Educating the designerly thinker

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This paper presents a hypothesis about design education that is framed within and derived from cognitive theories of learning. The relevance of design thinking and cognitive approaches to the development of pedagogical approaches in design education is presented and discussed. A conceptual model for design education that emphasizes the acquisition of explicit knowledge of design is proposed. The acquisition of knowledge is achieved through the explication of cognitive structures and strategies of design thinking. The explication process is constructed by exploiting a representational formalism, and a computational medium which supports both the learning process as well as the potential re-use of this knowledge. Finally, an argument is presented that the measure of learning, generally equated with the evaluation of the product of designing, can instead be based upon evaluating learning increments of acquired knowledge.

Keywords: design education, design cognition, design knowledge, conceptual design, computational models

Irrespective of the specific design domain, traditional educational models in design education are based upon the replication of professional task performance. The measure of learning is generally equated with the evaluation of the product of designing rather than on what might be considered a learning increment. *The cognitive porperties of design learning have never been the subject of design education*. As a consequence, there presently exists a lack of educational theories of learning which function as an underpinning of design education.

In the last decade, however, a considerable body of design research has begun to increase our understanding of the cognitive properties of design, and has provided new directions for the development of design education. In order to enable the construction of a general theoretical foundation, we argue the need to redefine the learning task in design education, from an orientation to the production of design artifacts, to a cognitive-based approach.

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1 Redefining the objectives of design education

1.1 Traditions of design education

Studio-based approaches have been widely adopted as a general educational foundation for design education. From a learning perspective, the studio as a medium for design education has been characterized by certain endemic problems. Cuff[1] presents a well-accepted description of the centrality of the studio in design education, in her case, in architectural education. She defines the sources for patterns of studio education as derived from the famous French design institute, the Ecole des Beaux Arts. Certain of these patterns include the setting of problems as the initiation of the educational process, the studio as a simulation of the professional environment, the content of studio methodology as a series of well-formulated steps of design process, such as the *esquisse* stage, or the graphic formulation of the conceptual design, the relationship with the studio master as a tutorial relationship based upon design documents, demonstration as a medium of communication, and the jury system as the forum for evaluation of the final product of design.

Of these traditional characteristics of the studio, many of which persist until today, it is the concept of experienced-based learning which has been widely adopted as a general educational foundation of design education. That is, the studio is considered a venue for making designs under the sporadic guidance of the design tutor who intervenes in the student's designing, generally in reaction to the student's explicit design. This is similar to craft education which is based on artistic presentation rather then the articulation of principles[2]. Any procedural explanations such as the correction of method, may occur in one-to-one session in which the criticism is dialectical, graphical, and based upon exemplification. It is not necessarily articulate of general design methodological principles, and, in most cases, the critical process is inefficient in the transfer of design knowledge. The nature of this traditional educational process is well symbolized in what is perhaps the Achilles heel of the traditional studio, that is, that evaluation is based on the final product rather than on a measure of increments of knowledge acquired as a result of the studio. Despite the numerous changes in studio pedagogy which have been developed in the subsequent revolutionary design educational institutions such as the Bauhaus, HFG Ulm, and the Design Institute, the design studio is still characterized by the faults of product orientation, creative design as a black-box, the pedagogical distance of the tutor, the lack of explicit definition of the requisite knowledge foundations of design, and the neglect of design methodological process as legitimate pedagogical content.

1 **Cuff, D** *Architecture: the story of practice* MIT Press, Cambridge (1991)
2 **Marda, N** 'Visual design thinking' *Stoa, European Association for Architectural Education* No. 2, November (1997)

