

**Metacognitive Cybernetics:
The Chess Master is No Longer Human!**



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Abstract

As we approach the next millenium most humans are facing serious concerns about being overtaken, even consumed, by the very technologies meant to make their lives easier. Instructional Technologists (and many others in related fields) have been given the task of designing learning systems which can take advantage of new technologies and apply them to traditional learning paradigms. Such systems today can not be developed within the constraints of traditional “...group-based, time-based, teacher-as-primary-source-of-instruction model of education.” (Reiser & Salisbury, 1995) Our hope is to develop learning systems which can utilize second order artificial intelligence capable of automating its decision making processes to adapt to the needs of the learner and be ‘cognizant’ of all the implications and nuances of that ‘style’ or model presented to the learner and be malleable internally (self-correcting) and externally (by the learner) in order to engender a rich world schema in which learners can emerse themselves. The system will then make ongoing adjustments as it interacts with each new learner. We are therefore faced with the challenge of developing learning systems which take on human characteristics, combining cognizance and mechanical immediacy in its serving the needs of the learner. Such a **Metacognitive Cybernetic** (MC) model seems to be utopian and the stuff of science fiction, yet there are a number of research projects which are moving in this direction and elements of such models are appearing in embryonic form today that bode well for the future. In this paper I hope to describe some of these projects and technologies, how they are changing the way humans and technologies are converging to deliver new learning experiences and perhaps how such developments are portending the creation of new learning theories born from the seeds of this technological (r)evolution.

Introduction

If the sum total of all human knowledge were put into a machine and if that machine could make decisions based on that 'knowing' it still could not match the human condition until it starts to 'learn' from its own mistakes and, most essential, take pride in that learning which further engenders and motivates new learning. The keys here are motivation and emotion, things which we still hold to be uniquely human. We should keep this position clearly in mind as we progress towards the development of Metacognitive Cybernetic models of learning. Lars Qvortrup in CYBERNETICS & HUMAN KNOWING states:

While natural and social systems are autopoietical or second order cybernetic systems in that they produce not only their own elements and relations, but also their own conditionality, or - as Kant puts it - their own purpose, technological and semiological systems - artificial systems - are heteropoietical or first order cybernetic systems: they may or may not produce their elements and relations, but they are not conditionalised themselves. Finally, higher order artificial systems e.g. second order technological and semiological systems or "semi-autopoietical systems" (examples such as artificial intelligence and recursive pieces of music, respectively) are briefly characterized. While internally they produce their own condition in order for example to "mimic" a natural or a social system, externally they are conditionalised by the social system: their purpose is to mimic, it is not themselves. (Qvortrup, 1993).

We are clearly aware of our inability to create systems conscious of their own existence and able to change themselves as their environment changes (at least for the foreseeable future). Research arising from emerging technologies is bringing with it new demands for developing learning theories which seem to transfer into the realm of the 'machine' that which we traditionally applied solely to human learning. Instructional Technologists interested in applying existing learning theories to new models of Instructional Design utilizing these emerging technologies will find some theories don't quite fit, precisely because new capabilities exist where none existed previously. Adaptations and permutations of existing theory will evolve but we stand on the threshold of new learning paradigms as man and machine begin to truly collaborate in a common learning 'schema'.

Some say we cannot hope to design such a system precisely because no learning theorists today can lay claim to truly understanding, much less fully modeling, how humans learn. If we can't design models which completely describe the processes of human learning how can we possibly design machines with such capabilities. Such a system would have to be 'metacognitively aware' of all its components; capable of interacting with a learner; analyzing their myriad of needs; while growing, learning and adapting as the learner grows, learns and adapts. (It is a rare thing to find a human teacher capable of this.) Such a system does not seem remotely possible with today's technologies but there does exist elements within the fields of artificial intelligence and computer aided instruction which are beginning to move in this direction and can provide micro-blocks that deliver components of such a metacognitive cybernetic unit. Although we can't provide the whole model of human learning we have made amazing progress in describing parts of the process. What remains is to begin understanding the potential myriad of new technologies, combining them with proven learning theory and begin producing early MC models.

