Activity theory as a framework for building adaptive e-learning systems: A case to provide empirical evidence

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Abstract

We apply activity theory (AT) to design adaptive e-learning systems (AeLS). AT is a framework to study human’s behavior at learning; whereas, AeLS enhance students’ apprenticeship by the personalization of teaching–learning experiences. AeLS depict users’ traits and predicts learning outcomes. The approach was successfully tested: Experimental group took lectures chosen by the anticipation AT principle; whilst, control group received randomly selected lectures. Learning achieved by experimental group reveals a correlation quite significant and high positive; but, for control group the correlation it is not significant and medium positive. We conclude: AT is a useful framework to design AeLS and provide student-centered education.

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1. Introduction

In this work, we take into account the activity theory (AT) to shape a framework oriented to develop adaptive e-learning systems (AeLS). The purpose of our framework is to enhance the apprenticeship for users of such systems. A relevant contribution of the approach is the representation of the AT principle of anticipation as a proactive student model (PSM). This kind of model enables AeLS to intelligently deliver lectures that offer the highest learning achievement. Thus, the PSM makes fuzzy-causal inferences to anticipate the effect produced by candidate lecture options to teach a given concept and choose the most promising.

As regards the AT, it was formulated during the 1920’s by several psychologists and has been evolving since then. The conceptual AT baseline is tailored by a diversity of statements such as: Lev Vygotsky who asserted: “Consciousness is constructed through subject’s interactions with the world and is an attribute of the relationship between subject and object”. Whereas, Aleksei Leontiev claimed: “Animals have an active relationship with the reality, which is called activity”. In addition, Sergey Rubinstein considered the human action as a unit of psychological analysis. What is more, Alexander Luria proposed a schema for explaining human activity as a sequential relationship between stimulus, tool, and reflex. Moreover, Nardi (2003) declares: “AT is above all, a social theory of consciousness”. The object of AT is to understand the unity of consciousness and activity. So the human mind comes to exist, grows and is understood within the context of meaningful, goal-oriented, and social interaction of people through the use of tools.

AT provides guidelines that have inspired many related works to accomplish specific applications such as: Asynchronous feedback at learning (Tarbox, 2012), mobile learning (Liawa, Hatalab, & Huang, 2010), the bias exerted by technology in teaching practices (Blina & Munrob, 2008), learning support (Daniels, Edwards, Engeström, Gallagher, & Ludvigsen, 2009), personal learning environments (Buchem, Attwell, & Torres, 2011), human activity modeling (Constantine, 2009), technology integration at classroom (Anthony, 2012), supporting mobile work (Er & Lawrence, 2011), collaborative virtual learning environments (Hanna & Richards, 2012), collaborative work (Harris, 2012), analysis of learning studies (Mosvold & Bjuland, 2011), learning objects (Hansson, 2012), Web application requirements (Uden, Valderas, & Pastor, 2008),

Abbreviations: ADL, Advanced Distributed Learning; AeLS, adaptive e-learning systems; AT, activity theory; CM, cognitive map; GMIM, Gardner’s Multiple Intelligence Model; IEEE, Institute of Electrical and Electronics Engineers; KD, knowledge domain; MMPI, Minnesota Multiphasic Personality Inventory; PSM, proactive student model; N, population; n, sample; P, value; r, Pearson’s coefficient; SCO, Sharable Content Object; SCORM, Content Object Reference Model; SRM, scientific research method; TEO, Taxonomy of Educational Objectives; UD, universe of discourse; WAIS, Wechsler Adult Intelligence Scale; Y, post-measure; Z, score; α, significance level.

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and accessibility in e-learning (Seale, 2007). All of those works apply AT to deal with a given functionality of e-learning systems, but none pursue to model the student and anticipate his learning achievements. Therefore, our work focuses on such a target by means of the design, deployment, and exploitation of a PSM, which represents fuzzy knowledge and infers fuzzy-causal reasoning.

The e-learning systems are the result of the evolution of the earliest computer-assisted educational systems built during the 60’s. Since then, several approaches have been designed to implement specific educational paradigms, such as: intelligent tutoring systems, computer-supported collaborative learning, learning management systems, web-based educational systems, and hypermedia systems. Nowadays, one of the current trends corresponds to AeLS. They are able to adapt themselves in an intelligent way to satisfy the particular needs of every user. The architecture of AeLS includes learning and reasoning engines to respectively acquire and infer knowledge about the student. Moreover, AeLS elicit, represent, and use such knowledge to dynamically adapt functionalities that satisfy personal requirements of the student such as: sequencing of teaching–learning experiences, content delivery, user–system interface, navigation mechanism, criteria for assessment, and evaluation indices (Peña-Ayala, 2012).

With the aim of demonstrating how AT is useful to develop AeLS, the paper is organized as follows: A method for designing AeLS is outlined in Section 2 through the description of AT principles, architectures, and perspectives. In Section 3, we explain how to build a prototype of AeLS based on our framework. Furthermore, our prototype is exploited in a case study, where we measure the impact that the anticipation AT principle, deployed as a PSM, exerts on students’ learning. In Section 4, the results are unveiled as statistical highlights, and a discussion of the outcomes is pointed out. Finally in the Conclusions Section, several assertions are made as consequence of the case study, and further work to be fulfilled is anticipated.


The AT offers a philosophical framework for modeling different forms of human praxis. One relevant practice is the education provided to students by means of e-learning systems. This kind of service is also a target study for the AT. Hence, we present a framework for using AT to design AeLS through the exposition of the AT principles, architectures, and perspectives.

2.1. Activity theory principles

AT consists of a set of principles devoted to shape a general conceptual activity. They can be used as a foundation for more specific theories (Engeström & Glâneanu, 2012). Such principles are the following:

- **Object-orientedness** represents something that objectively exists and is fulfilled by an activity.
- **Hierarchical structure** guides the interaction between individuals and the world through a functional hierarchy composed of three levels as follows:
  - Activity is a collective system driven by an object and a motive that a subject pursues. An activity is performed through a set of actions to accomplish an object.
  - Actions are conscious, driven by goals and are carried out by a series of operations.
  - Operations are routine tasks whose activation depends on the conditions of the action.
  - Mediation is fulfilled by tools that facilitate activity and are used to control human behavior.
  - Internalization–externalization they respectively represent mental and physical actions accomplished by an individual.
  - Anticipation is a motive of the activity. Human activity is guided by anticipation. The prediction of future events is the purpose of the anticipatory reflection strategy.
  - Development produces human interaction with reality by mediation.

2.2. Activity theory architectures

As result of AT research evolution, several structures of components and relationships have been tailored to define the theory scope. In consequence, four architectures have been built to reach different AT targets. The first focuses on the activity; whereas, the second depicts the activity at individual level. The third explains collective activities and cooperative work; whilst, the fourth joins activity systems into a network. A profile of the four architectures is given next.

2.2.1. Activity as basic unit

The activity is the basic unit of AT analysis and is under continuous change and development. Moreover, the AT evolution is uneven and discontinuous. Activity is a longer-term formation, whose object is transformed into an outcome through a process. Such a process consists of several short-term actions (Kuutti, 2009). Therefore, activity is manifested as a transformation process, which is performed through the AT principle of the hierarchical structure. In consequence, activity is split into actions, which in turn embrace operations to shape an activity as an organization of three levels, such as the one drawn in Fig. 1.