1.2 Cognitive re-orientation

Over many years Schon's work in educating the reflective practitioner presents two important modifications to the traditional model of design education. First of all, the dialectical nature of design is treated as 'an interaction with the materials of the problem'. The idea of reflection on the problem in the medium of conceptual drawings, or sketching, introduces a *cognitive orientation to design reasoning as a foundation of design learning*. The second re-orientation is the definition of the distinction between the interactive modes of visual reasoning and design ideation. Finally, the interaction between student and tutor becomes more of a participatory process in which the articulation of principle during the dialectical process of design becomes the responsibility of the tutor as an articulator of the values and issues which motivate changes in the subsequent stages of the design representation as a process of search. Despite these theoretical changes, the educational focus still remains on the representation of the design object, rather than on an explicit articulation of knowledge. However, Schon and others did much to promote the understanding that design reasoning is a subject of seminal importance[3,4] and that design is characterized by a uniquely significant component of visual reasoning[5]. The cognitive phenomena of visual reasoning in design influence the way in which we might develop an approach to design education which is cognitively-formulated, rather than based upon the product-making orientation of professional traditions. In addition to the seminal importance of visual reasoning, its interaction with conceptual processes, is a second unique component of design thinking. This linkage between visual reasoning and conceptual processes is a foundation stone of the contemporary cognitive study of design.

1.3 Cognitive design media

How can the uniqueness of design cognition provide a theoretical foundation for design educational approaches? If we wish to impact upon the traditional educational situation, we must first identify relevant cognitive approaches to learning and the related educational methods which appear relevant to the unique cognitive aspects of design. In this paper an alternative foundation for design education based on cognitive theories is presented and discussed. Cognitive approaches which emphasize and exploit the explication of knowledge processes and knowledge structures in learning are identified. Among these is the theory of 'creative cognition', certain of the principles of which relate to knowledge structures in creative processes[6], the theory of representation–redescription[7] (RR) and constructionism[8,9]. Based upon such sources it is propopsed that learning through the structuring and manipulation of knowledge in design may be considered a significant educational objective in design education.

3 **Akin, O** *Psychology of architectural design* Pion, London (1986)
4 **Eastman, C** 'On the analysis of intuitive design processes' In **Moore, G T** (ed) *Emerging methods in environment design and planning* MIT Press, Cambridge (1970)
5 **Schon, D and Wiggins, G** 'Kinds of seeing and their functions in designing' *Design Studies* Vol 13 No 2 (1992) pp 135–153
6 **Finke, R A, Ward, T B and Smith, S M** *Creative cognition, theory research and applications* MIT Press, Cambridge (1992)
7 **Karmiloff-Smith, A** *Beyond modularity*, MIT Press, Cambridge (1995)
8 **Papert, S** 'Situated constructionism' In **Harel I and Papert S** (eds) *Constructionism* Ablex Publishing Corporation, Norwood, NJ (1991)
9 **Harel, I and Papert, S** 'Software design as a learning environment' In **Harel, I and Papert, S** (eds) *Constructionism* Ablex Publishing Corporation, Norwood, NJ (1991)

An educational model is proposed in which the explicit learning of design knowledge structures and related cognitive strategies are the main objectives. This approach which we have termed, *cognitive design media*, is based upon the student's exploration of *the design problem's conceptual space and the formulation of knowledge structures which are related to potential solution spaces*. A series of learning exercises are described and their results as a medium of design education is evaluated. This approach also provides an objective basis for assessment and measuring increments of design learning.

The following section 2 discusses the theoretical bases in cognition which appear most relevant to design pedagogy. Certain unique cognitive attributes of design thinking are presented and discussed. The contribution of these cognitive approaches to design theory and their implications in design education are presented. Following this theoretical introduction, a model for design education is proposed. We demonstrate our model in the framework of a pilot educational program in which the computer-lab is exploited as a significant venue for design learning. Finally, we discuss problems of evaluation of the various types of cognitive learning processes and present examples of an approach to evaluation.

2 Cognitive approach to learning: a prolegomena for design education

2.1 Unique cognitive characteristics of design thinking

Definition of the cognitive characteristics of design thinking should constitute the foundations of a theory of design education. Among the considerations in modeling design thinking is first to establish a modeling technique which supports the representation of thinking processes employing both visual and conceptual knowledge.

