An IT-based Strategy For Design Education: Knowledge Engineering

Manolya Kavakli

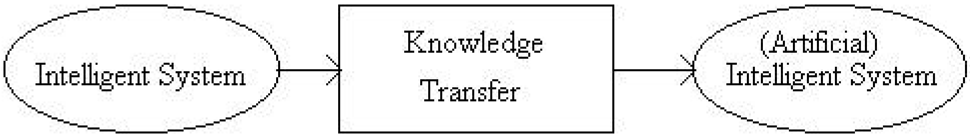
Faculty of Architecture
Istanbul Technical University
Taskisla, Taksim, 80191, Istanbul, Turkey
e-mail: kavakli@sariyer.cc.itu.edu.tr

University education is considered to be a "knowledge industry" in a knowledge society. In this paper we describe education as the knowledge transfer from one intelligent system to another, and draw upon the experience in Artificial Intelligence in order to apply it as an active knowledge acquisition strategy for the use of Human Intelligence. In current educational strategies, too often students are treated as passive recipients of knowledge unlike their counterparts (knowledge engineers) in Artificial Intelligence. In design education, we should be concerned with providing students the ability to extract the acquired knowledge from their teachers. In this paper, we put six hypotheses and prove each of them by discussing the methodology of Knowledge Acquisition to improve the process of design education. For an active learning strategy in Knowledge Acquisition, we turn to the wealth of experience made in Knowledge Engineering. In our analogy, we consider students to be Knowledge Engineers, designers to be Knowledge Based Systems, teachers to be the domain experts, and the learning process to equal the Knowledge Acquisition process in Expert System development. Thus, we suggest the use of Knowledge Engineering methods in the acquisition of design knowledge to build a knowledge base. A well-defined knowledge base represented in a Knowledge Based System can serve as a reasoning mechanism for the design actions that are unteachable in characteristics.

Introduction

The goal of education is to enable students to cope with the challenges of professional life as individuals and as members of the society. Life in a rapidly changing knowledge society (Drucker 1993) requires concurrent teaching and learning strategies. In a knowledge society, knowledge is dynamic and rapidly goes out of date, leaving people behind who know that they do not know. Glanville (1996) claims that "in order to learn, the learner must not already know. Apart from the obvious condition of ignorance, the implication is that the learner not only does not know, but knows that he does not know; then he can do something about it, including gaining the motivation to learn." With this motivation, learning continues forever. This might suggest to keep the learner's motivation in the peak, knowledge should not be given directly to the students, but then, what should be given in design education?

Education is the system of training and instruction designed to give knowledge and develop skills. In a knowledge society, university education, is considered more of a knowledge industry that aims at transferring both knowledge and abilities to students. We attempt to describe education as the knowledge transfer from an intelligent system into another system having some sort of intelligence. From this point of view, we could claim that both education and Artificial Intelligence (AI) intersect at the context of Knowledge Transfer demand. There is no matter what kind of intelligence needs it (either human or artificial intelligence). They both demand Knowledge Transfer from an intelligent system.



Transmitter Hardware Receiver
Figure 1. Education system

There are three components of an education system: Transmitter, Receiver, and Hardware system. While Transmitter is in charge of teaching and Receiver of learning, Hardware is the responsible of the Knowledge Transfer between these two. In the current education system, the success of teachers at reliably passing down the design knowledge depends largely on their pedagogic talents as well as their motivation. Teachers therefore control on the flow of knowledge as active transmitter of the education process. Students, however, must assume the passive role in receiving knowledge even though their education inevitably affects their professional lives. To balance the roles of transmitter and receiver, students become more active receivers and control the amount and quality of the knowledge transferred to them in their education.

