OCTR: A Model of Learning Stages

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Abstract

This paper describes a model of learning stages called OCTR. Learning under OCTR advances gradually as the degree of social context increases. Furthermore, OCTR can also serve as a framework for describing the cognitive development and motivation of students, categorizing many existing teaching strategies, and better understanding how to introduce meta-cognition and attitude in systems for education.

1. INTRODUCTION

Our learning theories affect our design of computer systems for education, and the artifacts we make reflect our theories. For example, being influenced by the behaviorism psychology and realizing that computer can provide an interactive learning environment, many educators adopted the stimulus-response approach in the development of early Computer Aided Instruction systems (CAI). Sometimes, our theories are implicit in our design. For example, starting from the Seventies, Intelligent Tutoring Systems (ITS), which drew attention of many computer scientists and cognitive psychologists, are basically modeled after the idea of private tutoring. This model promises to pay better attention to individual student needs [Bloo 84]; therefore, a substantial amount of ITS research in the Eighties was devoted to the study of student modelling. However, since the mid of the Eighties, the tutor-tutee model has been challenged.

J. Self and his colleagues first argued that the role played by the computer as an authorized teacher for transmitting certified knowledge should be de-emphasized. They suggested that the computer can be treated as a collaborator (or a co-learner) [Self 85, GiSe 88, CuSe 90, DiSe 92]. Later on, as an alternative to one-on-one model, Chan and Baskin [ChBa 88, ChBa 90] proposed that the computer can be simulated as two coexisting agents, a teacher and a learning companion. The addition of the learning companion to the traditional ITS model yields collaboration as well as competition. More recently, an inverted ITS model which treats the computer as a student and the human learner as a teacher was suggested by Pathepu, Greer, and McCalla (1991). In summary, whether it is a collaborative system such as People Power [DiSe 92], a learning companion system (LCS) such as Integration-Kid [Chan 91], or a learning by teaching system, the scenario suggests: (i) computer should personify learning activities explicitly; in particular, we can model an *artificial* learner in a system (by simulation or machine learning); (ii) human students make cognitive gains by collaboration, competition, or teaching the artificial learner; and (iii) the computer can model multiple agents with different roles, like LCS, forming a small society in learning.

The last implication is to recover the social context that has been lost in most computer-based learning environments. Despite the existence of an artificial learner in the system, this line of research coincides with the current interest of distant learning or computer supported collaborative learning via computer network. Moreover, the advancement of multimedium platforms provides powerful devices to support complicated peer dialogue, gestures or facial expressions, and so on, and makes complex social learning systems more viable than before. But when we began to design a social learning system, LISA [1] (Learning IS Active), that intends to cover the whole repertoire of the student's learning process, we soon discovered that there are occasions when one-on-one tutoring is

[1] LISA is an inter-university project sponsored partially by National Science Council and Ministry of Education of Taiwan. LISA intends to teach a set of small pedagogical languages for freshmen [ChWa 91]. Currently there are four computer scientists, three educators, two psychologists, and twelve graduate students are involved in the project. The vision of the project is described in [Chan 93].

more effective. Thus, the need of a model of learning that incorporates both tutoring and social learning to facilitate system design becomes apparent.

Apprenticeship learning [CoBN 89, Coll 91] which influences the design of many learning systems resembles the skill acquisition process of an apprentice from a master. It consists of a set of teaching methods: (i) *modeling*, where the student observes how the teacher carries out a task repeatedly; (ii) *scaffolding*, where the student is given a support to carry out a task and the support is removed gradually when the student is being able to perform the task; (iii) *coaching*, where the teacher involves a whole range of activities: choosing tasks, modelling, providing hints and scaffolding, challenging and offering encouragement, etc.; (iv) *articulation*, where the teachers have a variety of methods for getting students to articulate their ideas and thinking process and; (v)*reflection*, where the student observes his own learning process and makes comparisons with others. While the master-apprentice model of learning does not seem to fit well into the paradigm of sociology of learning, the OCTR model introduced in this paper can be viewed as an extension of the apprenticeship learning model with a richer social context, mimicking the intensive knowledge communication nature of the modern society. Our study differs from other studies of learning (such as the three modes of learning by Rumelhart and Norman [RuNo 78]) in its emphasis on learning stages and articulation of a number of learning perspectives.