A second significant consideration is to establish a learning model which respects the fundamental *dialectic process* of design thinking. Schon's model of 'reflection in action'[10,11] is his term for the description of the dialectical phenomenon in cognitive design processes. The primacy of this unique cognitive characteristic demands cognitive models of design thinking which reflect both the duality of the visual and the conceptual and their dialectical interaction in design thinking.

Beyond the basic characteristics of visual reasoning and the dialectical nature of design as a reflective process, there is a third characteristic feature of design thinking which we might refer to as knowledge[12]. For example, the categories and variables of a family of design types can be considered as a knowledge structure of design.

10 Schon, D 'The architectural studio as an exemplar of education for reflection-in-action' *JAE* Vol 38 No 1 (1984) pp 2–9
11 Schon, D *Educating the Reflective Practitioner* Jossey-Bass, San Francisco, CA (1987)
12 Galambos, J A, Abelson, R P and Black, J B *Knowledge Structures* Lawrence Earlbaum, Hillsdale, NJ (1986)

2.2 *Knowledge structures*

Among the models relevant to design learning and the explication of the interaction between visual and the conceptual content is the model of representation–redescription[7]. This model is important since it refers to learning as the succession of representations which becomes progressively more manipulable and flexible for the emergence of conscious access to *knowledge structures*. According to this theory the human means to gain knowledge is for the mind to exploit acquired information that it has already stored as general schema by re-describing its representations. For example, in one of their examples, a cognitive development of the child, the understanding of the concept and form, 'man' provides a schema for the redescription of the concept in a graphical derivation such as 'funny man'. In the process of re-representation implicit knowledge of the schema becomes externalized in the sequence of representations The process of representation redescription suggested by Karmilloff-Smith is relevant to design learning, since it involves conscious construction and exploration of the *cognitive structures of schema*. We can summarize that learning in Karmilloff-Smith is a process of the acquisition of knowledge structures which are related to schema differentiation.

2.3 *Cognitive strategies*

Another important principle for design learning, is *the interaction between visual and conceptual content in global strategies of design thinking*. An example of the explication of this interaction in characteristic strategies in design thinking can be found in the theory of Creative Cognition[6]. Formal structures of global processes can be described, or characterized, in terms of models explaining how conceptual knowledge is employed.

Global strategies in the cognitive sense refers to the larger structures of cognitive phenomena which characterize the exploitation of knowledge in thought. That is, global strategies in design such as typological or analogical thinking can be modeled as complex graphical schema. These models of design strategies build on the two principles of representation already defined: the fundamental duality of graphical and conceptual content, and the creation of knowledge structures as basic categories of design knowledge.

We have been working on the explication and formalization of global strategies such as refinement in generic design and typological design, and of adaptive design[13]. Both refinement and adaptation are global strategies which are based on formal schemas of re-representation. Refinement is based on a schema of staged particularization, while adaptation is based upon a structure of knowledge which supports re-representation. For

13 Oxman, R E and Oxman, R M 'Refinement and adaptation in design cognition' *Design Studies* Vol 13 No 2 (1992) pp 117–134 example, our approach to the representation of typological strategies was based on the derivation of a set of generic representations which support typological design transformations.

By comparison, in global strategies of creative design the strategy is less formally based on generic knowledge and developmental processes, and is more exploratory. This different class of strategy illustrates the distinction between 'processes used in the generation of cognitive structures and those exploring the creative implications of those structures'[6]. In creative cognition, cognitive structures that are generated have emergent properties that can be explored, where some of the properties could not have been anticipated in advance. In this way one might generate radically new and unexpected ideas.

It is our hypothesis that learning in design is the acquisition of the cognitive ability to manipulate the representations of design knowledge, to acquire basic schema in design thinking, to understand knowledge structures and to be able to manipulate characteristic strategies of design thinking such as generic and typological design, adaptive design, analogical thinking and creative exploration. That is, the cognitive attributes of design cognition and learning can become the content of design education.

3 Towards a cognitive design education

3.1 Learning through construction

Our hypothesis of design education is that modeling the representation of design thinking can be a lucid medium of design education, and through modeling of knowledge structures and strategies the student gradually develops his conceptual understanding of design.