In this paper, we aim at discussing how the best hardware system of Knowledge Transfer, that balances the knowledge transmission between the transmitter and the receiver, can be achieved in design education by adopting strategies from AI. The main focus of AI is Knowledge Transfer from an intelligent system into a machine. Since 1950, AI scientists have been working on to find an answer to the question of the English logician A.M. Turing, "Can machines think?" This question, stemmed from the 17th century with Pascal and Leibnitz, raised general-purpose AI applications in 1960s. The complexity of the human mental processes directed AI researchers to concentrate on narrower fields that are still the focus of the current work, and the first Expert Systems appeared in 1970s. Expert Systems attempt to emulate relatively simple areas of the experts' reasoning. In spite of all the restrictions, they are still regarded as one of the most important paradigms for solving complex tasks in design process, because they are successful "...where the knowledge is encoded into computer as declarations in the form of clauses, rules, objects or frames" (Wiig 1990). The objective of this paper is to investigate the success of the artificial definition of human intelligence and to discuss how it can be applied to grow new designers and used to build a good knowledge base for design education.

Considering the success of Knowledge Engineering in building Knowledge Based Systems, it is consequently desirable that a new learning strategy is devised which accepts students as knowledge engineers building themselves (Kavakli 1996, Kavakli & Schindler 1996). In such a strategy, the teacher provides guidance to students in their strategies of eliciting the knowledge which is most beneficial to them, placing them in the active role of the knowledge transfer. In this way, students become knowledge engineers, building knowledge bases corresponding to their own capacity, background, demands, and style. This might be a contemporary version of the well-known educational strategy "learning byself".

Hypothesis I: Education => Knowledge Acquisition Process.

Knowledge Acquisition is an approach developed for building Knowledge Based Systems in various fields. As explained by Hayes-Roth et al. (1986), the traditional meaning of knowledge acquisition is "incremental addition of knowledge to an intelligent system." Knowledge Acquisition is a process that involves eliciting, analyzing, and interpreting the knowledge used by human expert when solving a particular problem and transforming knowledge into a suitable (machine) representation. With these contents, Knowledge Acquisition has similar characteristics to the design education.

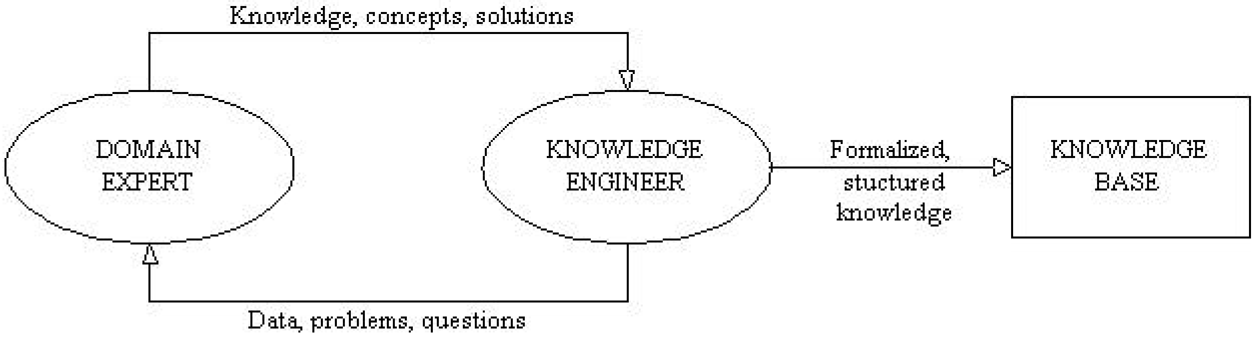


Figure 2. Knowledge Acquisition Process (Waterman 1986)

In a Knowledge Acquisition process, as in design education, knowledge engineer defines a set of problems and interviews the domain expert on how to solve them. The domain expert explains concepts, solutions, and knowledge in the interviews. Knowledge is then formalized and structured by the Knowledge Engineer to construct a knowledge base of a Knowledge Based System. The domain expert then extends and tests the Knowledge Based System, which can be further refined by the knowledge engineer in drawing upon other knowledge sources. This is an evolving process. A Knowledge Based System is never really complete and is built incrementally. We suppose the same would be the case of the design education, beyond the formal education.