2. OCTR: A STAGED LEARNING MODEL

The OCTR model views learning as a staged process. In these stages, learning objectives are defined and social context is incrementally embedded in the learning activities. The model is composed of four stages:

Orientation: in this first stage, the system helps the students relate their prior knowledge of the domain to learn;

Coaching: this second stage is the same coaching activities in apprenticeship learning;

Tuning: in this third stage, knowledge tuning is exercised via peer interactions and the teacher plays a less active role; and

Routinization: in this last stage, students solidify their knowledge by keeping on practicing, perhaps under some forms of peer pressure.

In the rest of this section, we shall discuss how OCTR can serve as a framework for studying a number of perspectives involved in learning, and a summary of this is given in Table 1.

Cognitive Development

The foremost goal of OCTR is to try to describe the cognitive process of learning. Seldom it exists a piece of completely isolated knowledge; or else it could hardly be learnt. As Piaget pointed out [Piag 67], a student is an active agent who seeks an equilibrium between what he/she understands and what he/she experiences in the environment. Thus, in the orientation stage, the objective is to bridge what the student knows and what he/she shall learn by reviving the student's prior knowledge of the subject to the target task. The related old knowledge can be used as the theory for the student to interpret the new knowledge.

In the coaching stage, the system helps the student establish an initial mastery skill, and the concern here is the knowledge accretion. Scaffolding and fading are essentially the system's control over the student's intellectual functioning: fading is the student's internal disequilibrium cause and scaffolding is the support for reaching an equilibrium state. The process fosters cognitive development.

After the coaching stage, the student should have acquired the initial skill and reached to a state of equilibrium again. Once the equilibrium state is reached, what will upset the equilibrium in order for the student to achieve higher levels of intellectual development? There are two ways: (i) by sequencing learning tasks with increasing complexity and diversity so that misconception or mistakes can be revealed; and (ii) by placing the student in a social learning setting where "cognitive conflict" in the form of different ideas, views, and opinions issued by peers will force the student to examine his/her thinking and look for alternative perspectives. The first way forces the student to apply what has learned to multiple contexts. The second way provides an environment where meaning can be negotiated from multiple perspectives. In both ways, students modify their cognitive structure and the environment to their own ends, resulting better articulated knowledge and developing abstraction of acquired knowledge. This is the tuning stage.

Several points of social learning worth noting here. First, due to hastiness and first encounter in the coaching stage, many overlooked details may be recovered in the tuning stage by shifting the most compelling elements in the stimulus from the coaching stage. This "decentration" [Piag 67] helps what are used to be the secondary aspects be incorporated into the modified and more accurate total perception. Second, collaborative learning is a form of scaffolding since it is the distribution of thinking loading. The product of social interactions such as comparing, evaluating, justifying, and criticizing has become part of the students' individual knowledge. Finally, peers' different perspectives of the subject can be considered as various versions of the student's own knowledge and are thus another form of reflection in apprenticeship learning. In short, as argued by Vygosky [Vygo 78], cognitive development process in such an environment is the gradual internalization and personalization of what was originally a social activity.

If tuning is aimed at making the target knowledge a robust part of the student's knowledge, then routinization or automatization through continuous practicing helps the student establish ownership and retention of that knowledge. Routinization empowers the students by freeing their minds to be more thoughtful about other things [Coll 92].

Qualitative Explanation

We offer a simple qualitative model that explains cognitive development in the OCTR model. The model stems from constructism view [BCDP 91; Jona 92] which holds that there is a real world we experience. Learners create personal interpretation of the world based upon their past experience and their interactions with the world. Learning is a constructive process of building up internal representation of knowledge. This representation is open to change constantly and its structure and linkages form the basis of new knowledge development and other knowledge attachment. The emphasis of constructism is on how we *construct* knowledge, rather than the studying of the object of our knowledge.