Instructional Technologists must be aware of emerging technologies as they begin designing their own learning systems and incorporate, where possible, such innovations as soon as it becomes feasible. It will soon become possible to have a program that can draw out of the learner their own 'learning schema' as they try to understand new concepts or processes and then begin developing learning modules to fit within that schema. As Osman & Hannafin state, "Although existing research and theory suggest that metacognition is integral to successful learning, existing instructional design (ID) models do not typically emphasize metacognitive strategies such as planning, monitoring, revising, and other self-regulating activities." (Osman and Hannafin, 1992) Such endeavors, by their very nature, involve a major rethinking of how we apply traditional learning theory to our instructional designs. "In attempting to simplify the learning in order to improve instructional efficiency and effectiveness, IST (Instructional Systems Technology) may be short-circuiting

relevant mental processing. Designer's attempts to simplify learning risk supplanting the complexity that is inherent in the learning process or the task to be learned." (Jonassen, D., 1991) The clear point here is that the models we build must adapt, not just to the learning situation, but to the learner as well (an extremely daunting task). We should be able to take elements of existing learning theories and adapt components of them to the models we build; mixing behaviourism, cognitivism, constructivism and beyond where it proves successful for the learner. We should also be aware of how the learner, the teacher (the sometimes forgotten partner in this process), and the learning environments we design work together in a group dynamic. This step is essential as our learning environments become more sophisticated and take on roles which may rival that of the teacher.

Artificial Intelligence

Lets look at some developments in the field of artificial intelligence as they apply to learning systems. Massimo Negrotti has stated that there is an urgency in defining theories in this field. "The need for a theory comes both from scientific and from practical interests. According to the former we have to understand the artificial in order to discriminate it from the purely technological activity and try to understand also their different anthropological roots and intellectual motivations. According to the latter, we have to understand the different requirements needed for the use of conventional machines as compared to the 'use' of artificial devices. The intensity of today's technology, both artificial and conventional, makes such theoretical work legitimate both on technical grounds and also because of its urgency socially and culturally." (Negrotti, 1993).

If we are to design 'true' units of artificial intelligence we must be certain to clearly understand what this means. If you access

<http://wombat.doc.ic.ac.uk/foldoc/index.html> and type in 'artificial intelligence'

you will be presented with this definition:

(AI) The subfield of computer science concerned with the concepts and methods of symbolic inference by computer and symbolic knowledge representation for use in making inferences. AI can be seen as an attempt to model aspects of human thought on computers. It is also sometimes defined as trying to solve by computer any problem that a human can solve faster. Examples of AI problems are computer vision (building a system that can understand images as well as a human) and natural language processing (building a system that can understand and speak a human language as well as a human). These may appear to be modular, but all attempts so far (1993) to solve them have foundered on the amount of context information and "intelligence" they seem to require.

This field is growing quickly and there are a number of projects we should be aware of.

The ACT Tutors being developed at Carnegie Mellon University

(**<http://sands.psy.cmu.edu/ACT/tutor/tutoring.html>**)

by the the Advanced Computer Tutoring Project group are mathematics and programming tutors able to accomplish the following:

Based on a computational theory of thought, our tutors can generate and follow the multiple possible solutions a student might attempt on any given problem and dynamically tailor instruction to each individual student and problem. Like a personal human tutor or coach, cognitive tutors observe student performance, identify strengths and weaknesses, and provide individualized, just-in-time instruction while students learn by doing.

The group of researchers working on this project

(**<http://sands.psy.cmu.edu/ACT/tutor/tutor-people.html>**) are making dramatic

claims about its effectiveness but ongoing research seems to be proving the validity of their

models. In fact these could easily be seen as early MC models. If you wish you can gain

access to demonstrations of these programs by linking to the following URL -

<http://sands.psy.cmu.edu/ACT/tutor/tutoring.html>.

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©IBM Corporation is probably best known for developing 'Deep Blue II', the computing system that defeated Kasparov in a chess match sponsored by the Association of Computing Machinery from February 10 -17, 1997. The sheer computing power put to task to accomplish this feat was impressive indeed. (see <http://www.ibm.com/Stretch/EOS/dbo.html>). Its architecture proves clearly that machines can be programmed to effectively select from a large array of options and outperform humans in strictly mathematical calculations. Much has yet to be done to see how these capabilities can be applied to the field of artificial intelligence. But one thing is certain. As we progress quickly into the next millenium new scales of computing architectures will be developed and existing massive parallel processing systems will be scaled down for use in personal desktop computing environments which will be essential in the development of more advanced MC models. Linking this power to a rich and diverse world of resources such as those available on the internet are opening up exciting possibilities that need to be researched much more extensively.