Knowledge Acquisition is an empirical approach developed by the methods of Cognitive Science. The difference between the knowledge representation model and the mental model of an expert is decisive for the quality of the knowledge acquisition and consequently for the Knowledge Based System itself. This is also a representative of the quality of design education. Knowledge Acquisition can be accepted as an empirical investigation tool for design research, in the exploration of design methods of experts (designers).

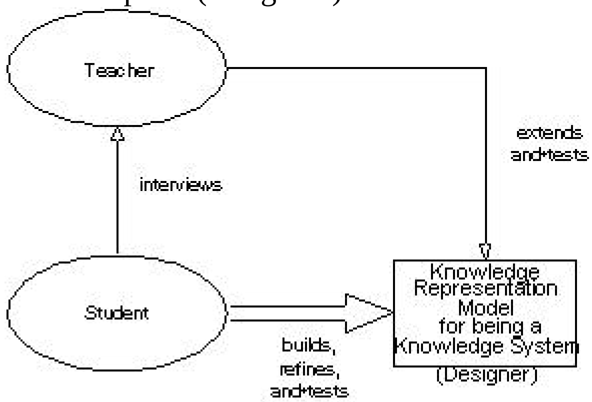


Figure 3. The roles in Knowledge Acquisition for AI and HI

In this paper, we explore the realizations brought on by years of practical experience in knowledge acquisition which can be useful towards design education. Adopting the descriptions from the Knowledge Acquisition process, we investigate the corresponding roles of Transmitter and Receiver that we initially defined as the components of an education system. Transmitter corresponds to the expert and Receiver to the Knowledge Engineer. On the basis of this assumption, we can presuppose that education is equal to the Knowledge Acquisition process in a Knowledge Based System development. In this analogy, we consider teachers to be the domain experts or Expert Systems, designers to be Knowledge Based Systems, and students to be Knowledge Engineers. We prove our hypothesis, illustrating the similarity of these roles in the following parts:

Hypothesis II: Experts Systems=> Teachers

The distinctive property of Expert Systems is to lead to knowledge processing, instead of data processing. The claim of Expert Systems is to provide with a new language and a new methodology for automating knowledge-intensive processes. Thus it opens a door to a new stage of information technology development. Unlike human experts, Expert Systems are claimed to be the first information processing systems being able to explain their line of reasoning (Schefe 1988), because they encode factual & heuristic knowledge as well as reasoning methods in a computer program in a structured form. The overall goal of Expert Systems is the reproduction of human expertise on a computer program. This reproduction is executed by means of inferences from a knowledge base. We believe that if human experts (teachers in our hypothesis) could explain their line of reasoning in a similar way to the Expert Systems, they would play more active role in knowledge transfer in design education. This requires them to have systemic knowledge of the domain. This means they have to be Knowledge Based Systems, before they become Expert Systems.

Hypothesis III: Knowledge Based Systems => Designers

Knowledge Based Systems is a term that is used, from some as a synonym for Expert Systems, from others as a term of classification. The term Expert Systems is generally reserved for systems that truly rival human experts and the term Knowledge Based Systems is used when speaking of small systems developed by means of AI techniques. Hillenkamp (1989) characterizes content and context of Expert Systems as "Knowledge Based Systems for knowledge workers in a knowledge-oriented industry." Regarding teachers as Expert Systems and designers as Knowledge Based Systems, we can refer to this definition: "Teachers are the designers for students in a university." This is true, because some Knowledge Based Systems are implemented as Expert Systems as some designers are regarded as experts. Expert Systems apply their knowledge to difficult, real world problems in professional practice, like other Knowledge Based Systems, but their knowledge is the expertise unlike the others.