In Fig. 1, dotted lines reveal hierarchical relationships (i.e., one activity embraces several actions, and an action is made up of various operations), and continuous lines depict a workflow (e.g., conditions take over operations). As regards the rectangle, circle, and oval, they represent activity, actions, and operations respectively. Nevertheless, when the shapes are sketched through hyphen lines, they respectively correspond to object/motive, goals, and conditions.

The AT principle of the hierarchical structure is illustrated in Fig. 2, as a basic activity architecture of three tiers. But, with the purpose to recognize the role represented by the conditions, a fourth layer is added at the bottom to show that: once a set of conditions is met, an operation is triggered. Next, in ascending order, several operations are fulfilled with the purpose of developing a specific action. As result, the action’s goal is satisfied. The second level
depicts that: when a sequence of actions is carried out, an activity is accomplished. In this way, the activity's object is reached. In short, the bottom-up organization of these four levels produces the basic activity architecture sketched in Fig. 2, whose shapes hold the same meaning as the ones represented in Fig. 1. However, they are allocated into specific planes to characterize a hierarchy of homogeneous items.

The action level of the hierarchical structure AT principle demands special consideration. It is conceived as a workflow composed of three stages called: orientation, execution, and control (Rambusch, 2006). In the orientation stage, the plan of the action is built; whilst during the execution stage, the operations are performed once the conditions are satisfied. Simultaneously, the control stage takes place with the purpose of checking if the conditions are met and the goals are in fact reached during the execution.

2.2.2. Activity at individual level

With the aim at outlining an activity to be accomplished by just one subject, the AT represents an architecture composed of four elements: subject, tool, object, and outcome. The subject identifies the individual responsible for the activity; whereas, the activity's objective and motive are unveiled by the object. The tool is an artifact that facilitates the achievement of the outcome by the subject; whilst, the outcome is the result of a transformation process.

According to the AT principle of mediation, the model is based on the assumption that tools mediate between subject and object. The tools (e.g., physical artifacts, language, and symbols) are created or transformed in the course of an activity.

The architecture at individual level represents a problem space, where the activity pursues an object, and thereby produces an outcome, as Fig. 3 illustrates. So, activity is characterized as the relationship between subject and object that is stabilized by a tool. In this way, a transformation process is oriented, executed, and controlled to yield an outcome.

2.2.3. Activity at collective level

As social activities demand the participation of many individuals, the AT extends the prior architecture's levels to represent collective work and include the next three new elements: community, rules, and division of labor. Thereby, the activity at collective level considers three factors: the community that is engaged to perform the activity, the rules to guide the development of actions and operations, and the division of labor to assign roles to members of the community. Thus, the architecture at collective level becomes a systemic model of an activity system. It adds a tier to the architecture at individual level in order to include the new three elements. As result, the architecture embraces seven elements that are organized according the structure shown in Fig. 4.
The study and representation of an activity system at collective level involves the definition of the activity and the identification of the architecture's elements. Thus, in order to be precise as to the nature of the activity and its elements, it is necessary to respond to the following questions made by Mwanza and Engeström (2005):

- Activity: What sort of activity are we interested in?
- Tools: By what means are the subjects fulfilling the activity?
- Subjects: Who are involved in achieving the activity?
- Object: What is the purpose of the activity and why is the activity taking place?
- Outcomes: What is the specific result to be delivered from the activity?
- Rules: Are there any cultural norms and regulations governing the development of the activity?
- Community: What is the social environment in which the activity is being accomplished?
- Division of labor: Who are the individuals responsible for what, and how are those roles organized?

2.2.4. Activity at network level

When activity is analyzed at top level, quite often several involved activity systems are found out. Hence, AT provides a network level to make explicit the presence of the activity systems and represent what happens when activity systems come into contact. The architecture at network level joins the activity systems and incorporates the concept of boundary objects.

Boundary objects operate at the interface of many contexts, where two or more activity systems come into contact. In consequence, there could be contradictions and tensions. However, the object or activity motive is reconsidered to embrace a radically wider horizon of possibilities than in previous levels of activity (Edwards, Biesta, & Thorpe, 2009). Such an activity at network level is sketched in Fig. 5, where two activity systems with their respective outcomes and boundary objects are outlined (Engeström, 2003). As result, there is potential for expansionist learning when the objects of the activity systems meet (Robertson, 2008).

2.3. Perspectives of the activity theory for e-learning systems

A sample of activity at network level corresponds to the approach for expansionist learning proposed by Jochems, Van Merriëboer, and Koper (2004). They analyze expansionist learning from three perspectives (i.e., viewpoints): organizational, pedagogical, and technological. Usually, the perspectives correspond to management, teaching–learning, and information technology respectively. In addition, the perspectives are described by means of a common lexicon. Thus, a perspective is considered an activity system that is characterized through the elements of the architecture at collective level. As result, a systematic perspective is authored for the involved activity systems. A graphical sample of the three perspectives is drawn in Fig. 6, where they are described at network level.

As regards Fig. 6, there is a chance for expansionist learning when the objects of the three activity systems encounter. Even though the object of each activity system is an improvement in e-learning, the outcome of the object will vary between perspectives due to their particular viewpoint (Robertson, 2008). With respect to the nature and outcome of the three perspectives, they are stated as follows:
The organizational activity system concerns the physical, financial, and human resources of the institution. Its desired outcome is the satisfaction of requirements regarding educational, social, economical, and physical demands. The pedagogical activity system represents the substantive function of an educational environment. Its outcome reveals the apprenticeship gained by students. The technological activity system pursues the design and delivery of efficient information technology for organizational and pedagogical systems. Its outcome is the level of satisfaction demanded by students, as well as the services provided by the e-learning system.

3. Result: Application of the AT to design adaptive e-learning systems

This section is devoted to explain how the AT is used to design AeLS. The main assumption is: to consider e-learning as an activity at network level. So, this approach takes into account the three earlier stated perspectives to tailor AeLS. Thus, in the first three subsections the organizational, pedagogical, and technological activity systems are characterized at collective level to identify their respective elements and outcomes. In addition, the consequent architecture at network level is stated in the fourth subsection in order to shape a holistic model of the study target. In the last subsection, we demonstrate how the prior introduced AT principles are applied by the instantiation of tools and rules that correspond to the pedagogical and technological perspectives.

3.1. Adaptive e-learning systems from the organizational perspective

An AeLS is considered as an organizational activity system when the subject is the whole school. The activity corresponds to planning, decision making, and investment in e-learning projects oriented to satisfy educational demands. Therefore, the object represents the provision of distance and adaptive educational services through AeLS. The outcome is the capacity to satisfy current and further requirements of education claimed by the society. Tools correspond to human, economical, and material resources. Laws, policies, and regulations concerned with educational services identify rules to be followed. Community is composed of organization’s principal, members of the board, investors, managers, employees, teachers, tutors, technical staff, and students. Division of labor reveals the role to be fulfilled by each member of the community. Some of these elements are depicted in Fig. 7.