First, we assume that knowledge consists of *units* and *links* (Figure 1). Units are pieces of knowledge and links connect these units. There are strong and weak units (represented by solid and hollow dots respectively) and so are the links (represented by solid and dashed lines respectively). A strong unit represents a piece of fully fledged knowledge[2] and a strong link represents a strong relationship between two units of knowledge. Units can be created. If a unit has no link connected, then it can be regarded as deleted. Also, links can be created, deleted, strengthened, or weakened.

In the orientation stage, proper old knowledge is invoked to interpret newly created knowledge; that is, new but weak units are created with weak links connected to prior knowledge units in a similar structure of the prior knowledge. In the coaching stage, knowledge is expanded; that is, many weak units and links are created. Meanwhile, existing units and links are strengthened. In the tuning stage, knowledge restructuring is the main concern; that is, many links are needed to be strengthened, weakened, and even deleted so that units created in the first two stages are better structured and more strongly related to prior knowledge. Finally, in the routinization stage, both units and links are strengthened to ensure its accessibility or usability in the future. Note that when multiple nodes and links are submerged to form a strong node, we are referring this node-link model as a recursive model where abstraction can be described as the formation of strong nodes. Also, we have not considered motivation in this qualitative model, but we can regard it as a factor that affects the rate of acquiring the knowledge in all of these stages.

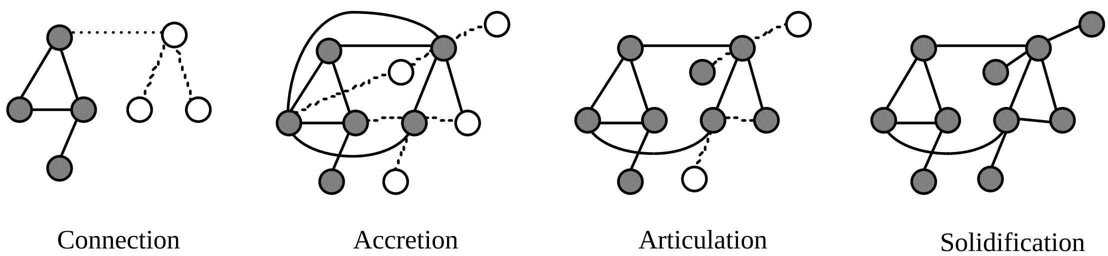

Figure 1 A Qualitative Representation of OCTR

Viewing learning as different stages of constructing knowledge may play a role in interpreting situated learning [BrCD 88]. Situated learning speaks of domain dependent learning in a rich context, practical knowledge, authentic activities in realistic settings, etc. In the first two stages of OCTR, situated learning's stress help knowledge construction 'anchored' [Cogn 90] at the proper 'site'. However, just on the contrary, the last two stages of OCTR should assume domain dependent learning, abstract and theoretical knowledge by self-explanation or teaching by the learner, decontextualization [Merr 91] by justifying knowledge via multiple perspectives given by peers, repetitively use of knowledge in multiple contexts, etc. It is this process that enables the student's knowledge

[2] We can also regard a strong unit as a cluster of well connected units.

to be 'transferable' from site to site. Contextualization and decontextualization applied at proper learning stages are both essential in preventing acquiring 'inert' knowledge --- encapsulated knowledge that rarely accessed or used again in the future [Whit 16].

Motivation

Motivation is a factor that determines whether the students *will* do, not just whether they *can* do. The general goal of motivation is to design learning environments engaging enough so that the students are able to learn without feeling that they are making effort to learn, and students can learn even better if the system can trigger their achievement-striving behavior. In the orientation stage, the motivational aspect is to draw the students' attention and to promote their initial interest in the subject, and to revive them as curious, reaching-out, and experimenting individuals. Also, an atmosphere of readiness such as focusing attention and developing expectation can be acquired at this stage, like a prelude that helps the audiences prepare their minds to better enjoy a piece of music. To foster intrinsic motivation of the subject in this stage, self-paced activities such as exploration or discovery games can be used, because the students can actively produce effects on the environments [Wood 18]. Also, helping the students understand the importance and significance of the material and how it relates to real life may create a sense of excitement.