©IBM is also doing some amazing work in the area of 'Intelligent Agents'. The people at IBM understand the massive commercial potential for developing systems capable of 'learning' about the needs of their clients and responding accordingly. In developing their system they talk about "Agency, Intelligence and Mobility" and provide a structure upon which to base their designs. On their web site they talk about agents in these terms:

Delegation of function (1) is an important response to these trends, because through delegation the computer and the networks behind it can assume more of the work. For example, software can take on responsibility for information finding, retrieval and filtering, can personalize human-computer interaction, and can enable tasks to be carried out on behalf of users whether they are present or absent, and with guidance rather than direct control by the user. Intelligent Agents are software which implements this delegation, thus managing complexity, supporting user mobility, and lowering the entry skill level for new users. Intelligent agents can best be thought of as a design model (2) , much like client / server computing, rather than a technology or a product offering. Though integration of intelligent agents into applications or services requires a mindset change, this new model is expected to be one of the key computing paradigms over the next ten years (3).
<http://www.networking.ibm.com/iag/iagptc2>

As 'agents' expand into the networks their functions extend beyond the desktop computer out into the world. They become capable of dynamically addressing the needs of the learner even when the learner is absent or disconnected from the network. Upon reconnection the 'agent' springs into action, bringing to the learner information or carrying out more complex job tasks.

IBM© has several tools in development that deserve further investigation. Click on any of the following for further details. [**Alter Ego**] [**Activist**] [**Globenet, RAISE**] [**Knowledge Utility (KnU), Aquí**] [**IBM Neural Network Utility**] [**Lotus Notes**] [**OBJECT REXX**] [**Flow Mark**] [**Conversational Agents**]. The most significant aspect of this research and development is the desire to establish an open standards architecture or a "common object model" upon which intelligent agents can be developed. This will allow the utilization of 'agents' across computer platforms, networks and between applications all working together to solve the learner's problems. Although IBM has directed their R and D at commercial ventures there is considerable promise in adapting these technologies to a myriad of more specific educational learning environments.

Speech Synthesis and Speech Recognition

IBM© Corporations last tool, Conversational Agent, provides us with an example of how using computer-synthesized speech can make the learning experience within many different applications feel more natural. As natural language systems are developed and computer generated voices become more realistic a whole new field of research is opening up for Instructional Technologists. We could, for example, tie a program into a database capable of generating logical responses to typed requests by humans and then respond utilizing synthesized speech. As well, computer systems capable of speech recognition

could also respond to specific verbal requests from humans and provide responses accordingly. The idea of carrying on an intelligent conversation with a computer system may seem a little far fetched today but there are components of these systems being built which are bringing us much closer to just such a reality. **(Click here to download the Netscape Plug-in called Talker. Install it in your Netscape plug-ins folder and restart Netscape. Sorry, Macintosh Only.) (Then click here to listen to an interesting rendition of Angels We Have Heard On High.)**

Primary efforts in the field of speech synthesis and speech recognition have been applied to the physically disabled and the visually impaired and their benefits have clearly allowed these individuals to take a more active and fulfilling role in society. Where research seems to be breaking new ground is in the area of integration, not within a specific program running on a specific computer, but within computing environments (<http://www.research.microsoft.com/research/srg/>) and especially over the World Wide Web (http://www.commandcorp.com/incube_welcome.html).

The commercial potential of such technologies seems to be self-evident but more research is needed in the field of Metacognitive Cybernetics and how speech technologies can be integrated into such systems. We can again turn to Carnegie Mellon University to investigate their research initiatives. (<http://werner.ira.uka.de/>). The Janus Project provides a fascinating example of this type of research:

At the Interactive Systems Laboratories we are developing Spoken Language Translation Systems that translate spontaneously spoken utterance from one language into utterances (spoken or displayed) in another. Such systems are aiming to make human-to-human communication across language barriers easier. The JANUS system is at present specific to discourse domains of common interest. and supports spontaneously uttered human-to-human speech. In doing so, the system has to handle fragmentary, errorful and disfluent language and heavily coarticulated and noisy speech. Instead of literal translation it has to provide useful interpretation of a user's intent. (<http://werner.ira.uka.de/ISL.speech.janus.html>)

The challenge for instructional technologists is to discover the methods and techniques utilized in this research and see if it can be applied more universally to the models they are building. The ultimate goal is find the tools (or build them ourselves) so that such innovations can be applied in regular classrooms for the benefit of all our students.

