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Interpretations of constructivism and consequences for Computer Assisted Learning

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Abstract

The changes that have occurred in accepted approaches to teaching and learning in recent years have been underpinned by shifts in psychological and pedagogical theory, culminating in moves towards a constructivist view of learning. This paper looks at the consequences of these theoretical shifts for Computer Assisted Learning (CAL).

Moshman has identified three interpretations of constructivism: endogenous constructivism which emphasises learner exploration, exogenous constructivism which recognises the role of direct instruction, but with an emphasis on learners actively constructing their own knowledge representations and dialectical constructivism which emphasises the role of interaction between learners, their peers and teachers. This classification scheme provides a framework for looking at the various constructivist approaches to CAL.

For example, constructivist CAL materials that draw on the endogenous view include hypermedia environments, simulations and microworlds. Materials that draw on the exogenous view include learner controlled tutorials, cognitive tools and practice modules. Lastly, materials that draw on the dialectical view include Computer Supported Collaborative Learning (CSCL) tools and support (or scaffolding) tools.

Introduction

Accepted teaching and learning practices have undergone significant changes in recent years. These changes are evident in situations as diverse as early childhood teaching, university education and workplace training. They have been underpinned by shifts in psychological and pedagogical theory, the most recent of which fit broadly under the heading of constructivism. This paper looks at the consequences of

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constructivist theories of teaching and learning for Computer Assisted Learning (CAL).

Constructivist teaching and learning

The recent changes in teaching and learning practices have had their roots in two broad theoretical developments. The first development, in the field of psychology, has been the demise of the *behaviourist* view in favour of the *cognitive* view of learning. A behaviourist view of learning emphasises teaching strategies that involve repetitive conditioning of learner responses. A cognitive view, on the other hand, places importance on the learner's cognitive activity and the mental models they form.(Leahey and Harris, 1993; Schultz and Schultz, 1992)

The second development, which is more of a philosophical shift than a new movement in psychology, has been the gradual rejection of the assumption, held by many cognitivists, that there is some objectively correct knowledge representation. The alternative view, termed *constructivist*, is that, within a domain of knowledge, there may be a number of individually constructed knowledge representations that are equally valid. The focus of teaching then becomes one of guiding the learner as they build on and modify their existing mental models, that is, a focus on knowledge construction rather than knowledge transmission (McInerney and McInerney, 1994; Slavin, 1994).

There are three broad principles that together define the constructivist view of learning. The fundamental principal, attributed to Kant and later adopted by Dewey, is that **each person forms their own representation of knowledge**, building on their individual experiences, and consequently that there is no single "correct" representation of knowledge (Von Glaserfeld, 1984). The second principal, normally attributed to Piaget, is that people learn through active exploration, and that **learning occurs when the learner's exploration uncovers an inconsistency between their current knowledge representation and their experience** (McInerney and McInerney; 1994; Slavin, 1994). The third principal, normally attributed to Vygotsky, is that **learning occurs within a social context, and that interaction between learners and their peers is a necessary part of the learning process** (Vygotsky, 1978).

Although there is general agreement on the basic tenets of constructivism, the consequences for teaching and learning are not as clear cut. It is generally agreed that learning involves building on prior experiences, which differ from learner to learner. Consequently, each learner should have a say in what they are to learn, different learning styles must be catered for and information must be presented within a context to give learners the opportunity to relate it to prior experience. It is also generally agreed that the process of learning is an active one, so the emphasis should be on learner activity rather than teacher instruction.

However, from here there is significant disagreement about the details of how to implement these broad principles. Radical constructivists claim that learners should be placed within the environment they are learning about and construct their own mental

model, with only limited support provided by a teacher or facilitator. More moderate constructivists claim that formal instruction is still appropriate, but that learners should then engage in thought oriented activities to allow them to apply and generalise the information and concepts provided in order to construct their own model of the knowledge (Perkins, 1991). Adding a third dimension is the view that knowledge construction occurs best within an environment that allows collaboration between learners, their peers, experts in the field and teachers.