In coaching, the goal is to nurture the student's intrinsic motivation of the subject. Intrinsic motivation, to some researchers, is the need to encounter a moderate difference between the student's experience and his/her environment [Berl 78], while others [Wood 18] see it as the need to feel competent; that is, the ability to deal effectively with the surroundings. To this end, it is important to sustain a moderate risk of the learning task while it could still be within the capacity of the student.

In the tuning stage, social learning protocols such as peer collaboration and discussion can be adopted. During collaboration, the success of solving a problem is considered as the success of each participated student and is thus a sharing of achievement. Also, it contributes to students' self-confidence for it relieves insecurity when students see others to struggle and realize that difficulties are not unique to them. Although it is still not clear what role motivation can play in social learning settings, the existence of a peer in learning may constantly stimulate the moderate difference which in turn arouses the student's innate need of competence [Ch+ 92].

In the routinization stage, learning tasks are not so challenging as before. Incentive is needed. Applying extrinsic motivation such as external rewards is one way. Another way is by means of competition that forces the students to evaluate their ability relative to their peers' in the social comparison process while at the same time provoking them to drive for survival --- a phenomenon of the Darwinian's "survival of the fittest." Higher competence information leads to higher intrinsic motivation while lower competence information results in lower intrinsic motivation. A recent informal evaluation of the Distributed West system shows that there are three times more students prefer learning under human competition to collaboration [ChCH 92]. This shows that competition is a powerful motivator. Finally, the relative perception of the student, which determines his/her motivational state, has to be modeled for guiding the system.

Quantitative Explanation

If knowledge can be constructed, then it must exist in some quantity that is measurable. For this reason, we propose a quantitative model of OCTR that embodies both cognitive and motivational perspectives. *Learning load* (LL) defined by the formula below is a simple relationship of cognition and motivation. Although the formula is not ready to be actually operationally measured, it helps explain an individual's learning ability in the stages of coaching, tuning, and routinization.

$$\text{Learning Load} = \frac{(\Delta D\text{-}S)}{D*M} + M_p$$

Here D stands for the background domain knowledge or experience, S for the scaffolding offered by the system, M for the motivation of the student, Mp for the peer pressure that is regarded as a part of motivation, and ΔD is the knowledge increment. Suppose that the maximum of the learning load that can be attained by an individual is a constant, then the overall objective of the system is, at any time, to maintain the detected LL as close to the student's maximum as possible, but not larger than the maximum (which means that the student cannot handle the task).

In all stages, we would like to keep the student highly motivated; that is, M is intended to be as large as possible. At the beginning, that is, during the orientation stage, we try to increase D by relating or activating as much as possible the student's prior experience. This strategy agrees with Kolodner's observation [Kolo 83] that a domain expert learns faster than a novice does. Thus, one can learn more effectively if one has a stronger experience. Note that, from the formula, if D and M are large, ΔD can be considerably increased. Thus, orientation is to enhance LL or to prepare for the next three stages.

The purpose of coaching is to let students learn to tackle a complete task. However, according to Martin's law [Wins 92], one cannot learn anything unless one almost knows it already. This means that coaching has to be in small steps. However, if the steps are too small, we hardly teach any thing new. The problem is how to maintain ΔD, the knowledge increment, at a level where the student can learn without degenerating intrinsic motivation from the task. However, at the beginning of that stage, ΔD is too large for the student to handle a complete task alone; thus, an appropriate amount of scaffolding, S, should be exerted to reduce LL. Note that, modelling where S is very close to ΔD, can be regarded as the extreme case of scaffolding. Also, fading begins as coaching proceeds, which means that S decreases.