The following are some web sites that deserve further investigation into this field of study:

Netscape Plugin for Macintosh -
<http://www.mvpsolutions.com/PlugInSite/Talker.html>
Apple's Plaintalk Technology - <http://www.speech.apple.com/ptk/>
Research Tools for Macintosh -
<http://www.cs.cmu.edu/~lenzo/mac/speech/research.html>
Apple's White Paper
on speech Technologies -
<http://www.speech.apple.com/dev/wpaper.html>
Speech Research Web Pages <http://mambo.ucsc.edu/psl/speech.html>
Microsoft Corporation
<http://www.research.microsoft.com/research/srg/>
Speech Typer
http://www.leonardo.net/kamprath/claireware/speech_typer.html

Modern Design Tools For Instructional Technologists

As implied in the previous section, one of the most challenging problems for Instructional Technologists is being able to incorporate new technological innovations into the learning materials (MC models) we design for our learners. I would like to elaborate on courseware authoring and perhaps see where they might take us as new innovations are seamlessly incorporated into their structures. (See the Multimedia Authoring Systems FAQ for more complete information - <http://www.tiac.net/users/jasiglar/MMASFAQ.HTML>)

There has been a great deal of research into the design of courseware authoring tools. One of the greatest problems identified to date is the way in which the vast majority of these systems remove the 'locus of control' from the learner. Traditional ID models

(Dyck & Carry; Leshin, Pollock & Reigeluth; et al) follow a rigid, structured approach that ensures the system (whether man or machine) maintains complete control of the learner - what they learn, how they learn it, how the system should evaluate this learning and so on. In terms of the practical application of these methods most courseware authoring tools have been structured physically to provide a framework which ties authors to just these constraints. And if authors want to go beyond these constraints they have to invest a great deal more time and effort for what appears to be little gain.

If we accept the view that learners construct their own realities and learn from them (**Constructivism**) then we may have to rethink the entire paradigmatic approach of courseware authoring systems. In describing courseware authoring tools Mayes states:

“While the problem solving approach of ITS does place the learner in an active, task-oriented, role it is also true that the locus of control stays with the system. Probably the best way for the learner to understand how to solve problems is to try teaching the elements of skill to other learners. This will not often be of great benefit to the recipients of the teaching but will serve to deepen the learner's own understanding to an extent rarely achieved through instruction. The learner will seek principles in order to achieve understanding, rather than acquiring 'mastery' in the solving of particular problems.” In describing the *StrathTutor* he goes on to state “Simply by changing roles - by placing the learner in the role of author - we realized that we had created a cognitive tool for learning.” (<http://www.icbl.hw.ac.uk/ctl/mayes/paper12.html>)

If such an approach could be designed into an advanced Metacognitive Cybernetic authoring system we could have learners attempting to ‘teach’ the system and the system could ‘learn’ from the student and adjust its lessons accordingly. Since these systems would be infinitely patient we wouldn’t be concerned with wasting other humans time. More time could then be spent concentrating on the learner’s own megacognitive strategies and modifying the MC authoring system accordingly.

Macromedia’s Authorware™ is one of the most powerful multimedia authoring tools available today, yet its structure is primarily rigid, linear and has no built-in tools to adapt or change its structure internally to the changing needs of the learner. But the tool is growing in its capabilities. The latest version (for a more complete description link to

<http://www-1.macromedia.com/software/authorware/features.html>). is capable of tying to powerful databases locally or on-line, integrating speech synthesis, linking to external applications and web sites automatically and much more. Unfortunately, the cost of these innovations has meant the tool is not one recommended for the beginning courseware author.

This state of affairs is, unfortunately, fairly widespread among most courseware authoring tools as those that are simple to use provide little more than 'slide-show' models and those that are complex become difficult or impossible to use by many Instructional Technologists. We can see some light at the end of the tunnel though. Mayes states, "Instead, we can think of a software environment which supports a wide range of activities for creating, editing, linking, capturing, storing, retrieving, structuring and otherwise actively manipulating information. Such an environment would provide generic support for the roles both of author and learner, and would very much favour a blurring of the distinction between them, as encouraged by a constructivist approach." (<http://www.icbl.hw.ac.uk/ctl/mayes/paper12.html>) One of the simplest and most comprehensive courseware authoring tools follows this approach rather nicely, I think. And that is the internet itself. It can be used independently by the learner to build or 'construct' a vast array of information to which that learner will hold a deep and personal interest. At this point in time it lacks an external evaluative component but few can argue its subjective value to each and every individual accessing it.