3.2. A pedagogical perspective for an adaptive e-learning system

In order to represent an AeLS from the pedagogical perspective, the subject corresponds to the pedagogical logistics held and applied by the institution. The activity pursues the design, implementation, and delivery of adaptive web–based educational services that facilitate and stimulate the acquisition of domain knowledge (DK) by students at any time and place. Thus, the object is the development of a pedagogical environment that is able to provide personalized education to students by means of an AeLS. As a consequence, the outcome is the apprenticeship accomplished by students through their interaction with the AeLS. Tools are the curriculum, DK content repositories, PSM, assessment records, and evaluation instruments. Rules are characterized by cognitive theories, teaching strategies, learning styles, pedagogical models, sequencing strategies, evaluation criteria, assessment policies, regulations, and laws. Community is represented by the principal, academic managers, pedagogues, teachers, tutors, librarians, advisors, and students. Division of labor depicts functions, attributes, and responsibilities carried out by members of the community. A graphical view of the pedagogical perspective is drawn in Fig. 8.

3.3. Adaptive e-learning system analyzed as a technological system

The technical staff devoted to build, exploit, and maintain the AeLS play the role of the subject for the technological activity system. The activity is responsible for the development, management, user-support, and maintenance of the AeLS. Thereby, the object represents technical facilities that take into account current and future educational demands to be satisfied by AeLS. As result, the outcome is the educational services provided and the degree of students’ satisfaction. The web–based system, learning objects, user–interfaces, accessories, hardware, communication platform, software licenses, procedures, and techniques are tools that ensure costs, security, reliability, and scalability of AeLS. Rules consist of architectures, models, methods, standards, techniques, procedures, and documents that offer the guidelines to design, develop, operate, and maintain Ae-LS. Community is the technical staff make up of the project leader, web master, database administrator, analysts, designers, programmers, content authors, graphic designers, communication specialists, and technical support team. Division of labor is given according to the main duties of the activity, technical specialties, and the role to be performed by the members of the community. Fig. 9 depicts an illustration of the technological perspective.

3.4. Architecture of the activity at network level for adaptive e-learning systems

Once the AeLS have been defined and characterized from three perspectives (e.g., organizational, pedagogical, and technological), the architecture of activity at network level is outlined in this subsection. Such architecture is a systematic perspective of the three already described activity systems. Moreover, it offers a holistic viewpoint of the elements that make up each perspective, the
outcomes, and the boundary objects, as well as the expansionist learning that represents the network outcome. In this case, the resultant architecture of activity at network level is sketched in Fig. 10.

3.5. Principles implementation

In this section, we explain how the AT principles are able to guide the design, development, testing, and exploitation of AeLS. As the first step, the application of the principle to the AeLS context is introduced. Afterwards, a statement, a criterion or an artifact is given to instantiate the nature of the tools and rules of the pedagogical and technological activity systems.

3.5.1. Object-orientedness

The object-orientedness principle requires students to acquire DK about a specific educational topic through the use of AeLS. As a pedagogical rule it is asserted: The essence of an educational topic is found in its ‘key concepts’. So the object is understood through the apprenticeship of several key concepts. Therefore, a pedagogical tool for measuring the apprenticeship of key concepts is the Taxonomy of Educational Objectives (TEO) proposed by Bloom (Su & Osi- sek, 2011). TEO defines a scale of six levels to measure the degree of mastery held by an individual for a key concept. The scale is organized in ascending levels of dominion, such as: (1) remembering; (2) understanding; (3) applying; (4) analyzing; (5) evaluating; (6) creating. However, we added level number 0 to reveal ignorance.

Another pedagogical rule constrains to ask just one question to assess if the student has dominated a specific TEO level. Hence, a sequence of six question cues is made to the student according to the ascending hierarchy of TEO. The first question determines if the student masters the remembering level when the individual rightly answers a question cue like: list, define, show, name, who, when... The second question assigns the understanding tier whether the student is able to describe, distinguish, interpret, contrast, associate... The applying value is reached when the person illustrates, applies, classifies... Whether the student also explains, compares, separates... the analyzing level is fulfilled. The evaluating tier is accomplished when the student generalizes, modifies, substitutes... The maximum level, creating, is given to the student when she tests, decides, judges...

TEO is implemented as a technological tool devoted to estimate student’s background and acquired DK about key concepts. Such a tool is deployed as the evaluator module of an AeLS to make inquiries about a specific key concept to the student. Concerning the technological rule, it claims: just one lecture is granted to the student for learning a key concept.

3.5.2. Outcome

As a result of the object-orientedness principle, the outcome is the DK acquired about a given educational topic by users of AeLS. The pedagogical tool is the process oriented to evaluate the students’ answers expressed in natural language. A pedagogical rule claims: The maximum TEO level of mastery held student about a
specific key concept reveals she also successfully satisfied all the previous TEO levels (e.g., when a student reached the applying level for a particular key concept, it means she satisfied remembering and understanding levels as well).

The technological tool is a scoring function devoted to identify the highest TEO level that the student achieves for each key concept. A technological rule validates the consistency of the highest TEO level. For instance, when the student is unable to answer the first question (related to remembering) the level number 0 (ignorance) is assigned as the maximum TEO level for the inquired key concept. However, when the highest TEO level is 4 (analyzing), it means that the student rightly answered questions number 1 to 4, but failed to respond to question number 5 that is related to evaluating. In consequence, the cue 6, creating, is not demanded of the student.

3.5.3. Mediation

The principle of mediation concerns the artifact that student uses to acquire DK about an educational topic. The pedagogical tool is the student-centered paradigm that pursues to deliver personalized education through Internet. The technological tool is an AeLs. This sort of computer-based educational system sufficiently and automatically adapts teaching–learning experiences according to the student’s particular characteristics (e.g., learning preferences, habits, weakness, personality, cognitive skills...). Such a kind of experience represents a lecture about a key concept that is provided through the web. During a lecture, the artifact delivers content and provides exercises about a key concept to the student – teaching –. As result of such stimuli, the student acquires DK and develops some cognitive skills – learning.

The pedagogical rules entail the following hypothesis: the student’s apprenticeship is successfully stimulated when the delivered lecture matches his profile. The technological rule is a sequencing criterion that demands the evaluation of the candidate lectures, the selection of the most profitable lecture’s option, and the delivery of just one lecture to teach a key concept.

3.5.4. Hierarchical structure

The hierarchical structure is the set of logistics, teaching–learning experiences’ scripts, and content authored to provide an educational topic. The pedagogical tool is the adaptation. This paradigm tailors teaching–learning experiences according to particular student’s attributes. The technological tool is the Content Model, which is part of the Content Aggregation Model. In turn, the last model is one item of the Sharable Content Object Reference Model (SCORM) proposed by Advanced Distributed Learning (ADL, 2009). The Content Model describes lecture facilities to guide the delivery and development of teaching–learning experiences. Such facilities identify resources, trigger duties, apply controls, and guide behaviors.

The pedagogical rule claims: A lecture is an educational event, where a series of stimuli is provided to the student in order she acquires DK of a key concept. The technological rule is the SCORM Metadata devoted to provide standard information and meaning of the lecture content represented in the Content Model (ADL, 2009).

3.5.5. Activity

Activity, as the root of the hierarchical structure AT principle, is the whole process fulfilled by an AeLS and a student to respectively teach (object) and learn (motive) an educational topic. The pedagogical tool is the DK of a given educational topic to be taught and learned. The technological tool is the SCORM Content Organization (ADL, 2009). This tool is depicted as a workflow that guides the delivery of the most promising lecture option to teach a key concept.