Next, in the tuning stage, strengthening the integration of new knowledge with prior experience is the concern. There are two aspects here. First, peer collaboration (task sharing) can be regarded as a form of scaffolding, S, especially when the learning tasks are getting complex during that stage. Second, through peer discussion, ΔD in the form of cognitive conflicts is generated. This ΔD is a part of the personal domain knowledge D regarded 'biased' in the social community [SaSW 93]. Through reconciliation, ΔD vanishes and is absorbed into D, and the process repeats when other issues arise. Note that, ΔD is no longer as large as that in the coaching stage; yet, each student has to think and contribute a piece of the discourse. This mutual responsibility and expectation yield certain amount of peer pressure. That is, when the first term of LL lessens, the second term, M_p, emerges.

In the routinization stage where the emphasis is to solidify the learned knowledge, both ΔD and S have declined; that is, the first term of LL vanishes. To maintain the momentum of learning, M_p, emanates to become a dominant term. In other word, students are engaged in a competitive environment where their innate impulse for survival drives them to face the challenge.

Teaching Strategies

The stages of OCTR bring together most of useful teaching strategies, placing them in a learning repertoire with increasing social elements. It begins from teacher-controlled description or self-paced exploratory learning, and advances to one-on-one coaching, and then to complex social learning settings.

For orientation, we may carefully choose examples in real life or use metaphors to bridge the gap of a new concept and the prior knowledge. Similarly, we can organize the material in a story form to invoke the students' experience and enable them to grasp the concept initially with an analogical model. Perhaps the most preferred way in this stage is discovery learning in which the students explore and gain experience on their own in a simulation game or microworld.

For coaching, it personalizes the interaction first by modelling, then by scaffolding and fading alternatively. In a computer-based learning environment, scaffolding can be in the form of specially designed devices, depending on the particular material to learn or the help or hints offered by the system.

Reflection, a part of apprenticeship learning, is a form of tuning by replaying and reviewing the student's learning process and achievement. Another form of tuning is through social interaction where social context can be structured by various protocols in a board spectrum with possible varieties on the number and the identities of the agents [ChBa 90]. Each of these varieties gives rise to particular cognitive issues in the student's learning. Finally, retrospection, rather than reflection, in the form of abstract reformulation of what has learned should also be taken in this stage.

Apart from external reward, a method for routinization is to design a problem solving game in which the acquired knowledge is a part of the means to solve the problem, such as the classical West program [BuBr 79]. We may also assign ranks to the student's ability or use a score board to record the achievement of different students as an explicit way for the student to compare with others. An intensive competitive method is to apply real time social pressure in a distributed learning environment such as the Distributed West system [Ch+ 92]. In such environments, group-to-group is preferable to one-to-one since success and failure can be shared, instead of having an individual to take the full responsibility.

Meta-Cognition

Due to the rapid progress of new technologies, what we learn today will inevitably become obsolete someday in the future. Learning "how to learn" in preparing for future job training is thus becoming more important than ever. Within the framework of OCTR, meta- and self-knowledge can be learned in the last three stages. In the coaching stage, meta-knowledge such as strategic, control, and heuristic knowledge can be made explicit by the coach in modeling. Learning strategies such as those discussed above and learning stages of OCTR can all be introduced by the coach as part of the student's learning experience. Learning self-knowledge seems to be best realized in the tuning stage where the student can see how peers deal with the same problem and compare different ways of doing things. This allows the students to develop new ways of seeing and talking about what they do [Coll 92]. An interesting protocol at tuning is reciprocal teaching [PaBr 84] where an implicit cognitive task is partitioned into several explicit sub-tasks taken by different students who take turns to undertake each of these sub-tasks. It is an effective form of peer discussion protocol. Learning by teaching that encourages self explanation can be utilized at this stage too. Finally, for routinization, Sophie game protocol [BrBD 82] may be adopted where one student is working on one computer while his/her activity is monitored by another student, probably via another computer.