These different interpretations of constructivism have been labelled by Moshman (1982) as *endogenous*, *exogenous* and *dialectical*, as follows:

- Endogenous constructivism emphasises the individual nature of each learner's knowledge construction process, and suggests that the role of the teacher should be to act as a facilitator in providing experiences which are likely to result in challenges to learners' existing models.
- Exogenous constructivism is the view that formal instruction, in conjunction with exercises requiring learners to be cognitively active, can help learners to form knowledge representations which they can later apply to realistic tasks.
- Dialectical constructivism is the view that learning occurs through realistic experience, but that learners require *scaffolding* provided by teachers or experts as well as collaboration with peers.

Constructivist Computer Assisted Learning

Having looked at the origins and the various interpretations of constructivism, we can now look at approaches to Computer Assisted Learning (CAL) that have grown out of constructivism. In doing so, Moshman's three interpretations of constructivist theory provide a useful framework. Before looking at the CAL techniques that are consistent with each of these interpretations of constructivism, it is appropriate to look at the nature of traditional CAL resources based on pre-constructivist views of teaching and learning.

Pre-constructivist approaches

Traditional CAL resources consisted primarily of tutorials, which were essentially computer based forms of Programmed Instruction (PI), drawing heavily on the behaviourist views of Skinner. These tutorials typically contained sequences of content broken into sections, with end of section questions to determine whether the learner required remedial content or was ready to go on to the next section. They also included drill and practice materials, consistent with the behavioural psychology emphasis on producing automatic responses by repeated reinforcement (Rieber, 1994).

An alternative is the Intelligent Tutoring Systems (ITS) approach. These systems maintain models of an expert's knowledge and models of the learner's current knowledge and use Artificial Intelligence (AI) techniques to dynamically generate a sequence of instruction to suit the needs of the learner (Orey and Nelson, 1993). Such systems are consistent with the cognitivist view that the instruction should depend on the learner's current cognitive state but are based on an implicit assumption that there is a single correct representation of a given body of knowledge (Jonassen, 1992a).

Endogenous constructivist approaches

Endogenous constructivism emphasises the importance of learner directed discovery of knowledge. Constructivist CAL materials that draw on this view include hypertext and hypermedia environments allowing learner controlled browsing of content, and simulations and microworlds, which allow active exploration within a virtual environment.

Hypertext and Hypermedia

The term hypertext was first coined by Ted Nelson in the 1960s, but the concepts are normally traced to Vannevar Bush in 1945 (Park and Hannafin, 1993). Hypertext consists of chunks of textual information (nodes) with groups of words acting as automatic links to other chunks (McKnight, Dillon and Richardson, 1991). Hypermedia is a more general term, indicating that the nodes can be composed of a variety of media and that screen objects such as icons, "hot areas" within pictures and graphical buttons can act as links in addition to words within text. As well as becoming popular for use in instructional systems, hypermedia has also found widespread application as a way of organising and accessing large information databases, typically delivered on CD-ROM. Most recently the Hypertext Markup Language (HTML) has become the information delivery standard for the World Wide Web.

Because hypermedia information databases typically allow browsing under complete learner control, with learners following a sequence of links that makes sense to them, it is suggested that they facilitate the formation of individual knowledge representations (Rieber, 1994). This freedom to browse through the content, is consistent with the constructivist principle that learners should be given the opportunity to discover knowledge through their own active exploration.

Hypertext has also been advocated as a mechanism for applying cognitive flexibility theory, a theory that focuses on advanced knowledge acquisition in ill-structured or complex domains (Spiro *et al.*, 1991). The use of hypertext links allows the learner to choose from a range of relevant examples of the theme or concept being illustrated. It also allows for a particular area of the content to be examined a number of times, from different perspectives.