The Internet

The internet may very well be the closest attempt yet at creating a universally accessible vessel for the delivery of true Metacognitive Cybernetic models of learning. In these early days of the internet it still lacks powerful, intelligent search engines, 'Intelligent agents' or cybernetic learner profiling systems with logic mechanisms for assisting learners

and their learning needs. But the infrastructure is in place now to allow the internet to be the vehicle for the delivery of individualized, context-sensitive, rich and varied learning experiences to anyone who is connected. Much of the information delivery systems we are using now (books, magazines, journals, etc.) are being moved to the internet. It is becoming much more common to find students doing their reading, research, communicating, shopping or even watching TV on-line. What remains is to incorporate many of the innovations described previously into web sites and web browsers and to expand these tools with more powerful components.

One tool which may provide the means with which to build more powerful web tools is the programming language called JAVA. Michael O'Connell describes JAVA as "-- the environment that turns static Web pages into interactive, dynamic, animated documents bolstered by distributed, platform-independent applications --". (<http://www.sun.com/sunworldonline/swol-07-1995/swol-07-java.html>).

The Java programming language was originally developed as a tool for programming appliances - those that can be seen in futuristic type homes. Examples would include 'intelligent' thermostats that adjust the temperature automatically based on a set of preferences input by the user. Lighting systems that go on and off as you enter and leave a room, stoves and microwaves that respond to spoken commands and much, much more. The vast majority of software that I have seen developed using JAVA is clearly in its elementary stages and would not qualify as an MC model. This will certainly change as programmers and designers become more proficient with the tools but the most important aspect of JAVA is the fact that programs will be platform independent and network-centric, NOT computer-centric. And, because JAVA is not necessarily confined to use on a computer, we will see integration within a wide array of 'information appliances' and crossing boundaries such as television, transportation and many new forms of interactive communications.

In their article *Characteristics of Technology-Based Virtual Learning Communities*, Kowch and Schwier speak of the World Wide Web as a 'community' as lively and interactive as any college campus... "A virtual learning community employs technology to communicate; therefore, it can, and does, happen anywhere, and it can be constructed anywhere." (Kowch and Schwier, 1997) This is a powerful concept and brings with it some rather disconcerting possibilities in the minds of many teachers. Today any individual can go on-line to access almost any type of information and communicate with 'experts' in just about any field of learning. Are teachers going to be replaced by this technology? If you view teachers as deliverers of information and no more than I would agree that this kind of teacher is going to be replaced. But because learning is very much a 'social' process and we are all seekers of 'knowledge' , I feel we are going to need more 'teachers', not less - both the human and the Metacognitive Cybernetic variety.

Conclusions

As we approach the twenty-first century it is clear that innovative, instructional technologies are offering heretofore unimaginable possibilities in education. They are also causing a great deal of concern. "Quite simply, if you think that the world is troubled by chaos, multiple meanings, lack of direction, uncertainty, irony, and confusion then you have encountered the postmodern condition." Hlynka goes on to say "Finally, educational technologies, by conveying the sheer amounts of information available, inevitably stumble across and even showcase the ironic juxtaposition of ideas, concepts, facts and theories." (Hlynka, D., 1995)

What is the poor teacher to make of all this when they enter their traditional classrooms. Many have taken some initiatives and done their own personal kinds of research. This has resulted in the use of some new technologies (usually in areas which are non-threatening, non-pervasive and 'fit in' with existing teaching practices). Does this

mean that the adoption of new technologies is only going to happen when they fit seamlessly into the existing fabric of educational institutions? To some degree, we all must admit to this being the norm. But teachers today have access to an enormously rich and challenging theoretical foundation upon which to build the learning experiences of their students. Educational theories have been evolving over the last fifty years moving from behaviourism, to cognitivism, to constructivism and beyond. Most master teachers have adopted one theory or another into their instructional paradigms, often changing them to fit the realities of each learning situation. But one pattern seems to be emerging - that of a postmodern reality theory. If we believe that the learner constructs his or her own unique view of the world then teachers can and should utilize whatever tools are at their disposal to accommodate the 'reality' of that learning. This is an area of research that begs further investigation.

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I dreamed I was a thought that floated in the breeze, carried on the wind through time.

And when I settled inside this mind I melted into other thoughts and changed.

I grew within a swirling mass and could not see or feel my form

but still I changed and grew and I began to see this mind.

Other thoughts were joining in and we danced in wild refrain.

Each song we sung was melded in to thought in source divine.

As I grew what once was me was lost within this mind

and transformed became another thing

unique, inspired as by design

a new idea had been born.