The pedagogical rule states: A lecture is designed as a set of learning objects. Where, each object is authored according to one viewpoint of several that are considered. A viewpoint represents a sort of teaching style that defines how the learning object is tailored according a given learning theory (e.g., objectivism, constructivism...), a way of human–computer interaction (e.g., static, dynamic, adaptive...), and a specific media (e.g., audio, video, text...). Thus, a lecture is available for being taught through several learning objects, called options; but, just one option is delivered to the student. The technological rule applies the SCORM Content Organization Metadata to facilitate reusability and discoverability of learning objects among e-learning systems (ADL, 2009).

3.5.6. Action

An action corresponds to the event of delivering a lecture to teach a key concept (the goal). The pedagogical tool is the set of learning theories, strategies of user–system interaction, and media representations to stimulate a specific sense (e.g., listening, seeing...). Such repositories offer instances that are combined to shape a particular viewpoint. These criteria lead the teaching style used during the lecture. The technological tool is the software and guidelines specialized for content authoring (Guttmersen & Krueger, 2001).

The pedagogical rule claims: The availability of suitable learning strategies, user–system interfaces, and media representations to implement efficient teaching styles. The technological rule demands to tailor one lecture option for each instance of teaching style. As result, the first option is inspired by objectivism learning, dynamic interaction, and video content; the second applies constructivism learning, adaptive interaction, and sonorous content, and so on.

3.5.7. Operation

Operations represent duties and interactions performed by the student and the artifact during a teaching–learning experience, whose conditions depend on the lecture option. The pedagogical tool is a set of guidelines that specifies: How student’s senses can be stimulated, the kinds of stimuli to be produced by the learning object, the types of actions that the student must accomplish, and the controls to be applied during the lecture (Guttmersen & Krueger, 2001). The technological tools are SCORM learning objects, such as the Sharable Content Object (SCO) and assets (ADL, 2009). Both, SCO and assets, contain text, images, video, sounds, animation, and user–system interaction tasks. However, a SCO sends and receives messages to and from the artifact; meanwhile, an asset does not trigger any kind of communication.

As a pedagogical rule it is said: The sequence of operations needed to accomplish an action must be varied and embedded in the learning object. For example, one task is devoted to identify the key concept through text; another provides the meaning through a picture; one highlights the full definition by means of video, sound, or virtual reality; one more requests an exercise based on a learning theory, and so forth. The technological rules are: (1) apply a standardized way to exchange learning content between different systems or tools through the SCORM Content Package (ADL, 2009); (2) pursue the interoperability and reusability of learning objects by the Learning Objects Metadata proposed by the Institute of Electrical and Electronics Engineers (IEEE, 2002).

3.5.8. Internalization–externalization

The principle of internalization–externalization corresponds to the teaching–learning phenomenon that occurs during the development of a lecture. The pedagogical tools characterize a profile about lectures and students. The lecture profile holds concepts to describe the used learning theory, prevalent stimulus, kind of student-artifact interaction, and level of content’s complexity based on the study made in (IEEE, 2002). The student profile embraces
three domains: cognitive, learning preferences, and personality. They are respectively described by attributes qualified by the Wechsler Adult Intelligence Scale (WAIS) (Benson, Hulac, & Kranzler, 2010), Gardner’s Multiple Intelligence Model (GMIM) (Mokhtar, Majid, & Foo, 2008), and Minnesota Multiphase Personality Inventory (MMPI) (Hahn & Petitti, 2006).

The technological tool is a cognitive map (CM), which represents cause–effect relationships between concepts of the domain study (Peña-Ayala, Sossa, & Gutiérrez, 2008). A concept is an attribute that characterizes the object of study (e.g., a learning preference or both values. A variation value reveals a change of the state after a period. A level value shows a degree of difference between current and normal states. According the fundaments of the Fuzzy Logic (Coletta, Vendramin, Hruschka, Campello, & Pedrycz, 2012), a concept’s state is considered a linguistic variable, which is instantiated by a linguistic term that belongs to a universe of discourse (UD). Hence, a variation UD owns linguistic terms, such as: [decreases: high... low, null, increases: low... high]; whereas, a level UD contains linguistic terms like: {low, medium, high...}. For instance, the state of the learning preference attribute “visual–spatial” is instantiated by the variation linguistic term “increases quite high”, and/or the level value “low”. Moreover, a CM identifies the causal influence that the state of a concept (i.e., the cause) exerts on the state of another attribute (i.e., the effect). Such states are called respectively antecedent and consequent to outline a fuzzy-causal rule (e.g., if the visual lecture’s stimulus is high then the learning preference visual–spatial increases too high).

The pedagogical rules represent the guidelines to plan, apply, measure, and interpret the tools used to tailor lecture and student profiles (Benson et al., 2010; Guttormsen & Krueger, 2001; Hahn & Petitti, 2006; Mokhtar et al., 2008). The technological rules specify the definition of linguistic variables, the use of membership functions to shape fuzzy sets that represent linguistic variables, and the integration of fuzzy sets into a UD. They also define the format of the fuzzy–causal rules and the composition of the respective fuzzy–causal rules base. Such a base represents just one rule for each linguistic value of the UD attached to the antecedent (Peña-Ayala et al., 2008).

3.5.9. Anticipation

The anticipation principle is the prediction functionality devoted to estimate the impact that a lecture option exerts on the student apprenticeship. The pedagogical tool is a proactive strategy to plan, deliver, and control the provision of lectures. The technological tool is a fuzzy-causal inference engine that deals with a CM (Peña-Ayala, Sossa, & Cervantes, 2012). Based on a system dynamics approach (Morecroft, 2007), the engine describes the behavior of complex systems over time. Thus, it deals with internal feedback loops and time delays that affect the behavior of the entire system sketched as a CM. In this case, as result of the fuzzy–causal bias between attributes, the state of effect concepts changes during time. Therefore, from the initial level and variation values attached to the concepts’ state, the states evolve during successive iterations until they reach a kind of stability or chaotic situation. Stability is met when the state of the attributes does not change any more after n iterations, where n ≥ 1. Chaos is recognized when stability has not been achieved after a threshold period. The causal behavior and outcome are shown by the intermediary and final state values respectively (Peña-Ayala & Sossa, 2012). In this way, the CM and its engine are used to implement the reflection anticipation strategy to choose and deliver the appropriate lectures’ option.

As regards the pedagogical rules, they are the following: (1) find the best way to teach a key concept; (2) analyze how the lecture profile of each lecture’s option biases the student profile; (3) choose the lecture’s option that is expected to impact the student’s apprenticeship with the highest TEO level. The technological tools are: (1) fuzzy reasoning based on fuzzy rules (Coletta et al., 2012); (2) fuzzy-causal reasoning (Peña-Ayala & Sossa, 2012); (3) an algorithm oriented to choose the best lecture option (Peña-Ayala et al., 2012).

3.5.10. Development

Development is the principle that yields the active participation of community members with the AeLS to plan, organize, monitor, and control the students’ apprenticeship. The pedagogical tool is the educational setting where students interact with an AeLS to learn an educational topic. The technological tool represents an AeLS and DK of an educational topic.

Pedagogical rules guide the activity carried out in the educational setting through a protocol, where the nature of the educational service, the research hypothesis, and the variables to be measured are established. The technological rules facilitate the activity of the educational setting by means of the guidelines oriented to choose the population and sample, the scales for measuring the variables, and the processes devoted to generate descriptive and inferential statistics, as well as test the hypothesis.