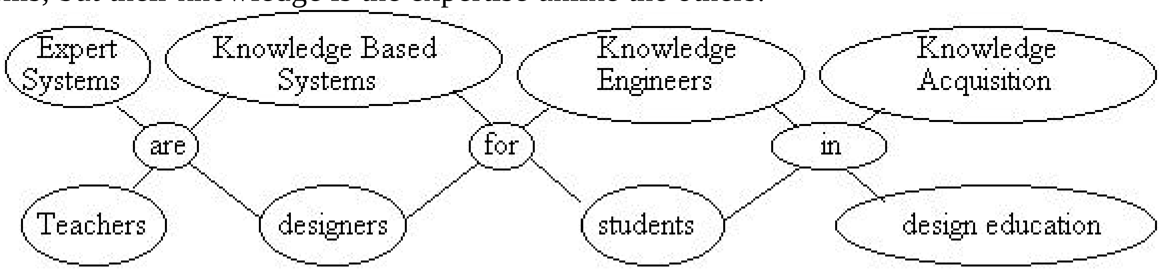


Figure 4. Similarity between Knowledge Acquisition and Learning Process

Hypothesis IV: Design Knowledge => Expertise

Expertise is the knowledge that is acquired over many years of experience (Rosenman et al. 1987). It is reasonable to suppose, therefore, that experts are the ones to ask when knowledge engineers wish to represent the expertise that makes their behaviour possible. Because experts are able to provide an answer to a very particular type of questions (Kornwachs & Bullinger 1989), and because of training and experience, are able to do things the rest of others cannot (Johnson 1983). However, they are not always successful in explaining their reasoning mechanisms. Cognitive Science explores the communication bottleneck in this field.

If we assume a designer as a KBS, its knowledge refers to the knowledge of the designer. As a design progresses, designers not only increase their store of information in the form of facts, but also appear to change the way information is organized. When a system learns it undergoes structural change. The system itself is seen as dynamic. Learning may also bring about changes in the control of a system. "The acquisition of any kind of information may be seen as a form of learning... There are two major sources for design knowledge. A system can learn from its own activities and also from the activities of other systems... The body of existing designs constitutes the knowledge base, and we reason with these designs anologically" (Coyne et al. 1990).

Design knowledge includes the reasoning with mental images formed in designer's mind. These images must be represented in some way using a kind of "transformation tool" such as speaking, sketching, modeling. Design can be regarded as the matching of the mental images to the represented images using some sign systems. The mental images reflect the domain knowledge of designer along with reasoning mechanisms of this design knowledge, which directly corresponds to the properties of Knowledge Based Systems. A successful transformation process requires the knowledge of a sign system, however. Computer Aided Design (CAD) systems have become an essential transformation tool for design and consequently play a key role in any designer's curriculum. Whereas current CAD systems restrict designers to the certain design methods they support, newer computer technology will increasingly be necessary for the creative aspects of designing. Nevertheless, the methods supported by any CAD system will always be limited to some extent and may never be necessarily representative of the design process itself.