Simulations and microworlds

There is no accepted definition of simulations and microworlds that allows for a clear distinction between the two. Typically a simulation is defined as a model of a real world environment, usually with the facility for the user to interact with the environment (Thurman, 1993). A microworld can be defined as a model of a concept space, which may be a very simplified version of a real world environment, or it may be a completely abstract environment. Normally, a user can create some sort of constructions within the microworld which will behave in a way consistent with the concepts being modelled (Papert, 1993; Rieber, 1992).

Simulations and microworlds are popular with constructivists for two reasons. Firstly, simulations (and some microworlds) provide a realistic context in which learners can

explore and experiment, with these explorations allowing the learner to construct their own mental model of the environment. Secondly, the interactivity inherent in microworlds (and usually in simulations) allows learners to see immediate results as they create models or try out their theories about the concepts modelled (Rieber, 1992).

Simulations have been used as part of CAL materials for at least three decades. One of the more well known examples is *Sim City* (Wright, 1989). Recent technological developments have made it possible to create Virtual Reality (VR) simulations. Such simulations range from fully immersive environments that require three-dimensional viewing helmets with head-tracking devices, to desktop environments that require only a standard PC, and which make use of technologies such as the Virtual Reality Modelling Language (VRML) (Macpherson and Keppell, 1998).

The term microworld was first coined by Papert (1993) who described the Logo microworld for exploring and constructing within a geometrical concept space. Other popular examples include *The Incredible Machine* (1992), a mechanical problem solving environment and *The Geometer's Sketchpad* (1995) a geometric exploration environment.

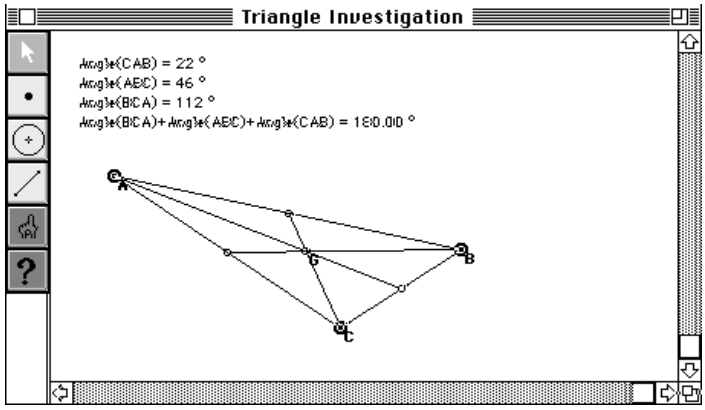

Figure 1: Geometer's Sketchpad

Exogenous constructivist approaches

The exogenous view of constructivism recognises the value of direct instruction, but not the teacher centred single sequence of instruction of behaviourists. According to the exogenous view, learners should have some control over the sequence and selection of content, should have the opportunity to actively construct their own knowledge representations and articulate these representations at all stages, and, after instruction should have the opportunity to apply their knowledge to realistic tasks. Constructivist CAL materials that draw on the exogenous view include tutorials that incorporate learner control over sequence, or conversely, hypermedia browsing environments that include context sensitive pedagogical guidance. The use of *cognitive tools*, to assist with knowledge construction and articulation during instruction, including concept

mapping tools and hypertext editing tools is consistent with exogenous constructivism. Practice modules, for example quizzes and problem solving exercises, which allow the learner to obtain feedback on their own construction of knowledge, are also consistent with this view.

Tutorials with learner control and guided hypermedia

Tutorial systems that are consistent with constructivist theories provide a structure that encourages the learner to follow certain instructional sequences, but allows them to choose alternative sequences, or to use the materials as a discovery learning resource if they are so inclined. In fact, often they use a hypertext or hypermedia metaphor, but provide a clearer structure or more guidance than environments that are designed specifically for discovery learning. These tutorials may also have within them practice exercises as well as annotation tools that allow the learner to articulate their knowledge constructions. For example, *Investigating Lake Illuka* (Harper, Hedberg and Brown, 1993) is an environmental education resource providing a hypermedia interface along with annotation tools and suggested exercises. Its structure allows it to be used either as a tutorial or as a discovery learning environment.