4. Discussion: Significance of the results

Based on empirical verification, we estimate the impact and usefulness of the AT as a framework to design AeLS. Hence in this section, the guidelines of a case study are described. Subsequently, the implementation of a prototype of AeLS is outlined. Afterwards, the development of a case study is summarized through the identification of the groups of participants and the provision of stimuli. Later on, the analysis of outcomes is carried out by the exposition of two kinds of measurements, and the estimation of reliability and validity criteria. Hereinafter, a sample of descriptive statistics is presented and an inferential hypothesis is tested. Finally, several findings are identified and discussed (Peña-Ayala & Sossa, 2012).

4.1. Case study guidelines

In order to lead the development of a case study, we take into account the development principle as follows: The pedagogical tool is a case study, where students acquire DK of an educational topic as result of their interaction with an AeLS. In this case, the educational topic corresponds to the scientific research method (SRM). The technological tool is starring by an AeLS prototype, as well as SRM content (Peña-Ayala et al., 2012). The essence of the SRM is summarized through ten key concepts such as: hypothesis, law, and theory.

As regards the pedagogical rules, they guide the case through the following instances: (1) explicative case oriented to confirm the cause of an event; (2) causal hypothesis to demonstrate a cause–effect relationship that asserts: “Learning is enhanced when the lecture successfully meets the particular attributes of the student”; (3) dependent variable to represent the apprenticeship gained by the student; (4) apprenticeship criterion to evaluate the gained learning as the difference between the TEO level measured before and after the provision of stimuli to teach a key concept; (5) independent variable to feature the lecture option delivered to the student; (6) intervenient variable to unveil the criterion used to choose the most promising lecture option; (7) two degrees to manipulate the independent variable by the intervenient variable, such as: lecture’s option is selected by the AT principle of anticipation (i.e. the AeLS follows the advice given by the PSM), and lecture’s option is randomly chosen by the AeLS (i.e. without the support of the PSM).
Concerning the technological rules, they define a series of steps devoted to: (1) integrate a population of students; (2) apply the WAIS, GMIM, MMPI tests, as well as a DK exam; (3) randomly extract a sample of students from the population; (4) randomly split the sample to organize two equivalent comparative groups, called control and experimental; (5) measure the former knowledge about the SRM held by members of both comparative groups; (6) deliver teaching–learning stimuli (i.e., just one lecture's option to give instruction of each of the ten key concepts) to the members of the comparative groups; (7) randomly pick the lectures' option for being delivered to control members; (8) teach the experimental members by the lecture's option that the anticipation AT principle considers as the most profitable; (9) measure the new DK held by members of both comparative groups; (10) estimate the apprenticeship reached by students and comparative groups; (11) carry out descriptive and inferential statistical processes to evaluate and interpret results. To sum up, this case study tries to avoid any kind of influence on the participants to identify the true apprenticeship; and thereby, the usefulness of the framework to design AeLS.

4.2. Adaptive e-learning system implementation

In order to apply and test our AT framework, we built a web-based prototype of AeLS. Hence in this section, we shape a profile of the AeLS and sketch the student modeling. In addition, we explain how adaptive DK content is authored based on the AT framework. Finally, a summary of how it is possible to adapt education is given.

4.2.1. A profile of the adaptive e-learning system

With the aim at seeking experimental evidence about the impact that the anticipation AT principle exerts on the students' learning, we built a prototype of an AeLS. Such a prototype represents the technological tool of the development AT principle. A typical architecture of AeLS is fully detailed by (Peña-Ayala, 2012). The architecture contains five layers oriented to carry out specific functionalities, which are worthy to be included as part of the technological perspective of an AeLS. In particular, the third tier identifies the system components and the way they interact to support the pedagogical perspective of the AeLS. Essentially, the following four system components make up the AeLS.

- The learner component features the pedagogical tool of the internalization–externalization AT principle to represent the student. It characterizes students through their preferences, skills, achievements, personality, and DK. Such traits are organized as the student profile that is part of the PSM.
- The evaluation component corresponds to the technological tool of object-orientedness AT principle. It tracks the student's performance, depicts her behavior, stores responses, questions, assesses advances and outcomes, as well as traces a history record of the student's development. What is more, it applies the TEO as the pedagogical tool of the object-orientedness AT principle. It represents one pedagogical tool of the internalization–externalization AT principle. Such a repository is exploited by the PSM in order to simulate the impact that a lecture option could exert on the student's learning.

4.2.2. A profile of the student modeling

An essential property of the AeLS is the implementation in some sense of the student-centered paradigm. It represents the pedagogical tool of the mediation AT principle committed in delivering personalized education through Internet. In order to accomplish such a goal, a key functionality is needed, the student modeling. Basically, it is a process oriented to acquire and depict a conceptual description of the student, which the AeLS takes into account to satisfy user needs. In this case study, we follow the guidelines, structure, and content fully described by (Peña-Ayala & Sossa, 2012). Thus, we offer a summary of the student modeling process and repository developed as part of the AeLS prototype.

During the development of the case study, described in Section 4.3, student modeling is performed during several stages. The first corresponds at the moment of the application of four instruments to measure the learning preferences, personality, cognition skills, and DK of the universe participants. In this case, the elicitation of students' traits is the result of the responses and evaluations made to the tests WAIS, GMIM, MMPI, and DK of the SRM. Based on attributes of these four domains, a first version of the student's profile is organized.

The second stage occurs during the application of pre- and post-measures about the background and acquired DK of the ten key concepts held by the participants of the sample. Moreover, the third stage happens during the provision of stimuli to track the students' behavior, outcomes, and achievements. Finally, the fourth stage is the result of the statistical analysis widely detailed in Sections 4.3–4.5.

The data, information, and knowledge gathered during the four stages is represented, stored, and managed in the student's profile. It represents one pedagogical tool of the internalization–externalization AT principle. Such a repository is exploited by the PSM in order to simulate the impact that a lecture option could exert on the student's learning.

4.2.3. Authoring of adaptive domain knowledge content

With the purpose of applying our AT framework to adapt e-learning content, in this section we summarize the approach devoted for authoring DK used for the case study. Firstly, the DK of an educational topic represents the technological tool of the development AT principle. The authoring of adaptive content to meet students' needs is an essential functionality to enhance the students' learning. An extensive description of how to accomplish such functionality is given by (Peña-Ayala et al., 2012).

The content represents the raw stimuli provided to students in order that they are able to acquire DK, develop skills, and reach some degree of awareness about the educational topic. Thus, the authoring of adaptive content demands the contribution of several disciplines, such as: philosophy, cognition, psychology, sociology, pedagogy, social communication, graphic design, and human–computer interaction. In addition, it claims the use of specialized instruments for authoring multimedia content, virtual reality environments, collaboration, monitoring, and social network facilities.

In regards to the content repository, it is part of the pedagogical perspective. It is composed of learning objects to embed concepts, exercises, and tests of a specific educational subject, in the case study a key concept. Such learning objects are classic deliverables of the technological perspective. They represent the vehicle for fulfilling the object-orientedness AT principle. The kernel of the DK to
be taught is summarized through key concepts with the purpose to obey the pedagogical rule of the object-orientedness AT principle.

The specifications for content authoring of the key concepts are outlined by the viewpoints stated by the pedagogical tool of the action AT principle. They provide a set of instances to characterize the teaching style, such as: learning theory (e.g., objectivism, constructivism...), human–computer interaction strategy (e.g., static, dynamic, linguistic...), and prevalent kind of multimedia content to stimulate a specific sense (e.g., visual, sonorous...).