This approach is motivated by Constructionism[8] as a theory of learning which emphasizes an epistemology of knowledge through construction. Through constructing representations of design thinking, the student gradually becomes richer in his ability to think in designerly ways. The constructional form provides a representation of the structure of knowledge which the student acquires. Design learning then may be considered a process of knowledge acquisition and development in which the knowledge is physically constructed. This contributes to an understanding of the cognitive processes which are characteristics of design, or as Papert has stated, this form of education contributes 'to knowing rather than to knowledge'. Within this general pedagogical approach the goal of design education is defined as the acquisition of design knowledge through constructing the explication of schema, knowledge structures, and global strategies in design thinking.

3.2 The model: representation, construction and implementation of knowledge structures

3.2.1 Representation

We have developed a taxonomy of basic elements in cognitive processes. These include the characteristic interaction between design strategies and form generation. This taxonomic code enables the modeling of cognitive structures and strategies. These are modeled as network structures in the form of nodes and linkages. The network structures explicate, and enable comparison between, various classes of design knowledge and cognitive strategies in design.

The elements of the network are based upon a formalism previously developed for representing design thinking. The representational formalism termed, ICF (Issue–Concept–Form)[14] addresses problems of representation of knowledge in design. ICF represents chunks of knowledge of designs, provides explicit linkages between the issues of a design problem (I), a particular solution concept (C) and a related form description (F). The formalism has been expanded in order to include analogy (A) and metaphor (M) as resources for ideation and to support design exploration processes which exploit these cognitive mechanisms.

3.2.2 Construction

According to Papert, 'constructionism, shares constructivism's connotation of learning as building knowledge structures'. We are motivated by the general constructionist approach that learning through construction can be a medium for building knowledge structures in the mind of the student. By constructing models of these structures, the learner acquires knowledge of the cognition of designerly thinking. That is, he learns the cognitive processes of thinking design as well as the cognitive structures of knowledge which are employed in designing. Further with respect to constructionsim, the learner is consciously engaged in constructing a public entity. This work benefits from the public format in which the models constructed have a communicative, as well as a learning, value.

3.2.3 Computer implementation

In our work we have elected to exploit the *computer laboratory* as a design learning environment. As design educators we use computers as educational tools in simulating cognitive processes; explicating knowledge structures and even gathering their content as potentially useful material for the designer, such as computer-based libraries, visual precedents, etc. This way, the computational system supports both the learning process as well as the potential re-use of this knowledge. In this case the computer is the medium for the construction and test of cognitive structures.

14 **Oxman, R E** 'Precedents in design: a computational model for the organization of precedent knowledge' *Design Studies* Vol 15 No 2 (1994) pp 141–157

The practical techniques of this methodology in our experiment have focused on the use of internet technology[15]. This has proven to be a powerful, stimulating and innovative educational medium for the acquisition of knowledge. In the following section, specific examples of student's exercises are presented and the teaching program is evaluated as a contribution to a cognitive-based design education.

4 A teaching program in the representation, construction and implementation of knowledge structures

We tested our hypothesis with a group of graduate students from the industrial design and architectural programs at the Technion, Israel Institute of Technology. These were primarily upper level undergraduates and second degree students, who had both computational ability and some background in the theoretical design context of the exercises.

Our work on design education is situated in the context of specific modeling tasks. In response to these tasks design thinking is formulated as *conceptual structures and strategies* by means of a network representational formalism[14]. Exploring the extended ICF formalism these structures formulate semantic nets of the conceptual space as well as the content of their related key design ideas. These representations may be considered to describe significant solution paths within problem genres of various design domains. The techniques of modeling and the exploitation of the ICF formalism within the HTML environment (hypertextual language of the Internet) was part of the preliminary methodological work of the teaching program. This preparatory period was relatively brief, after which the students had gained the tools and the conceptual fundamentals of modeling design thinking.

