to the levels of difficulties and concepts. The concept level was worked on, leading the teacher to only enter the equations (activities) in the system and an assessment of the level of difficulty. The domain representation is structured according to Figure 1.

Domain Agent sorts all entries (see Figure 3). The teacher only needs to write the input equation (1) and afterward, the Domain Agent analyzes (2). When the equation is input into the system, the agent inferred which concepts are inhered according to the domain (3) (see, Figure 1).

The proposal is focused on studies related to the initial teaching of Algebra in the form $ax + b = c$, where $a \neq 0$, a e $b \in N$. This involves symbolizing and operating numerical relationships and mathematical structures [22], as shown in Figure 2.

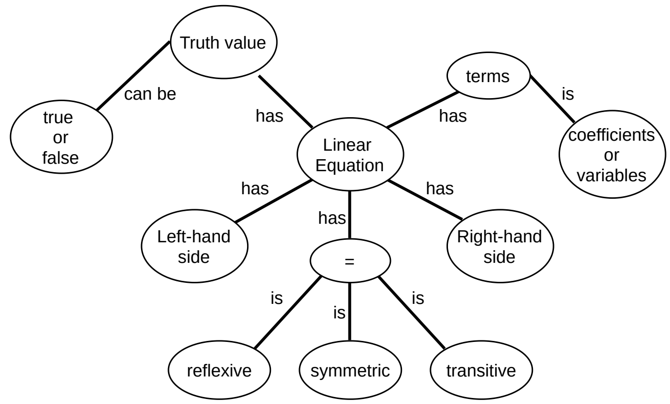

Fig. 1. The map of equation concept.

Solve for x: 2x - 6 = 14 - 3x

Steps:

1. Isolate the variable — 2x - 6 = 14 - 3x
   a. Add 3x to both sides — 2x + 3x - 6 = 14 - 3x + 3x
   5x - 6 = 14
   b. Add 6 to both sides — 5x - 6 + 6 = 14 + 6
   5x = 20
2. Group
   a. Divide both sides by 5 — $\frac{5x}{5} = \frac{20}{5}$
3. Simplify — x = 4

Fig. 2. The Linear Equation problem [23].

The theme was chosen for two reasons. First, it is one of the fundamental topics of mathematics. Second, that the lack of skills to solve equations or understand their structural meaning (e.g., use of a variable) can compromise the academic success or other occupational activities of the student [24].

Aiming to assist the teacher, the *Domain Agent* was structured following the concepts structured by [25]. Wasserman [25] examined the contributions of the connections of knowledge and the application of algebraic structures. The solution steps logically and reasonably explain the importance of mastering these contents as listed in Table I.

The different topics and concepts seen in Table 1, are useful for modeling a simple and easy to use and maintain environment. For the process and teaching of the content of Algebra, the sequencing of concepts proposed by [20] was addressed.

After the content is classified by the Domain Agent, the following information is stored in the database: 'DB_problems' (4): *<idProblem, equation, difficulty,*