The authoring of content corresponds to the operation AT principle. It specifies the values for the next criteria: the nature of the concept to be taught, the learning theory to guide the apprenticeship, the student’s sense to be stimulated, the type of multimedia to be authored, and the kind of student–system interaction. Once these criteria are filled by at least one instance of the available values held by the viewpoints, a lecture option is authored. These criteria compose the lecture profile of a specific lecture option. Such a profile represents a pedagogical tool of the internalization–externalization AT principle.

As regards the pedagogical tool of the operation AT principle, it splits the content of the lecture option into several learning objects. Where, specialized learning objects are authored with specific content in order to: introduce a concept, develop exercises, respond questions, make tests, evaluate responses, control the lecture, and so forth.

With the aim at providing valuable adaptive content for developing the case study, the earlier AT framework (i.e., composed by perspectives, principles, tools, and rules) was applied for authoring a basic repository. As result, 40 lecture options were authored to teach the ten key concepts from four different teaching styles each. This means, there are four teaching styles to stimulate the students’ apprenticeship of a key concept with the aim at delivering the one that offers the highest achievement.

Thus, in order to adapt e-learning content to satisfy the specific needs of a student three factors are taken into account: The first corresponds to the student’s profile, which uncovers the student’s learning preferences, as well as their cognitive and personality strengths and weakness. The second represents the application of the already stated AT framework to author diverse lecture options to teach a given key concept with the aim that at least one of them promises a high learning achievement for a specific student. The third is the belief of the impact that a concrete lecture option will produce on a particular student to learn a given key concept. This supposition is estimated by the application of the anticipation AT principle in the way explained in Section 4.2.4.

4.2.4. Adaptation of the education

The student-centered education aims at providing personalized lectures to students, which take advantage of their strengths and preferences, as well as consider their weakness and dislikes. Hence, it demands to adapt the education for each particular student, instead of delivering the same lectures to the group of students as traditionally occurs. In order to meet such a claim, three factors, already identified in the prior Section 4.2.3, are needed to adapt the lectures. In this section, we briefly explain the third factor based on the full approach detailed by (Peña-Ayala et al., 2012).

We are interested in implementing a proactive strategy for adapting education, instead of a classic reactive one. Therefore, the anticipation AT principle is the baseline to estimate the impact that a lecture option could exert on the student’s learning. In this sense, the pedagogical tool features a proactive strategy to identify and evaluate the available lecture options with the purpose to choose the most promising.

In order to predict the impact exerted by a lecture option on the student’s learning, the AT principle of internalization–externalization is taken into account. Thereby, the externalization is represented as the lecture option that produces the stimuli to teach a key concept; whereas, the internalization is featuring by the apprenticeship of the student. Hence, a cognitive map is used as the technological tool to outline this kind of cause–effect relationship. Furthermore, the technological rules sketch a topology of causal relationships made up of three layers, where: the first corresponds to the concepts that compose the lecture’s profile, the second contains the concepts of the student’s profile, and the third represents the key concept to be learnt. Concepts of the first level are the cause that biases concepts of the second tier; whilst, concepts of the second layer influence each other and also bias the concept of the third level. Finally, the concept of the third level biases itself and the concepts of the second tier as well. These relationships are qualitatively defined by a fuzzy-cause rules base.

The implementation of both AT principles, anticipation and internalization–externalization, is achieved by the mediation AT principle. It is represented by the PSM, which is responsible for demonstrating the pedagogical rules that suppose: the student’s learning is successfully stimulated when the provided lecture meets her profile. According to the pedagogical rules, the goal is to find out the best lecture option to teach a specific key concept for a particular student. Hence, the available lecture options are evaluated to estimate the impact they exert on the student’s apprenticeship. Such an evaluation is performed by a fuzzy-causal inference engine, which corresponds to the technological tool. Based on the technological rules, the PSM makes fuzzy and fuzzy-causal reasoning upon the CM that depicts the causal relationships between a given lecture option and a specific student. Once all the candidate lecture options have been evaluated, the PSM chooses the lecture option that predicts the highest learning achievement.

4.3. Case study development

This subsection is oriented to explain how the case study was performed. As the first subject, the range of participant groups is described. Thus, a chronicle is pointed out to explain how the group of participants evolves from a universe to a population, subsequent to a sample, and finally to a couple of comparative groups. The provision of stimuli is the second subject. Based on the AT principle of anticipation, experimental group is taught; whereas, randomly chosen lectures are provided to participants of the control group.

4.3.1. Groups of participants

In this section, we explain how the participants were recruited and the group progressed from a universe up to a couple of comparative groups. First of all, the field of the case study corresponds to our institution. It is a national organization funded to provide academic services for the country, where some of them correspond to scientific and technological deliverables. Hence, it promotes the development of new researchers among its graduates.

Thus, with the aim at contributing to achieve such a goal, we made a call for training in the application of the SRM to graduates of the 32 Mexican states through the Internet. As result of the response given by hundreds of interested graduates, just 200 electronic applications were accepted to define a universe of 200 subjects.

Afterwards, a population (N) of 50 participants was organized. They were participants that successfully answered the four instruments applied to measure learning preferences, personality, cognition skills, and DK of the SRM. As regards the remaining participants, some abandoned the training, others did not correctly answer the four instruments, and many finished late. All the accepted participants hold a B.Sc. degree, several have reached a
M.Sc., and others a Ph.D. as well. The population is geographically distributed in 13 states of the country.

Later on, a pre-stimulus was provided to the population in order to train the participants in the use of the AeLS prototype. They revised their background DK about science, scientific research, and philosophy. Moreover, the participants developed different exercises and responded diverse questions. As an additional result, a sample was organized according to the following criteria: Based on a phenomenon occurrence probability of 0.92 and a sample distribution standard error of 0.05, the sample \( n \) is composed of 18 subjects. Therefore, the first 18 participants who successfully accomplished the pre-stimulus were invited to make up the sample and continue to the next stage.

Prior to provide the stimuli, personalized education based on the anticipation AT principle, to the sample, a pair of comparative groups was conformed. So, members of the control and experimental groups were randomly assigned. Hence, nine members made up each comparative group, where both resulted as equivalent groups.

4.3.2. Stimuli provision

The success of our AT framework for designing useful AeLS is determined when participants are stimulated during the case study. The stimulus corresponds to the set of lectures authored to teach ten key concepts about the SRM. The DK content embraces 40 lecture options, which are authored based on the criteria explained in Section 4.2.3. Hence, there are four lecture options to teach a given key concept. Thereby, four teaching styles are available to stimulate a participant; but just one of them is applied. Hence, the selection of the lecture option to be delivered is the main functionality to adapt the education to the participant. In the case study, two criteria are used to choose the lecture option; one takes into account the anticipation AT principle, the other makes a random pick. In order to differentiate the impact of the anticipation AT principle, only participants of the experimental group took lectures chosen through the proactive strategy for adapting education; whereas, participants of control group are taught through randomly selected lectures. Based on the sequencing engine proposed by Peña-Ayala & Sossa (2012), a brief description of how the functionality is performed according to both criteria is outlined as follows.