Attitude

There is an old Chinese adage stating that the Five Educational Objectives are *Morals*, *Knowledge*, *Athletics*, *Sociability*, and *Art*. Among them, knowledge is getting so important that schools function just as factories to produce massive graduates equipped with needed knowledge to meet the demand of the society. One characteristic of the apprenticeship learning used in the old days is that the student can learn things like personality, temperament, disciplines, etc., directly from his/her master. A mission of future intelligent learning systems perhaps is to embody morals, sociability, attitude, etc. However, this mission is controversial because these elements are beyond our domain knowledge. This is analogous to the well-known debate happened a thousand years ago in China at Tung Dynasty whether literary work is for the sake of morals or just for literature itself. It is also potentially difficult to implement for it is not easy to identify which are the right or wrong in morals, sociability, etc., to be taught, and these elements are on the brim and can only be touched at opportune moments while learning the domain knowledge.

In the orientation stage, the system helps the student set up goal and expectation, so that learning is a clearly defined task to achieve something. In the coaching stage, the coach is talking around the student and may encourage the student to try more difficult problems without being afraid of failing. Besides, the coach's valuable learning experience, enthusiasm, vigour, etc., can also be passed on to the students. In the tuning stage, collaboration helps the student develop attitude to be more open, and willing to seek out help and input from others also helps students learn to share success and failure with others. In addition, by observing peers at work, the student will learn that making errors is a natural phenomenon in learning. In the last stage, routinization, some students may be inhibited or discouraged rather than motivated by competitive situations if they believe that making errors makes them "dumb" [CoBN 89]. Thus, the value of effort, not the product or ability, should be emphasized [Ande 92]. The society is indeed filled with competition and collaboration, and the students have to learn to face them.

Students' attitude is the outcome of their internal beliefs. Apart from the didactic instruction discussed above, it is important to represent and detect student's wrong beliefs (such as making mistakes makes one dump) in the system.

	Orientation	**Coaching**	**Tuning**	**Routinization**
Cognitive Development	prior knowledge connection	knowledge growth	knowledge articulation	knowledge solidification
Motivation	attention, curiosity, excitement	competence, moderate risk	sharing success, self confidence	drive for survival, challenge, competence, external reward
Teaching Strategies	metaphors, story telling, etc.	modeling, scaffolding, fading	reflection, peer collaboration, retrospection, learning by teaching	assigning rank, competition game, etc.
Meta-cognition	none	learning strategies, learning stages, meta-knowledge (strategic, control, heuristic), etc.	self knowledge (by teaching peers or self explanation)	self-knowledge (by monitoring peer working)
Attitude	goal , task, expectation, responsibility, etc.	enthusiasm, disposition, etc.	open, seek help & input from others, sharing success and failure, accepting making errors, etc.	effort

Table 1 Summary of OCTR

3. SYSTEM DESIGN WITH OCTR

There is a firm link between a model of learning and the prescriptions for practical system design. We may show that by highlighting the OCTR-Tree architecture that we are building for LISA project. OCTR adopts the assumption of Curriculum-Tree knowledge-based architecture [Chan 92a] where the domain knowledge structure is isomorphic to the learning goal hierarchy.

In this curriculum hierarchy, each node can possess a cluster of episodes. An episode is a small unit of learning activity, usually having a beginning and an end. Based on different stages of the OCTR model, these episodes are classified into O, C, T, and R. There is no strict distinction among different stages of OCTR and the distribution of the episodes in the tree is iteratively spiral (Figure 2).