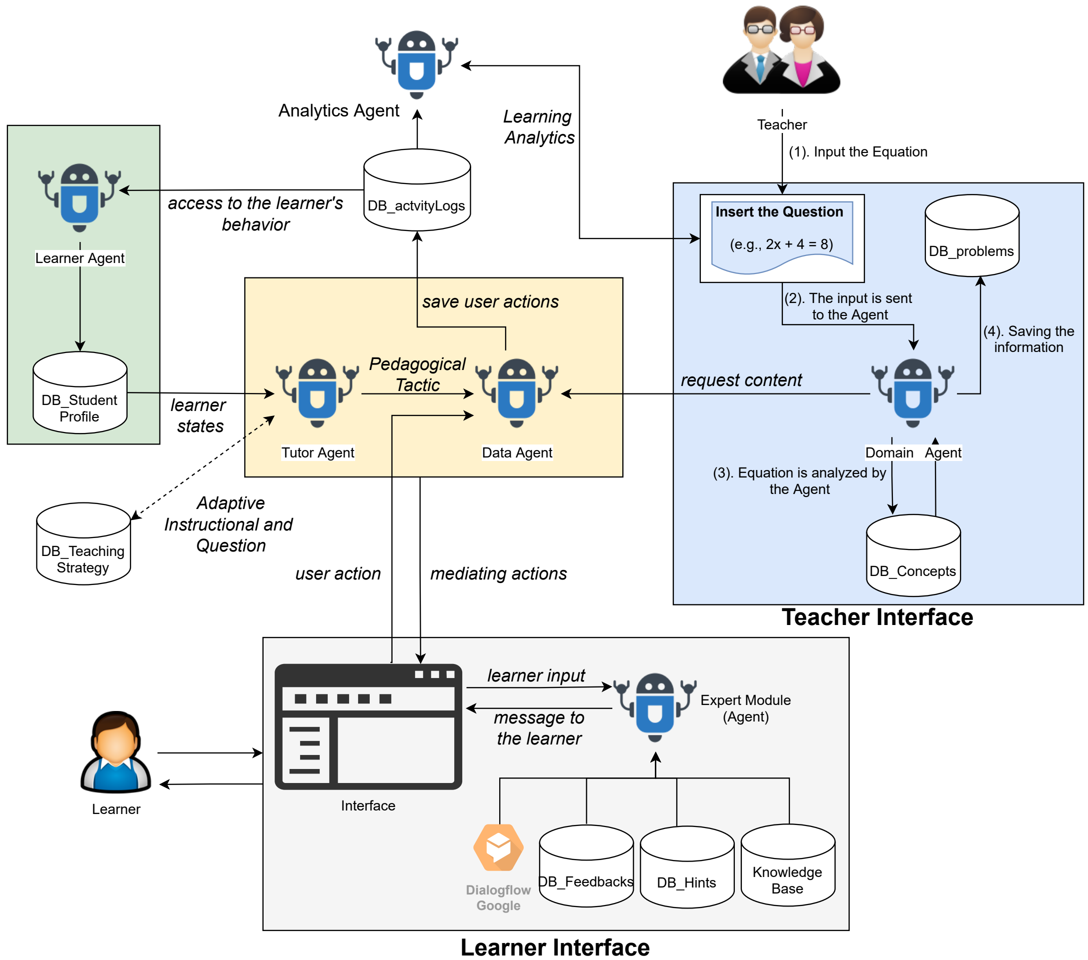

Fig. 3. Architecture of the system.

TABLE I
SOME OF THE EQUATIONS AND THE RESPECTIVE LEVELS OF DIFFICULTY PRESENT IN THE ITS DATABASE.

Difficulty Level	Equations to Solve	Mathematical Properties
Easy	2x = 8 3x = 33 6x = 92	Equivalence, Multiplication Associativity and Inverse Multiplication [25].
Average	4x - 6 = 9 2x - 62 = 21 3x + 6 = 15 - 5x	Equivalence, Associativity, Inverse Elements, and Identity Element [25].
Difficult	7(8x - 6) = 8(7x - 5) 2(9x + 1) = 4(3x - 1) 8(9x + 6) = 2(9x + 7) + 7	PEMDAS

idTeacher, concept[1...n]>. Finally, the content can be used by *Data Agent* to suggest activities for any student who is exercising some concepts. In addition, the teacher can manage the insertion of students within the ITS. The teacher can check the activities performed by the students, as well as the interaction time to solve each of the equations.

We know that an analyzer does not constitute the entire adaptive educational system, but intervenes as a facilitator who can assist in the creation of questions and in the modeling of the ITS. The registration carried out in this first moment, helps to maintain the concepts of domain related to Algebra allowing the system, in the social interaction model, to be able to monitor and support with clarity and efficiency.

B. Learner Agent

The second pedagogical agent designed for this research is the *Learner Agent*. The main objective is to build a student model that is useful for adapting the student's knowledge to the field of Algebra.

To build the student model, the *Learner Agent* is based on the Overlay Model. According to [26], *Overlay Model* allows the student's knowledge to be a subset of the system's knowledge. It is one of the most dominant models, presented as a hierarchical or semantic network, directly associated with the concepts of the domain area.

The student's level of knowledge is stored in the database named '*DB_StudentProfiel*'. In order to find the equations that best adapt to the student's profile, the system can look at the following fields: <*idStudent, Grade,* *Nível, [concept1_rigth, concept1_wrong,...,conceptN_right, conceptN_wrong], skill[1...n]>.*

The *Learner Agent* defines the level of knowledge of the learner based on performance from the records of the DB_ActivityLogs database. For this, some levels of knowledge were defined for students, observed in Table II.

TABLE II
LEARNER KNOWLEDGE LEVELS IN THE FIELD OF CONCEPTS IN ALGEBRA.