Figure 2: Investigating Lake Illuka

A criticism of many hypermedia exploration environments, from an exogenous constructivist point of view, is that there is a tendency for learners to become "lost in hyperspace" (McKnight, Dillon and Richardson, 1991). One approach to this problem is to provide pedagogical help to the learner as they browse. This help could be in the form of a standard pop-up help system, an animated *guide* or an intelligent *agent*, monitoring the browsing patterns of the learner (Wills, 1996; Oren *et al.*, 1990).

Cognitive tools

All three views of constructivism emphasise the importance of individual knowledge construction. A consequence of this is the use of metacognitive strategies, that is, strategies employed by the learner to improve their comprehension, retention and individual construction of knowledge. Explicitly teaching these strategies to students is particularly consistent with exogenous constructivist principles. It has been proposed that the use of computer based cognitive tools can be of assistance with these strategies. According to Jonassen, such tools "amplify thinking and facilitate knowledge construction" (1992a, 4), while Wild and Kirkpatrick state that these tools can "provide the means by which learners can construct, manipulate and evaluate representations of knowledge" (1996, 414). These tools include text and hypertext editing tools, modelling tools and concept mapping tools.

The node-link structure of hypermedia environments has been compared with the way information is stored in the brain (Warren, 1989, in Lohr, Ross and Morrison, 1995). Consequently, it has been argued that an effective way for learners to articulate their knowledge representation is to construct their own hypermedia databases (Jonassen, 1992b).

Concept mapping (also called semantic networking), whereby the learner draws a diagram indicating the concepts that make up an area of knowledge and the way that these concepts relate to each other, has long been advocated as an effective metacognitive strategy (Fisher, 1992; Gaines and Shaw, 1995). A number of computer assisted concept mapping tools have been developed, including *SemNet* (Fisher, 1992) and *Inspiration* (Inspiration Software, 1999).

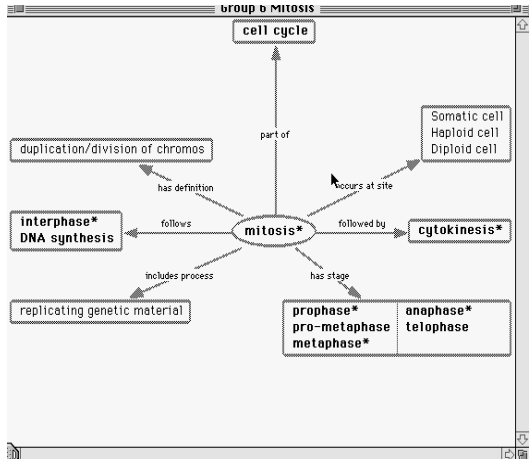

Figure 3: Sem Net

The use of modelling tools that allow the learner to develop their own simulation of a particular aspect of the world can require the learner to develop a very deep

understanding of the concepts involved. *Stella* (1996) is a modelling tool that provides a graphical environment allowing the learner to specify the quantities to be modelled and their relationship, and will then carry out the simulation producing charts showing the changes in quantities over time.

Practice modules
If direct instruction is to be used, an important element of the instructional process is the provision of opportunities for the learner to put their knowledge into practice and receive feedback on their knowledge constructions. In some knowledge domains this could occur through the learner carrying out activities within a simulated environment or a microworld. In others it might occur through the learner articulating their knowledge representation in a written form, or in the form of a hypertext database. However, in some cases, the use of simple practice exercises with feedback is quite appropriate. These might consist of multiple choice, single word or numeric answer quizzes, or the graphical matching or grouping of words and symbols.

Dialectical constructivist approaches
Dialectical constructivism emphasises the role of social interaction in the learner's knowledge construction process, leading to an emphasis on cooperative and collaborative learning strategies. The term Computer Supported Collaborative Learning (CSCL) is typically used to describe tools to assist in this type of learning. Additionally dialectical constructivism emphasises the provision of support (or *scaffolding*) for learners as they carry out tasks at the edge of their capabilities. Although such support would normally be provided by either peers or teachers, software tools can in some cases fill this role.

