Computers in Human Behavior 30 (2014) 131–145

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

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

Alejandro Peña-Ayala [a,b,*], Humberto Sossa [c], Ignacio Méndez [d]

[a] WOLNM, 31 Julio 1859 # 1099-B, Leyes Reforma, DF CP 09310, Mexico
[b] ESIME Zacatenco, Instituto Politécnico Nacional, U. Profesor Adolfo López Mateos, Edificio Z-4, 2do piso, Cubiculo 6, Miguel Othón de Mendizábal S/N, Col. La Escalera, DF CP 07320, Mexico
[c] CIC, Instituto Politécnico Nacional, U. Profesor Adolfo López Mateos, Gustavo A. Madero, DF CP 07738, Mexico
[d] IIMAS, Universidad Nacional Autónoma de México, Circuito Escolar s/n, Ciudad Universitaria Coyoacán, DF CP 04510, Mexico

ARTICLE INFO

Article history:
Available online 7 September 2013

Keywords:
Activity theory
Adaptive e-learning systems
Proactive student model
Anticipation principle
Teaching–learning experience

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.

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, & Huangc, 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 Multiphase 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 Intelligent Scale; *Y*, post-measure; *Z*, score; α, significance level.

* Corresponding author at: WOLNM, 31 Julio 1859 # 1099-B, Leyes Reforma, DF CP 09310, Mexico. Tel./fax: +52 55 5694 0916, mobile: +52 55 5454 2611.

E-mail addresses: apenaa@ipn.mx (A. Peña-Ayala), hsossa@cic.ipn.mx (H. Sossa), imendez@servidor.unam.mx (I. Méndez).

URL: http://www.wolnm.org/apa (A. Peña-Ayala).

0747-5632/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.chb.2013.07.057

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.

2. Method: A framework for applying activity theory to adaptive e–learning systems

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 & Glăveanu, 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

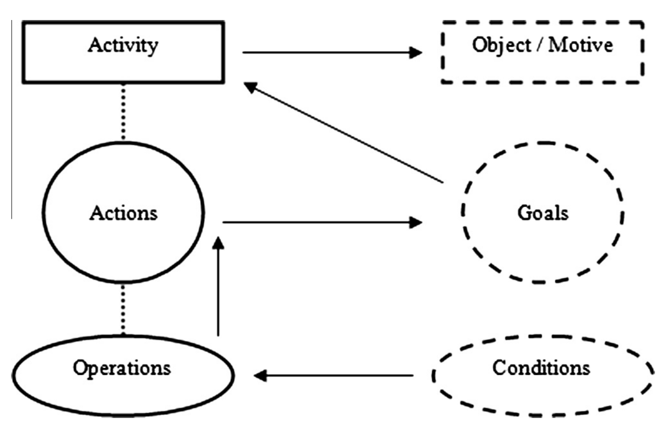

Fig. 1. Architecture of the AT principle of hierarchical structure.