During the provision of the stimulus to participants of the experimental group, a cyclic process is fulfilled for each key concept \( k \) (e.g., \( 1 \leq k \leq 10 \)) through the next steps: (1) identify the participant \( p \) and the key concept \( k \) to be taught; (2) retrieve the student’s profile that corresponds to \( p \); (3) for each available lecture option \( l \) (e.g., \( 1 \leq l \leq 4 \)) of \( k \) do the next four steps: (3.1) retrieve the lecture’s profile that corresponds to \( l \); (3.2) tailor the CM to characterize the cause–effect relationships between, lecture option \( l \), participant \( p \), and key concept \( k \); (3.3) estimate the impact exerted by lecture option \( l \) on participant \( p \) to learn the key concept \( k \) through the simulation process based on the fuzzy-causal inference carried out by the PSM; (3.4) track the behavior and the results generated during the simulation, which respectively correspond to the intermediate and final outcomes; (4) choose the most promising lecture option \( b \) whose final state value that instantiates the key concept \( k \) is the highest among all the evaluated lecture options \( l \); (5) deliver the lecture option \( b \) to participant \( p \).

As regards the stimulus given to participants of the control group, a cyclic process is carried out for each key concept \( k \) (e.g., \( 1 \leq k \leq 10 \)) through the next four steps: (1) identify the participant \( p \) and the key concept \( k \) to be taught; (2) retrieve the student’s profile that corresponds to \( p \); (3) randomly choose one of the available lecture options \( r \) (e.g., \( 1 \leq r \leq 4 \)) of \( k \); (4) deliver the lecture option \( r \) to participant \( p \).

4.4. Outcomes analysis

During the development of the case study, two sets of measures were made. The first corresponds to the evaluation oriented to shape a student profile for each participant of the universe. The second concerns to the estimation of background and achieved DK of ten key concepts held by members of the comparative groups. What is more, the second measure faces the reliability and validity criteria. These analyses of results are presented as follows.

4.4.1. Measurement of traits for the student’s profile

In another vein, the first set, the WAIS, GMIM, and MMPI tests were implemented for being applied through the web. Moreover, a general test of DK about SRM was also authored. Later on, the members of the universe answered the four tests through the Internet. However, only 50 participants successfully answered the four tests before the deadline.

As a result of the application of the four measures, a repository of 50 student’s profiles was organized, one for each participant. Hence, a student profile is composed of four domains: cognitive, learning preferences, personality, and DK. Such a profile holds attributes to characterize the responses and evaluations given by the participant to the WAIS, GMIM, MMPI, and DK tests. The student profile is used as a valuable source for the PSM.

4.4.2. Measurement of student’s knowledge domain

The second set of measures estimates the success achieved by the delivery of education based on the anticipation AT principle. However, such kind of estimation demands three components: The first corresponds to the DK to be learned, which is featured by ten key concepts of the SRM, which are considered as the target of teaching and learning. The second concerns the criteria for assessing the mastery level demonstrated by the participant about a key concept. Such criteria are featured by the TEO. The third gathers the pre-measure and the post-measure of the KD held by participants of the comparative groups, as well as the difference between the post- and pre-measures. Both measures are estimated by means of the same instrument, the evaluator module of the AeLS. The instrument follows the rules and tools of the pedagogical and technological activity systems that are defined for the outcome principle. Thereby, it is possible to identify the student’s previous and acquired DK about every key concept.

The TEO embraces seven levels organized in ascending order of complexity for being dominated. In consequence, a quantitative value is attached to the qualitative one to reveal an increasing progression (e.g., 0 for ignorance, 1 for remembering, 2 for understanding, etc.). Hence, during pre- and post-measures, the highest TEO level that a participant is able to reach for any key concept ranges from 0 to 6. Thereby, any participant can achieve a total score from 0 to 60 as result of the accumulation of the values given for the ten key concepts. Thus, the global score that a comparative group can obtain is found between 0 and 540. As sample of the statistical process, a set of descriptive statistics for the comparative groups is outlined in Table 1. The sort of measures presented in Table 1 includes: sum, mean, median, range, mode, standard deviation, skewness, and kurtosis.

Table 1 reveals: Although the experimental group had lower previous domain DK than the control group (e.g., 38 points versus 42); at the end, the experimental group’s learning achievement is higher than the result produced by the control group (e.g., 198 against 174 points).

4.4.3. Reliability

Reliability is evaluated for the second set of measures, the ones oriented to estimate the target, through the Chronbach’s Alfa
method. It estimates the consistency of six types of questions oriented to measure the student's DK about ten key concepts. The coefficient achieved during the pre-measure and post-measure for the union of comparative groups, the control group, and the experimental group is given in Table 2. In this table, an acceptable coefficient around 0.8 for each measure-group appears with just one exception, the pre-measure of the experimental group.

4.4.4. Validity

Validity requirement is also tested for the second set of measures by means of the factor analysis method. It describes variability among observed variables in terms of fewer factors. Therefore, a factor analysis is estimated for pre-measure and post-measure stages in Tables 3 and 4 respectively. This process uses the principal component extraction method and the Varimax rotation type.

The tables' rows reveal a sample of key concepts that represent the student's DK about the SRM. The first column identifies the number of the key concept (e.g., 1 for hypothesis, 2 for law...). Columns two to seven depict six factors, such as: (1) student's former DK; (2) evaluation method; (3) concept's nature; (4) quiz requirement; (5) response time limit; (6) user–system interaction. Tables 3 and 4 state in the last column the communalities between factors and loads that rotated and classified factors exert upon key concepts. In both tables, it is possible to identify high values for key concepts 1 and 6, medium values for key concepts 5 and 10, and low values for key concepts 4 and 7.

4.5. Inferential hypothesis testing

In this section, the causal hypothesis defined in the development AT principle is tested through the following inferential methods: mean for the population, confidence range, correlation, and linear regression between previous and current knowledge. The results produced by the testing methods are presented as follows.

4.5.1. Mean for the population

The method of mean for the population corresponds to the hypothesis about population's mean. Hence, in Table 5, the probability that the sample's mean is close to the mean of the sample distribution is estimated with a significance level ($\alpha$) of 0.05 to produce 1.96 as $Z$ score. Such a table shows the hypothetic mean, which is computed from the average mean estimated for experimental and control groups as result of the pre-measure, post-measure, and difference. The success criterion number 1 is met when: $Z$ score for a sample mean $\leq$ $Z$ score for the significance level $\alpha$ of 1.96. In Table 5, it is possible to identify that each measure for every group satisfies the criterion for the hypothesis about population's mean.
Table 4
Validity based on the factor analysis to post-measure the student’s knowledge.