Level	**Hyerarchy of concepts**	**Evaluation**	
		Skills involved	**The level of student's knowledge**
excellent	Algebra	Understanding symbolic representations, like variables and Understanding order of operations and inverse relationship between operations	The student with satisfactory knowledge. (know >=70%)
beginner	Arithmetic	Understanding numerical values and basic math symbols (like the = sings)	
	Associativity	add or multiply regardless of how the numbers are grouped	
intermediate	Inverse elements	Comparing numbers and place value	
	Identity element	Understanding inverse relationship between operations.	

According to Table II, the named level of *excellent* identifies that the student has satisfactory knowledge of the mastery of most concepts on Algebra. ITS understands that the student knows a concept when evaluated about 70% on all the accumulated skills as structured in Table I.

The *Learner Agent*, analyzes the information present in the database '*DB_ActivityLogs*´ and converts them into numerical values that facilitate the accounting of the level of concepts already mastered by the learner. This makes it easier for the *Tutor Agent* to assess the level of knowledge and map the appropriate Pedagogical Strategy for adapting the teaching to the student.

C. Tutor Agent

The *Tutor Agent* is the third and last Pedagogical Agent designed to assist in teaching and learning algebra. This agent has the role of informing the *Data Agent* how to conduct the tutoring cycle and providing the activities according to the Teaching Strategies mapped after checking the information stored by the *Learner Agent*.

To conduct the tutoring cycle, the proposal follows the learning model for the development of Pillay's Wilss and Boulton-Lewis [20] competencies described by [22] in two stages:

1) **Arithmetic competence**: operate numerically and understand the operational laws and the relational meaning of the equal sign (i.e., both sides have the same value) in standard equations. This provides the basis for a pre-algebraic stage, characterized by understanding non-standardized equations.
2) **Concept of unknowns in the equations and the concept of a variable**: has its relational meaning of the equal sign (=) in non-standardized equations. The concept of unknowns in equations and the concept of a variable clarifies the potential connection between arithmetic and algebraic and captures essential points to measure the progression of arithmetic to Algebra. This internship supports the final development of algebraic competence [22].

For the development of the tutorial intervention model for this proposal, a study was carried out on the categories of tutorial interventions applied in virtual learning environments. Based on research by [27]–[32] a classification of tutorial interventions for this proposal was developed, where:

- **Scaffolding**: is a concept used to describe how learning is mediated by interactions with other, most experienced people in various environments at different times. For teaching and learning mathematics, scaffolding provides support for procedural skills, conceptual understanding, meta-cognitive strategies, and mathematical practice. [28], [32].
- **Feedback**: in instructional contexts, feedbacks inform the student about their real state of learning or performance [31], in order to regulate the learning process. Feedback can be provided by several external sources of information (e.g., computer-based training) and internal sources e.g., information that is perceived by the student during the processing of the task [31].
- **Hints**: making a set of data, additional scenarios, and elaboration of operations necessary to complete the tasks [33]. The goal is to assist students in recalling facts that help them answer a task.

At the ITS LEIA, hints, feedback with their objectives, corrective actions, contingent responses, and knowledge of correct answers were implemented [30]. The link between scaffolding and ZPD provides conceptual and operational structures for the project under study, where both constructs involve interaction between a specialist and a novice in the execution of a specific task [32].

In the present research, scaffolding is defined as a two-step process. First, ITS provides the learner with appropriate support to identify strategies for accomplishing learning tasks or objectives. Second, ITS gradually decreases interventions as the learner becomes more and more competent. Therefore, scaffolding is characterized by continuous and constructive in-

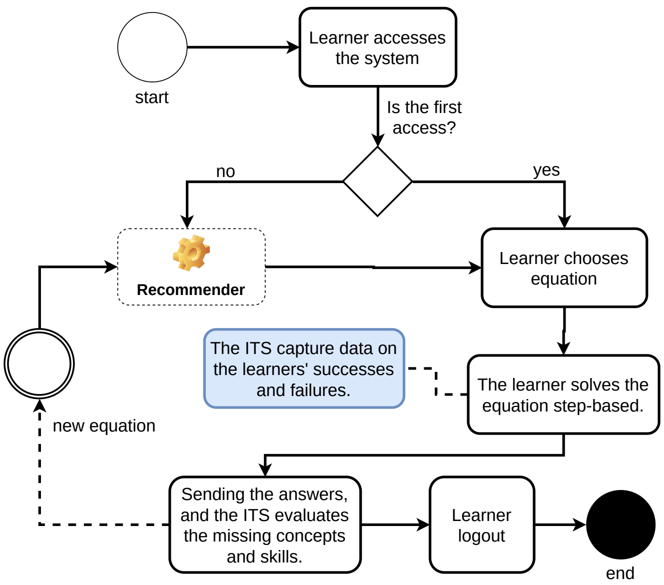

Fig. 4. System access flow

teractions as ITS and students work collaboratively to conclude the task and mastery of the content.