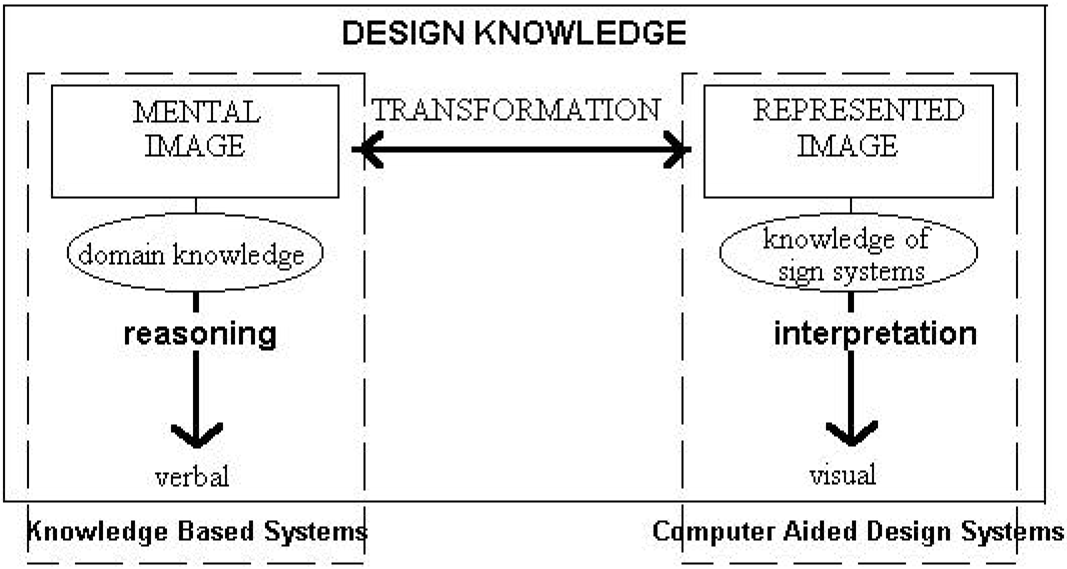


Figure 5. Design Knowledge

According to Coyne et al. (1990), interpretation is the mapping between design descriptions and their performance requirements. From this point of view, interpretation includes causal explanation and reasoning (Popper 1959). Considering the extensive literature on mapping, it may be classified in two different approaches, such as visual and verbal. CAD systems require visual mapping (March & Steadman 1971), but Knowledge Based Systems generally require verbal mapping. Design education should provide the design student with the ability of interpretation including both visual and verbal mapping characteristics.

Hypothesis V: Knowledge Engineers => Students

A Knowledge Engineer is the person who designs and builds the Knowledge Based Systems (Waterman 1986). Knowledge Engineer extracts domain knowledge from the human experts (their procedures, strategies, and rules of thumb for problem solving), and builds this knowledge into the Knowledge Based System. A knowledge engineer who is in charge to organize knowledge for his knowledge base must be able to handle formal tools like (programming) languages (in AI) as well as to have a satisfying understanding of the field the knowledge comes from. Moreover he must be able to be a serious and competent dialogue partner for the experts and he must be able to translate from one specific area language into another. He must keep in touch with all participants of this process and he is in charge to perform the management for the knowledge acquisition phase. With these characteristics, the role of a Knowledge Engineer is similar to a design student.