It is difficult to develop an awareness of design thinking through conventional design activity. However, if taught explicitly, it is remarkably easy to understand. Virtually all of the students developed proficiency with this methodological foundation of design thinking. We will describe such learning processes in the following examples. In each of the examples we provide a brief theoretical introduction, present and demonstrate the use of the code for the representation of knowledge structures, and finally describe examples of computer implementations.

The diagrams illustrated below are schematic representations of one of the student's work.

15 Oxman, R E, Sarid, A, Bar Eli, S and Rotenshtriech, R 'A conceptual network for web representation of design knowledge' *CAAD Futures'97* Kluwer Academic Publishers, Dordrecht, Netherlands (1997)

4.1 Generic and typological design

This exercise appears to have provided an efficient and articulate medium for understanding and acquiring skill in generic thinking. Students were given a brief theoretical introduction to generic design and typological design. Generic design was presented as a form of knowledge structure that connotes the body of prior knowledge which enables the designer to evoke generic representations, or to extract schema from specific images. It includes both the derivation of generic representational schema as well as the knowledge of exploiting these schema[13].

Students were asked to represent typological knowledge as a set of generic representations which are associated with specific problem types, and to organize the variables of the type in a hierarchical order of which the highest level is that of the schematically represented class description.

4.1.1 Representation and construction

A basic coding of thinking process in interacting with a representation includes an issue (derived from the problem), the resulting concept, and the resultant form (see Figure 1).

This basic coding was exploited to model generic design and typological design as follows. In the first case, a representation of generic design is presented as the derivation of a solution class which then results in the production of a 'generic representation'. This is a recognized phenomena in design which results in a schematic graphical representation (level 1) which is subsequently developed as a realized scheme (levels 2, 3 and so forth). Figure 2 illustrates this process of generic design.

This general model of generic design was extended to accommodate the knowledge of a specific building type. Thus another global developmental strategy which builds upon generic thinking to exploit typological knowledge is commonly referred to as typological design. In Figure 3, typological knowledge is represented as a variation on generic design in which each refinement level of the generic representational initiates reasoning regarding issues and solution concepts which derive from knowledge of the

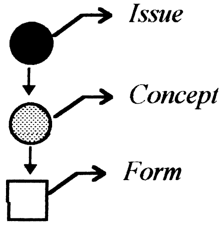

Figure 1 Simple cognitive process employing a problem specification, solution type and the resultant form

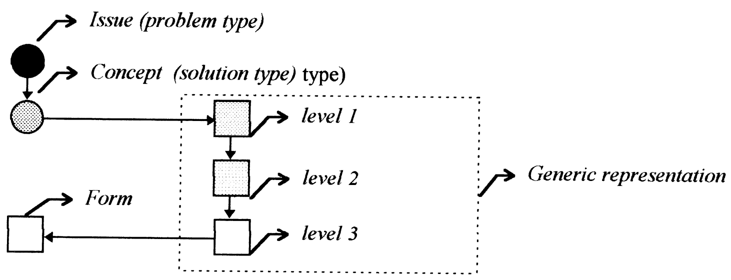

Figure 2 Generic representations in a refinement process

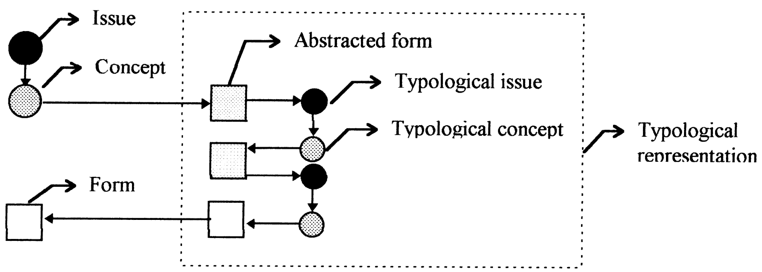

Figure 3 Typological representation in a refinement process

building type, its sub-problems and sequence of significant design variables. This way, generic thinking is guided by typological knowledge, one of the well-known design phenomenon.