V. Dynamic Learning Construction

An important challenge that every educator faces is to organize the contents and activities aimed at the development of certain competencies. This challenge is evident when it is intended to identify and recommend distinct, personalized activities for each apprentice based on the individual needs and skills to be developed.

Therefore, the proposal of the Pedagogical Agents mentioned in the previous sections aims the development of students' algebraic skills through the recommendation with the reorganization of exercises with more linear solutions, with less complex structures according to the skills acquired in the learning path.

A. Pre-Requisite Recommendation

As shown in Figure 4, when the student accesses the system, being a new student, he or she is registered and a new profile is created. For the first access, two policies are used, which are (1) Random, the contents are selected at random, and (2) the range policy, the second content is selected in order of difficulties. On the other hand, to make the dynamics of the exercise recommendation, ITS matches the tables '*DB_StudentProfiel*' and 'DB_problems', as shown in Figure 5.

The ITS of this proposal follows the equation defined by [34] to calibrate the level of difficulty of the exercises,

$$D^q = \frac{\sum_{J=0}^{J=n} T_J^q}{N_e^q + N_a^q} \quad (1)$$

where:

- D^q: difficulty degree of the question q after an exercise session;
- T_J^q: number of unsuccessful attempt's student J to answer question q. If the number of attempts is greater than 10 trials, then 10 is taken as T_J^q.
- N_e^q: number of students that were unsuccessful in answering question q.
- N_a^q: number of students that were successful in answering question q.

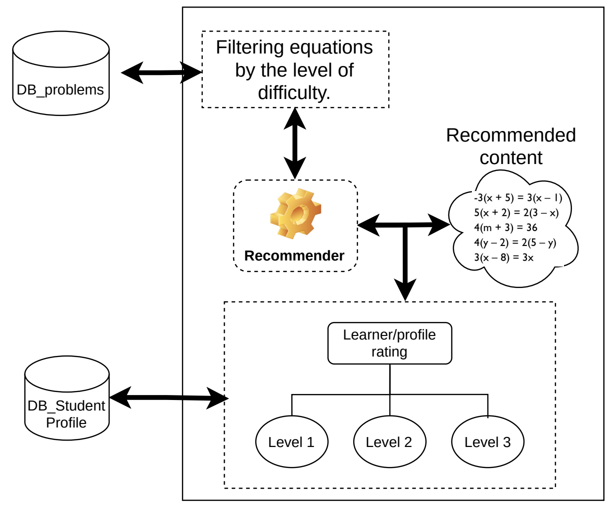

Fig. 5. Recommender equations module.

According to [34], the calibration of the exercises has some advantages: (1) the easier the question, the greater opportunity for the learner to answer correctly. (2) the learner who succeeds in trying to resolve an issue gets a higher score on his or her level of knowledge. In addition, ITS considers that equations that skipped are considered wrong.

This equation fits well with the domain of knowledge covered by this research. This allows the *Tutor Agent* to identify the best approach to scaffolding at the right time with the solution and the level of knowledge of the learner.

B. Scaffolding Teaching Strategy

The Zone of Proximal Development is one of the educational philosophies that assist students in the time of learning.

The teacher, or more competent child, uses scaffolding to support and facilitate learning for another student. When using scaffolding, the activities are in the student's ZPD, i.e., some of what the student can do on his own and the knowledge he wants to achieve. In this research, the role of competent specialist is performed by the ITS LEIA [17]. In Figure 6, the interpretation of Vygotsky's theory for this research is shown.

In order to increase the strategic capacity of ITS, the following scaffolding strategies were developed, based on [29]:

- ***Strategy 1: solution-oriented process***. In this strategy, scaffolding is based on structured guidance in each solution step by step. In this case, the student is free to mix or change the order of the solution steps.