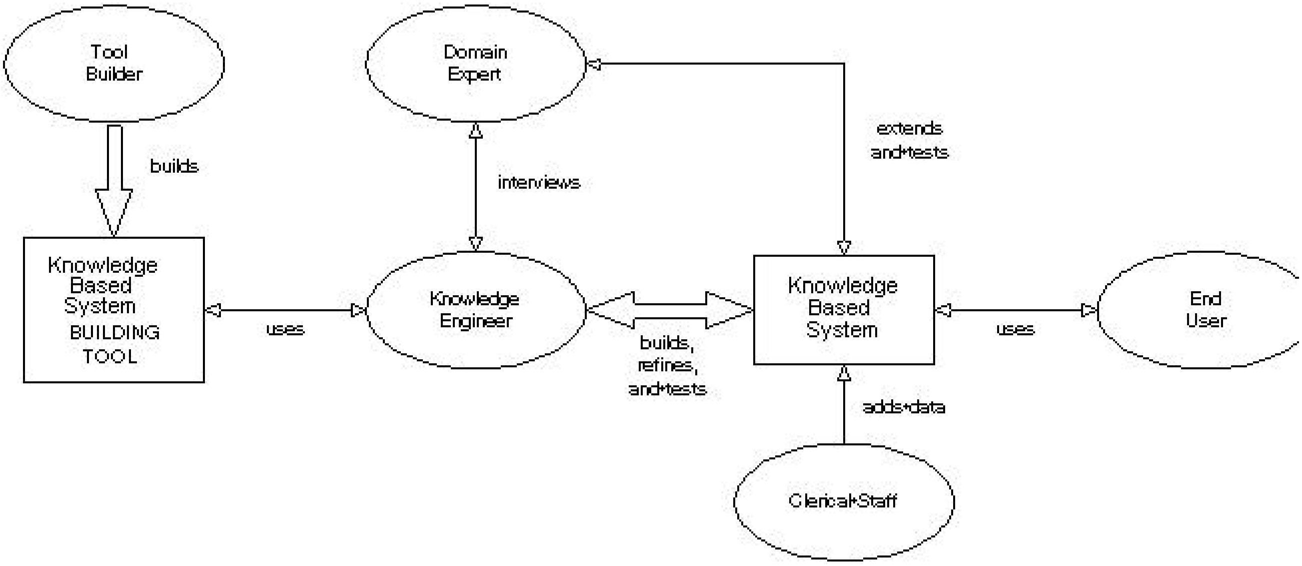


Figure 6. Role of Knowledge Engineer (Waterman 1986)

According to Wiig (1990), "In Expert Systems, the domain knowledge and reasoning strategies of one or several experts are captured through knowledge elicitation and modeling by Knowledge Engineers and then automated as a Knowledge Based System to support either the experts themselves or other knowledge workers." In design practice, this expertise is captured through knowledge acquisition methods applied by the design students. Students who work for gaining the expertise of their teachers can be regarded as knowledge workers.

Hypothesis VI: Knowledge Engineering => Knowledge Acquisition Strategy for Design Education

Design education is a creative information transfer to the candidate designers from academics and to be a knowledge acquisition process. Which mode to represent and to transfer knowledge is appropriate? Simon (1969) defines "design" as "a science of the artificial" and "the science of design" as "... a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process." Designer is a system scientist and design is systemic thinking, not a problem solving activity (Ackoff 1995). Systemic thinking requires not only analysis about problem environment, but also synthesis of the related systems. However, in design education, there is a tendency to teach what can be taught, and increasingly, what can be taught is analysis. Following statement of Simon (1977) refers to the reason of this imbalance in progress: "While analysis has become orderly systematic, theory-based, synthesis (design) has remained artistic, implicit, intuitive - and, as a result, nearly unteachable." This unteachable characteristic of the synthesis has caused the design to become a learning by doing activity. If learning design is only a learning by doing activity, then, what is the role of design education? In this paper, we aim at discussing how we can teach the unteachable the design students.

It is possible to find out the trails of two different tendencies in design education. Design is assumed to be a science education from one point of view and an art education from the other. This is why some designers are educated as if they only need theoretical knowledge, and some are educated as if they only need to practice an art until they reach the level of a master. The first strategy is called guideline approach (Stolterman 1994) based on the idea of the possibility of guiding the designer through the design process with the help of prescriptive guidelines. In this approach, design process is considered a problem solving activity that its result seems impossible to foresee. Therefore, the designer needs to be guided and the secrets of a skillful designer tried to be formulated as guidelines and transferred to the candidate designer. In the extreme case, this will lead to the situation where the designer is no longer a designer but merely an operator. The guideline approach is process-oriented in the sense that it is assumed that by controlling the design process, it is possible to control the result. Based on this assumption, design education becomes to teach designers to read, understand and be able to follow guidelines (in the form of methods, techniques, standards, etc.). Thus, the design becomes a map that can always be compared and tested against reality.

The second strategy is aesthetics approach (Stolterman 1994) based on the idea that a designer can only be guided through the design process by his own ideals and values. In this approach there is a hidden rationality of design practice. The candidate designers need well-developed abilities to judge quality. They are guided by their aesthetics, not by theoretical guidelines. The aesthetics approach is product-oriented. A strong vision is the force that will drive the designer in the right direction. There is no right or wrong solution, only good or bad designs. This approach is based on practical training. The method is to accept the student as a real designer, but this time design education will never take an active part in the development of design practice. The students are expected to develop their own styles, rather than design know-how itself. The teacher's role is only to discuss the students' products.