4.1.2 Computer implementation

The construction and the final implementation of generic representation of the student's work was dynamic and interactive. The user could interactively modify the form according to the typological variables and the generic structure of knowledge That is, the student in preparing the representation, understood and respected the potential user. This is a form of metacognition which can be materialized in the particular computational medium which we exploited.

The implementation in this example was of a chair design which supports generic and dynamic back and forth particularization through navigation between hierarchical levels of abstraction. An interactive environment employing the VRML (virtual reality modeling language on the Internet) provided for design zooming which simulates the generic representational levels of a specific class of chair designs. In this way, the user can alternate between a schematic and particularized representation through the medium of zooming. Each of the abstraction levels may be elaborated by adding more specific details.

4.2 Adaptation through re-representation

This exercise has provided a significant medium for understanding the role of representations in adaptive design. In the theory of design adaptation a specific design is selected and, through adaptation, transformed into a new design. In comparison to generic design it is represented as a specified design representation. Adaptation processes can be defined as successive modifications through a series of representations which are executed upon the original design. We have referred to this process as *re-representation*[16], exploiting the term which has been applied to the cognitive phenomenon as well as to the cognitive capabilities which make these complex processes possible.

4.2.1 Representation and construction

Students were asked to identify and present these classes of representations as well as other sources with which designers can interact, and modify. This is an example of their coding of multiple representations. The representations may be derived through interacting with exploratory visual resources such as analogies and metaphors.

4.2.2 Computer implementation

It was suggested to the students that one way to support adaptive change was by providing a medium to interactively construct explicit multiple representation of sub-structures. Figure 4 illustrates an example of one student's work in the re-representational support of chair design. The final representation employed a rather traditional structure of a chair: a seat, support, and legs. Each representation was provided with 'modification buttons'. In this example, clicking the various buttons, resulted in size modifications of components.

4.3 Visual–conceptual ideation in precedent-based design

Precedent based design is accepted as one of the cognitive phenomena in design creativity as a source of ideation. The generation of a conceptual

16 **Oxman, R E** 'Design by re-representation: a model of visual reasoning in design' *Design Studies* Vol 18 No 4 (1996) pp 329–347

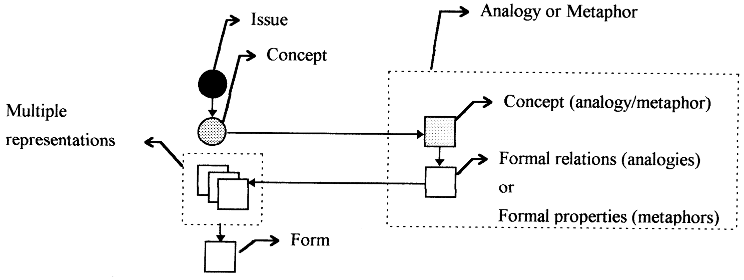

Figure 4 Representation of multiple representations and their mental resources

basis for the inception of design is one of the most interesting of the cognitive phenomena of early design. The students were asked to consider series of issues such as how precedents should be represented, indexed, and organized in order to support the process of ideation. Rather than selecting specific precedents, it was the exploration of their conceptual structures which were to be supported. Students were asked to construct a *resource for design ideation* in which the conceptual content of design precedents acts as a vocabulary of design ideas within the framework of a particular class of design problems. They were asked to employ a *concept vocabulary* of the resource base of selected precedents in the construction of a semantic network of ideas which can be browsed by the designer as a cognitive resource for design ideation.

4.3.1 Representation and construction

With respect to exploratory thinking, the following student employed the same principles of graphical coding to distinguish exploration. The student employed the code to represent complex networks. Furthermore these networks introduced references to specific designs, or precedents. This is represented in Figure 5, which models associative reasoning and the exploitation of precedents in design. In Figure 6, another student presented complex hybrid processes including both exploratory and developmental sequences.