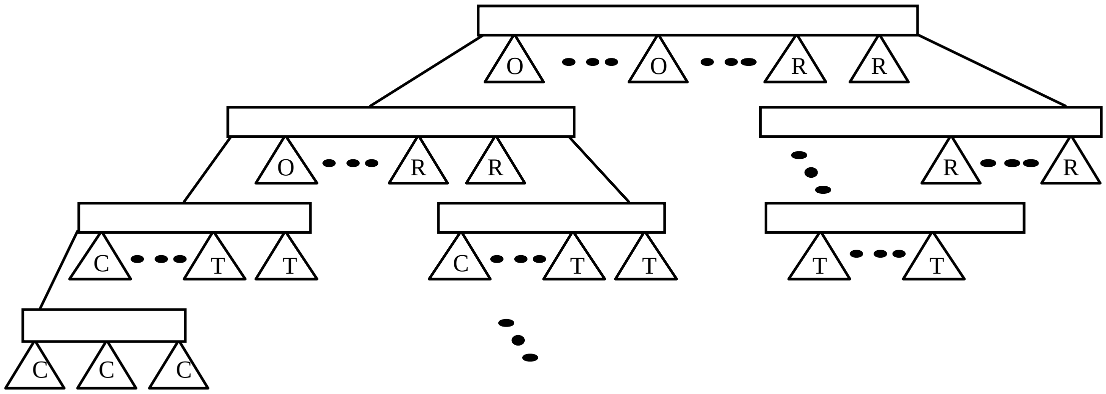

Figure 2 OCTR-Tree Architecture

4. DISCUSSION

We have shown that OCTR is a common thread of more specific learning theories such as motivational considerations, situated learning, and social learning, and it makes them easier to present, analyze, and contrast. In addition, OCTR can be used to compare some phenomena. For example, from the functional point of view, traditional CAI systems seem to focus on orientation and routinization and ITS research more concentrates on coaching. This is the case for ITS partly because there are more intriguing AI issues such as student modelling in the coaching stage than orientation and routinization stages. Social learning, on the other hand, may contribute to tuning and routinization. Thus, if all stages are equivalently significant in learning, then OCTR unifies the different addresses of these communities.

OCTR can also serve as a framework to compare different educational practices in the East and the West. In the competitive educational systems developed in some Asian countries, the survival for public examinations is the main objective of almost all students, the emphasis is mainly on modeling (the first part of coaching) and routinization, and leaving other parts of coaching and tuning unattained. However, many Asian families employ private tutors for their children. In the West, orientation and tuning seem to be key parts of the classroom teaching. While orientation and tuning encourage independent thinking and innovative ideas, inadequate emphasis on routinization will result in the decline of the students' performance in examinations. This difference in educational philosophies partly reflects the cultural difference between the West and the East.

There seems to have two ways to embed intelligence in a system for education. One is to facilitate system designers to build systems that can take into account of our learning theories in a general architecture, such as the OCTR-Tree. The other is to ensure individualization by student modelling. Constructism considers learning a construction process of personal interpretation of the world. This implies that the content of cognitive structure is unique to individual student; hence assumes infinity and, therefore, does not favor strong student modelling unless experience of all students can be modelled or constrained. However, we feel that there is at least a need of weak student modelling to detect and bring individual student's 'biased' knowledge back to within the boundary accepted by the larger community. Furthermore, the horizon of student modelling research should be broadened: student modelling = cognition + motivation + meta-cognition + attitude, like our discussion of the OCTR model above. For motivation, there is some initial attempt [Sold 92]; for social learning, even though there are a number of prototypes, many problems remain; for meta-cognition, some discussion can be found in the literature but few systems are implemented; and for attitude, not even much discussion available in literature. Therefore, this extended notion of student modeling is undoubtedly more challenging.

Perhaps, from the system design's point of view, the most important contribution of OCTR is that it offers a *learning completeness*. By this we mean that a model of learning that subsumes all the learning sub-processes of the student; and shows how learning be taking place in a clear and objective indication, both microscopically and macroscopically. Moreover, this learning completeness underlies *learning soundness*. By this we mean during the design process, the model facilitates identification of goals and justification of teaching strategies in developing an approach toward the goals. Of course, whether OCTR model can accurately and sufficiently describe the stages of human learning and be a 'useful' framework for designing effective learning environments remain to be tested. Nevertheless, we feel that this direction of research is a pressing need, and we hope that our work will initiate more study in this direction in the future.

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