Today learning is mainly based on time-consuming trial and error, the increasing pressure placed on the knowledge industry requires more efficient strategies. Design is a creative and innovative activity corresponding to designers' individual creativity. With these characteristics, it should have a unique learning strategy. The learning strategy should therefore emphasize the style and characteristics of the designer, providing the opportunity for the student of discovering his own professional identity. In this learning process, the designer should be informed about design know-how which we believe is much more important than knowledge itself. A learning process is not limited to formal education - a designer needs the tools for constant personal development in a rapidly changing environment. Although design is a creative activity, knowledge can be acquired through know-how itself.

As a model for the knowledge acquisition in design education, we turn to the wealth of experience made in knowledge engineering. "The process of building a Knowledge Based System is often called Knowledge Engineering. Knowledge Engineering typically involves a special form of interaction between the knowledge engineer and one or more human experts in some problem area. "The professional activities of a knowledge engineer are associated with eliciting (or acquiring), codifying and encoding knowledge, conceptualizing and implementing Knowledge Based Systems, and engaging in activities to formalize knowledge and its use, particularly through application of AI" (Wiig 1990). The methods developed in Knowledge Based System technology can act as a model for the design education process. Knowledge Engineering employs a technique to elicit data (usually verbal) from the expert and helps to interpret these verbal data in order to infer what might be the expert's underlying knowledge and reasoning process. For building a Knowledge Based System, domain knowledge and reasoning strategies of experts are captured and automated by Knowledge Engineers through Knowledge Acquisition and Knowledge Modelling. In Knowledge Engineering as a learning strategy, students, like Knowledge Engineers, try to capture and replicate the domain knowledge and reasoning strategies of their teachers, unlike the current educational strategies in that the knowledge is directly transformed to the students. Following the big hidden arrows in Figure 7, we propose to change the direction in education and the students to take the active role in Knowledge Acquisition and Knowledge Modelling for building themselves as Knowledge Based Systems (designers).

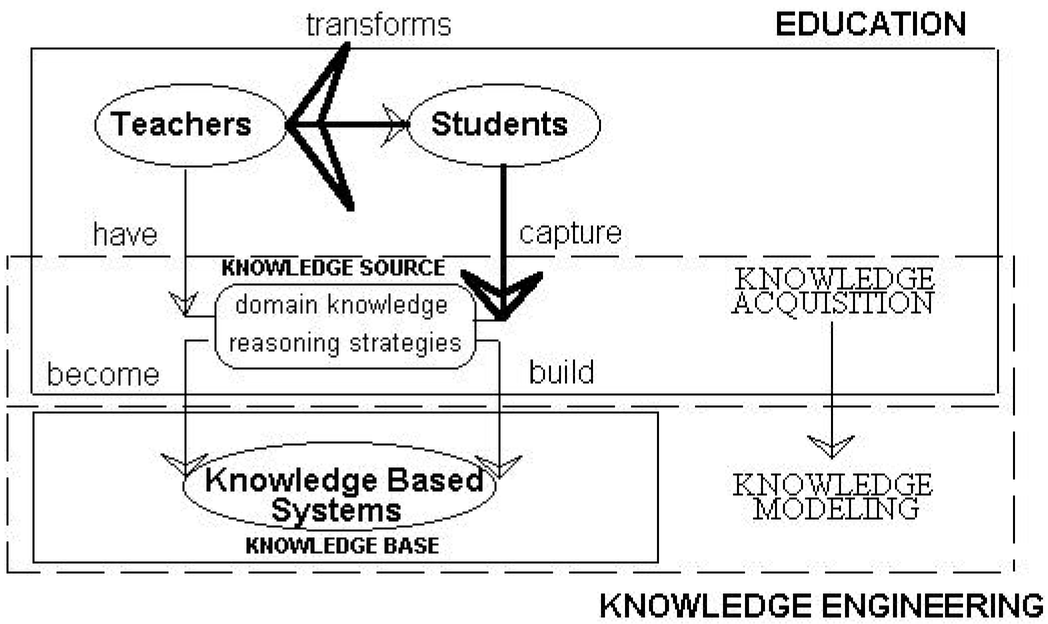


Figure 7. Knowledge Engineering as a Strategy for Design Education

There are a number of knowledge acquisition approaches used to reach the knowledge sources in Figure 7. Public knowledge may in part be acquired from textbooks, articles or other sources in the public domain through reading or even copying of databases. Expert knowledge and private knowledge, however, require sophisticated elicitation methods. It may be useful to try following direct elicitation methods (Wiig 1990) in design education as follows:

l Interviews: These are categorized such as; structured interviews, unstructured interviews, group interviews with the teachers.

l Group discussions: This refers to set both student and teacher juries discussing the design problem.

l Verbal protocols: This requires protocol analysis and includes the observation and interpretation of a designer's (or the teacher's) behaviour in design process step by step.

l Observational studies: This requires the observation of a designer or the teacher in design process.

l Expert or novice simulation: Imitating the design strategy of the observed designer is a kind of simulation.

l Interactive prototyping: Teacher and the student can work together to define the knowledge base. This might be a report or an article, as well as a Knowledge Based System.

l Questionnaires: These are the documents used by the students to extract expertise from the teacher.

l Self-elicitation: This is the elimination of domain knowledge from others.

We believe that these elicitation methods have already been used by successful students unconsciously. If the traditional knowledge acquisition methods are replaced with systematic AI approaches and the design students are encouraged to use these new approaches, design practice may be donated by more effective designers. The designers growing with a defined expertise can interpret their own reasoning mechanisms. Thus, the designer gaining know-how can understand his/her own behavior, why and what to do to solve a design problem. This will also encourage the willing to define design expertise and cause more successful Knowledge Based Systems to develop.

Conclusion

AI aims to simulate or reconstruct human intelligence and to computerize it by means of systems. It tries, thereby, duplicate or automate knowledge, experience, reasoning methods and sensory ability of human beings. This is a kind of education given by an intelligent system to an artificial intelligent system. In design education, we should be concerned with providing students the ability to extract the acquired knowledge from their teachers. Yet all too often students are treated as passive recipients of knowledge. Since design is a creative activity, design students should be given the best opportunity to draw upon the knowledge and experience of their teachers which is the most suitable for themselves.

As a model for knowledge acquisition in design education, we turn to Knowledge Acquisition in Knowledge Engineering. Knowledge Engineers face the problem of acquiring expert knowledge, and transcribing it (in a logical form) to a Knowledge Based System. They actively acquire domain knowledge from experts to develop Knowledge Based Systems. We attempt to profit from the successful Information Technology and Knowledge Acquisition in order to teach to speak to the "silent designers" of the future and improve design education process. Thus, the Knowledge Acquisition bottleneck in AI science, could be broken by the successful structured interpretations of design knowledge by Knowledge Based Systems. This may also have positive effects on AI science, as well as design science. Therefore, we could also suggest that AI scientists should change the research direction from experts to students, not for acquiring knowledge, but for Knowledge Acquisition methods in a "knowledge society" like a "knowledge industry" where the knowledge is rapidly produced and updated.

It has always been discussed how much a Knowledge Based System can simulate a designer. As a verification, we should ask ourselves how much a designer can simulate a Knowledge Based System, especially in reasoning and interpretation to overcome the bottleneck of knowledge acquisition. Before we judge the success of an artificial Knowledge Based System, we should judge the success of ourselves as designers, as teachers, as natural Knowledge Based Systems. This verification will bring us to remember thinking vice versa. First, we can, thus, teach ourselves how to teach with the rules we defined to teach a machine. Second, we can discover new methods to overcome the bottleneck of knowledge acquisition. It is the time to replace our traditional design methods with new approaches. Otherwise we, academics, can help neither our students nor Knowledge Engineers through this bottleneck and we let the designers silent and AI scientists as Fiddlers on the Roof?

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