4.3.2 Computer implementation

An implemented system of design precedents was developed which included a set of Web pages. An example of browsing and exploration modes in this system is illustrated by the following series of steps. The first step is the selection of an issue from the set of all currently existing domain issues. Once an issue is selected, the second page appears with related concepts. The user than selects relevant conceptual linkages by activating related windows. By activating the window which connects concepts to forms the user may explore how a similar design concept may be realized by different form elements in two designs. Through this, the user

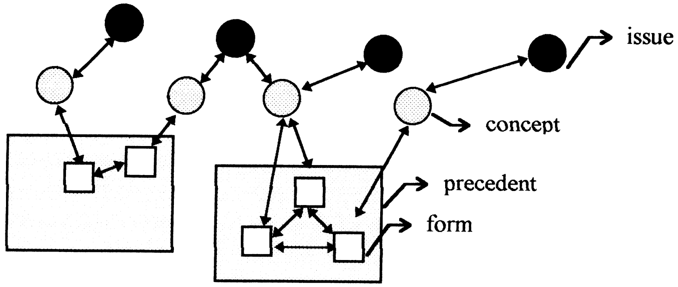

Figure 5 Representation of associative browsing among multiple precedents

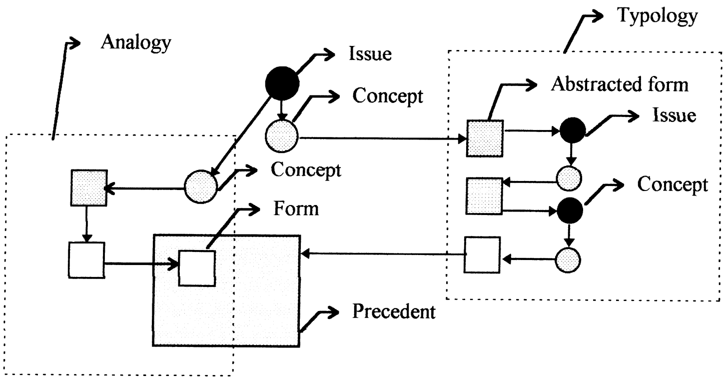

Figure 6 Complex network of linkages and nodes

may browse to explore how a similar conceptual form may be realized in different designs. Conversely, by selecting specific precedents the user may explore other concepts which were not expected and emerge as a result of the navigation process.

5 *Problems of evaluation of learning experiences*

As we have stated, in most conventional approaches to design evaluation, only the final product is evaluated and not the cognitive learning increment of the student. How can design learning be measured and evaluated?

Although we have not undertaken a rigorous form of analysis to demonstrate that subjects in our teaching program did improve their ability to design we have obtained some significant insights and qualitative results. The validity of the qualitative results of this experiment derives from the use of mixed methodologies of assessments such as formal interviews with participating students during and after completion of their projects as well as discussions, criticism, evaluation of student's work and observation of progress. Based on these assessments, we could make observations of changes that occurred in student's thinking about design, their growing skill to deal with the complexities of design thinking and the dynamic progress of their performance.

5.1 *Evaluation of representation and construction*

In the brief example below, we refer to *the development of concepts and knowledge structures in design learning* as one of the most significant qualitative results we obtained in our program. This is a significant category in measuring design learning.

The qualitative assessment of learning as the development of concepts and knowledge structures in design learning was measured in our experiment by an evaluation of modeling performance. We have traced the use of concepts according to their ability to draw inferences concerning their acquisition of design knowledge. We defined linkages and terms of the knowledge structures. For example, in employing conceptual linkages we assessed the collection and organization of knowledge through such indicators as the type of linkages, and the degree of development of the structure of knowledge represented. Such measures include the types and the number of conceptual linkages, employed. We illustrate evaluation in the following example from one of our students.

In the assessment of the evolution of a representation in the work of one student, we briefly analyze the learning processes which were observed during the interaction with the teacher. The project involved the representation of ideation processes in precedent-based design.