Computer Supported Collaborative Learning (CSCL).
Technologies used for CSCL can be divided into three groups, those that are general purpose Computer Mediated Communication (CMC) tools, those that are designed for Computer Supported Cooperative Work (CSCW) and lastly those that have features specifically for group learning (O'Malley, 1995).

CMC technologies can be classified according to the type of communication that they allow, that is whether they allow one to one or group communication and whether they allow synchronous (parties communicating at the same time) or asynchronous (parties communicating with a time delay) communication (Bonk, Medury and Reynolds, 1994). Technologies that are helpful with asynchronous communication include Email for one to one and mailing lists, news groups and web-based bulletin boards for group communication. Technologies that are helpful with synchronous communication include talk programs for one to one and computer conferencing environments such as Internet Relay Chat (IRC) or ICQ for group communication. Dalgarno and Atkinson (1999) describe the use of such tools to facilitate group learning tasks.

Dede (1995) discusses the possibility of combining the capabilities of virtual environments with the capabilities of CMC tools to allow collaborative learning within a distributed virtual world. Recent extensions to VRML, such as Blaxxun Contact, support

such environments using the Internet as a communication medium (Blaxxun Interactive, 1999). The use of Multi-User Object Oriented Domains (MOOs) provides a similar capability, but through the use of text descriptions of the environment rather than graphical simulations.

Figure 4: Blaxxun Contact

CSCW tools, commonly known as *groupware*, typically include CMC tools along with shared workspaces for collaborative work, scheduling tools and workflow organisers (Grudin, 1990). Although designed primarily for use within the workplace, groupware tools have been found to be useful in a learning context for group projects (Collings, Richards-Smith and Walker, 1995).

Systems designed specifically for collaborative learning typically include a CMC component as well as tools for group learning tasks. These may include tools for group writing, tools to facilitate discussions (such as allowing role playing within the discussion), tools for shared annotation of hypermedia spaces or tools for shared problem solving (Bonk, Medury and Reynolds, 1994; Scardamalia and Bereiter, 1996; Harasim, Hiltz, Teles and Turoff, 1995).

Support tools

An important element of constructivist theory is the idea that learners should be given the opportunity to carry out realistic tasks, with assistance or scaffolding provided to enable them to complete the larger task without needing to learn all of the sub-tasks involved. Ideally, as a by-product, the learner will learn how to complete the sub-tasks so that eventually they will be able to carry out the larger task unassisted. The provision of scaffolding as the learner attempts to carry out authentic tasks is consistent with Vygotsky's emphasis on learners undertaking activities just beyond their capabilities, in what he terms their *Zone of Proximal Development* (Vygotsky, 1978).

Scaffolding can be provided in part by the computer, through support software. The software may be designed specifically for the purpose, such as the lesson planning tool described by Wild and Kirkpatrick (1996) or alternatively general purpose software such as a language translator, a spell checker, a thesaurus, or a spreadsheet program can fill a similar role.

Conclusion

This paper has summarised the recent psychological and pedagogical theories that have led to significant changes in accepted teaching and learning strategies. It has examined the way that these theories may be applied to Computer Assisted Learning, showing that the range of possible CAL approaches incorporating constructivist theory are broad and varied. The resources described that make use of these techniques, indicate that there has been some progress made by developers. However, there are still numerous resources available that are built on behaviourist assumptions about teaching and learning, or worse still, are built on no assumptions at all. This is especially true of many Web Based Learning resources, which in some cases are essentially printed materials, converted directly to an electronic form. It is hoped that as educators become more knowledgeable about Computer Assisted Learning they will become more discerning, and will insist that the resources they use are built on sound pedagogical principles, and most importantly, really do facilitate learning.

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