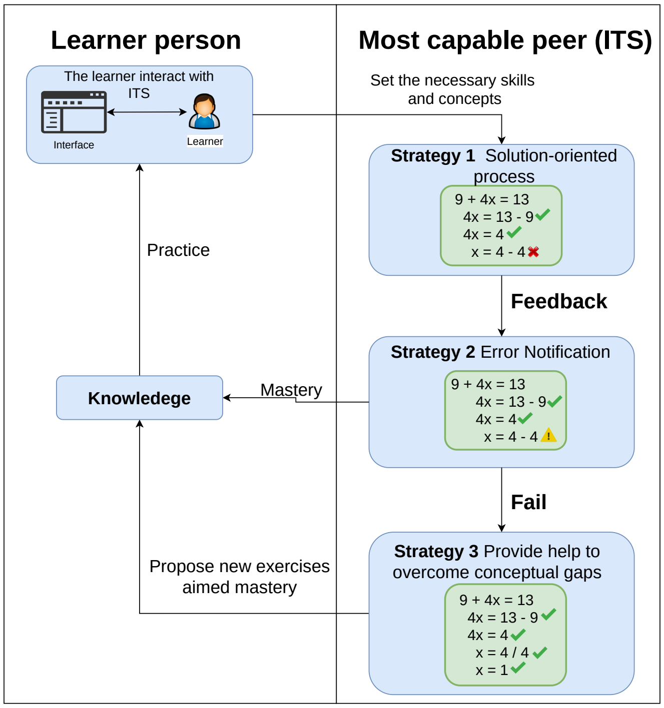

Fig. 6. Interpretation of Vygotsky's ideas as a pedagogical approach to this research.

- **Strategy 2:** ***error notification***. In this approach, the automatic evaluation of any student action is done. Tutoring based on step by step is more likely to accurately point out the student's difficulty [29]. Based on [30], this process does: (1) Response feedback until correction with several attempts at the same activity until it is completed. (2) Feedback of the result, providing exactly the value of the answer (i.e., correct or wrong); and (3) Feedback of the final value of the activity, i.e. correct answer.
- **Strategy 3:** ***provide help to overcome conceptual gaps***. This strategy allows students to fill in the gaps in the concepts and build or self-repair their knowledge [29]. The structuring of the domain (see Section IV-A) allows identifying the conceptual structures that related to the student's difficulties. This creates an opportunity for the student to continue working on the problem instead of abandoning it. After identifying the gap, ITS should offer tips to complete the student's solution in cases where there is disorientation in the solution path and does not know how to continue or propose a new partial solution [27].

VI. Conclusion and Perspectives

The main objective of this research was to enable improvements in the ITS LEIA [17] in order to improve the problem selector and teaching strategies considering aspects of remote teaching and the combination of actions by teachers and students to assimilate knowledge early in Algebra.

The multi-agent approach was adopted to simplify the tasks of modeling and structuring the distribution between different agents. The concept of ZPD is being applied as a model for interaction and tutoring of the ITS. It is understood that the use of ZPD can maintain the degree of adaptation of activities and preserve the level of complexity without prejudice to overload or confusion for the student.

This proposal takes advantage of the pedagogical aspects found in the literature. The techniques help to provide flexibility of place i.e. insertion of new equations (Domain Agent), learning pace (Scaffolding and Tutor Agent), division of responsibilities (i.e., monitoring of students), and the possibility of monitoring the individual performance of the student. In addition, it provides improvements in the identification of concepts and skills (Learner Agent).

The contributions of this research, first, highlight that mathematics education needs to be adapted through distance education to better respond to the pandemic through personalized and technology-mediated education [35]. Furthermore, the proposal integrates learning theory concepts [20] to provide web-based learning according to the materials and resources available according to the Algebra domain.

As limitations of this research, this study considers that all students have an identical learning style. Another limitation is the formal structure of mathematical skills and competences that vary according to the educational pattern of each country. And finally, the infrastructure difficulties [16] and the lack of formalization of the educational process until the time of writing this article, for the practice of distance learning prevent some tests to be performed to validate the proposal.

In future work, an experiment will be carried out to evaluate the ITS LEIA. The study will be conducted with more elementary school students and learning gains will be measured. New examples of equations will be inserted in the ITS knowledge base and the extended domain for word problems, aiming to cover the field and investigate mathematical thinking. Another improvement will be to employ new tutoring strategies that can significantly improve the scaffolding effect.

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