<table>
<thead>
<tr>
<th>Key concept</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
<th>Factor 6</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.902</td>
<td>0.159</td>
<td>–0.088</td>
<td>0.032</td>
<td>0.087</td>
<td>–0.183</td>
<td>0.888</td>
</tr>
<tr>
<td>5</td>
<td>0.808</td>
<td>0.284</td>
<td>0.011</td>
<td>–0.265</td>
<td>0.172</td>
<td>–0.285</td>
<td>0.914</td>
</tr>
<tr>
<td>2</td>
<td>0.638</td>
<td>0.526</td>
<td>–0.319</td>
<td>–0.301</td>
<td>0.220</td>
<td>–0.004</td>
<td>0.925</td>
</tr>
<tr>
<td>9</td>
<td>0.568</td>
<td>–0.032</td>
<td>0.085</td>
<td>0.453</td>
<td>0.532</td>
<td>–0.308</td>
<td>0.914</td>
</tr>
<tr>
<td>10</td>
<td>0.291</td>
<td>0.895</td>
<td>0.155</td>
<td>–0.121</td>
<td>–0.001</td>
<td>–0.074</td>
<td>0.929</td>
</tr>
<tr>
<td>4</td>
<td>0.003</td>
<td>0.761</td>
<td>–0.450</td>
<td>–0.125</td>
<td>–0.005</td>
<td>–0.282</td>
<td>0.886</td>
</tr>
<tr>
<td>3</td>
<td>0.071</td>
<td>0.043</td>
<td>–0.966</td>
<td>–0.073</td>
<td>0.092</td>
<td>–0.125</td>
<td>0.969</td>
</tr>
<tr>
<td>8</td>
<td>0.134</td>
<td>0.203</td>
<td>–0.089</td>
<td>–0.890</td>
<td>0.272</td>
<td>–0.081</td>
<td>0.941</td>
</tr>
<tr>
<td>1</td>
<td>0.162</td>
<td>0.021</td>
<td>–0.130</td>
<td>–0.317</td>
<td>0.894</td>
<td>0.026</td>
<td>0.943</td>
</tr>
<tr>
<td>6</td>
<td>0.397</td>
<td>0.235</td>
<td>–0.212</td>
<td>–0.060</td>
<td>0.011</td>
<td>–0.835</td>
<td>0.959</td>
</tr>
</tbody>
</table>

% Variance 2.4950 1.8626 1.3461 1.2297 1.2492 1.0153 9.2678

Table 5
Hypothesis about population’s mean for control and experimental groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Trial stage measures</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-measure</td>
<td>Post-measure</td>
<td>Difference</td>
</tr>
<tr>
<td>Sample count</td>
<td>9</td>
<td>9</td>
<td>14.67</td>
</tr>
<tr>
<td>Sample mean</td>
<td>4.67</td>
<td>19.33</td>
<td>2.8186</td>
</tr>
<tr>
<td>Sample standard deviation</td>
<td>4.4441</td>
<td>9.7468</td>
<td>2.8186</td>
</tr>
<tr>
<td>Mean distribution sample standard deviation</td>
<td>1.4817</td>
<td>3.2490</td>
<td>2.7233</td>
</tr>
<tr>
<td>Z score for sample mean</td>
<td>0.151</td>
<td>–0.411</td>
<td>–0.571</td>
</tr>
<tr>
<td>Success criterion 1</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>P value</td>
<td>0.881</td>
<td>0.682</td>
<td>0.567</td>
</tr>
<tr>
<td>Success criterion 2</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>

Table 6
Pearson correlation for pre and post-measures fulfilled by control and experimental groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Measures</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-measure–Post-measure</td>
<td>Pre-measure–Post-measure</td>
<td></td>
</tr>
<tr>
<td>r Pearson's coefficient</td>
<td>0.554</td>
<td>0.828</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>0.0059</td>
<td>0.0059</td>
<td></td>
</tr>
<tr>
<td>Nature of the correlation</td>
<td>Positive and medium</td>
<td>Positive and high</td>
<td></td>
</tr>
<tr>
<td>Significative of the correlation</td>
<td>Non-significative</td>
<td>Quite significative</td>
<td></td>
</tr>
</tbody>
</table>

4.5.2. Confidence range

As regards the method of confidence range, the population mean is stated in the last three rows of Table 5, where the confidence level is 0.95 with 1.96 as Z score. Likewise, the hypothetic mean is the average of the mean for experimental and control groups estimated from pre-measure, post-measure, and difference. Based on such items, a P value is computed, and a comparison is made as a success criterion number 2, where P value > α significance level of 0.05.

4.5.3. Correlation

The correlation between previous and acquired knowledge (i.e., pre- and post-measures respectively) is presented in Table 6. In such a table, the Pearson’s coefficient r and the P value are stated for the correlations between the pre- and post-measures estimated for control and experimental groups with a significance level (α) of 0.05. The significance of the correlation is well appreciated when the P value is ≤ α significance level of 0.05, otherwise it is not significant.

As result of the correlation, the lecture selection criterion, based on the anticipation AT principle, exerts a high bias on the apprenticeship achieved by participants of the experimental group. In consequence, the correlation for the experimental group is quite significant (e.g., 0.0059). In addition, the r coefficient reveals a high positive correlation for experimental group (e.g., 0.828).

However, the random selection criterion produces a non-significant influence (e.g., 0.122) on the learning accomplished by participants of the control group. Moreover, the r coefficient uncovers a medium positive correlation for control group (e.g., 0.554).

4.5.4. Linear regression

Regarding the causal influence between former and acquired DK, a linear regression is estimated for control and experimental groups in Table 7 and Fig. 11. According to the significance level (α) of 0.05, the source of variation is not significant when P value is > α significance level. In such table and figure the high causal influence that the stimulus yields on the previous experimental
The student’s apprenticeship is successfully stimulated when the subjects of the control team. This means that the pedagogical rule: were more stimulated than the cognitive capacities shown by sub-

The learning abilities held by members of the experimental group measures given in Table 1. They demonstrate: Despite holding anticipation features chosen according to the advice given by the PSM, which AT principle, reach a higher students’ learning than the apprenticeship achieved through lectures se-

This affirmation is grounded on the pre, post, and difference measures given in Table 1. They demonstrate: Despite holding the lowest previous DK (38 points); at the end, the experimental group overcame and improved in such a way that it reached the highest score (198 points). Hence, the accumulated apprenticeship acquired by participants of the experimental group was higher than the learning achieved by participants of the control group (e.g., 160 versus 132 respectively). Thus, the intercept value of the post-measure (Y) estimated for the experimental group is smaller by almost half than the one produced by the control group (e.g., respectively 3.28 versus 1.22). Furthermore, the slope achieved for the experimental group is higher that the one fulfilled by control group (e.g., 7.72 versus 13.7 respectively). However, the slope of the linear regression equation for the experimental group is nearly three times greater that the one produced for the control team (e.g., 7.72 versus 13.7 respectively).

4.6. Findings

The most relevant finding derived from the case study is: Lectures chosen according to the advice given by the PSM, which implements the anticipation AT principle, reach a higher students’ learning than the apprenticeship achieved through lectures selected without considering such a personalized support offered by the AeLS.

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Another relevant finding derived from the earlier arguments is: The learning abilities held by members of the experimental group were more stimulated than the cognitive capacities shown by subjects of the control team. This means that the pedagogical rule: “the student’s apprenticeship is successfully stimulated when the delivered lecture matches their profile” is reinforced according to the collected empirical evidence.

Fig. 11. Linear regression between pre- and post-measures for control and experimental groups

5. Conclusions

The AT as a framework composed of several principles and items is quite useful to analyze, model, and study human praxis. In this work, we take into account AT as a framework to design AeLS and provide empirical evidence to assert: Anticipation is a key AT principle to enhance the apprenticeship of students.

Such a statement is based on the statistical results that reveal: Although the previous DK held by subjects of the experimental group was lower than the one of control group participants, the provided stimuli, chosen by anticipation AT principle, produce a higher apprenticeship than the learning accomplished by control participants, whose lectures were randomly selected.

As further work, a systematic method for applying AT must be built to facilitate its application. More experimental research is also required to add empirical evidence regarding the impact of the AT in e-learning fields. It is also necessary to design psychological tools to measure several domains of the student profile through Internet. Likewise, new predictive models based on the anticipation AT principle must be built. Finally, the consideration of automatically author and adapt DK content during the student-system interaction is a challenge to be tackled.

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