The first step of the student was to model a particular example of a design idea in a particular precedent. For example, an idea such as achieving phenomenological content in housing design can be achieved by use of traditional elements such as an inner court. The conceptual content and the form of this particular example was presented as a simple reasoning process, linking between issue: phenomenological content, concept: use of traditional elements, and the form: inner court. This is illustrated below in Figure 7.

In dealing with two precedents which had the same formal solution, gradually a greater generality and a greater ability of generic understanding appeared in the use of the concept ‘inner-court’. The need developed to employ a higher form of conceptual representation such as prototype and generic solution. The second concept which developed in the student’s working with the representation of ideas in concrete case studies is the need for generalization, or ‘association through an abstraction level’ which is modeled by links between the two similar design solutions that employ the same conceptual solution (Figure 8).

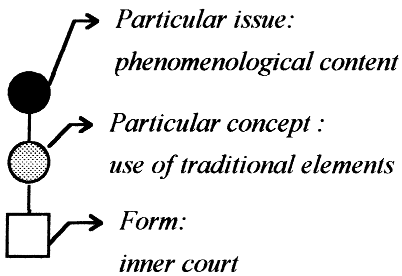

Figure 7 Development of concept (a): particular issue, concept and form solution

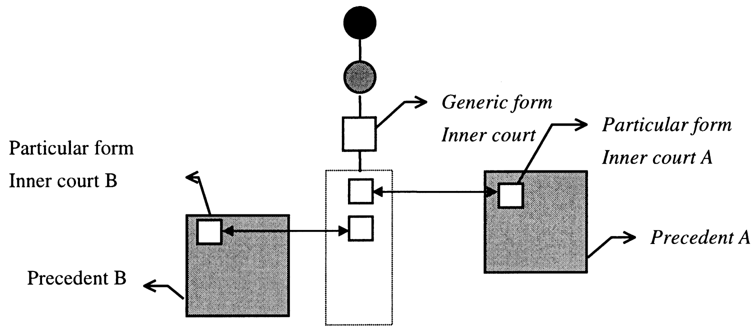

Figure 8 Development of concept (b): generic form and associative thinking

The third representation developed the notion of an abstract concept. We can see that the concept 'use of traditional elements' can also be realized by the use of 'niches' in the design. Following this, the student expanded the concept of 'abstraction' through the use of an abstracted solution concept (Figure 9).

In the next representation the student developed the concept of 'exploration'. By interpreting the links as browsing devices in which exploration has enabled the finding of new ideas in design precedents (Figure 10).

Having observed such phenomena as improved representational ability might not necessarily guarantee that the student is a better designer, but that he/she has definitely begun to be a designerly thinker. It is these kinds of evaluations based upon the observation of the growth of knowledge and understanding which should become among the measures of design learning. This is not to say that we should abandon traditional design pedagogy

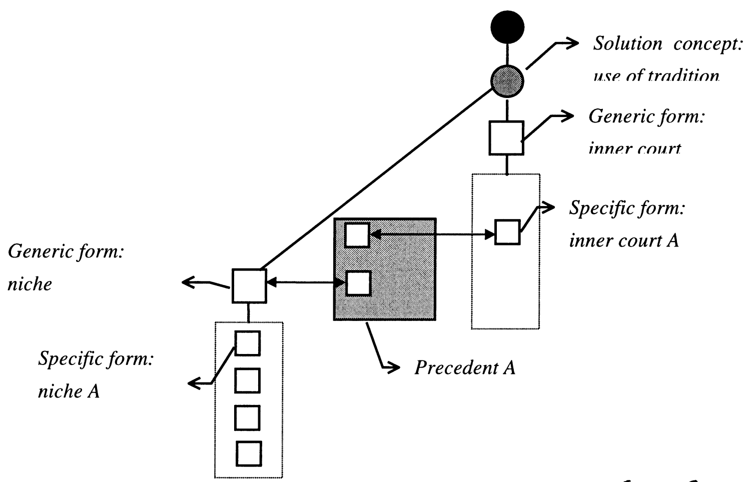

Figure 9 Development of concept (c): expanding the concept of abstraction

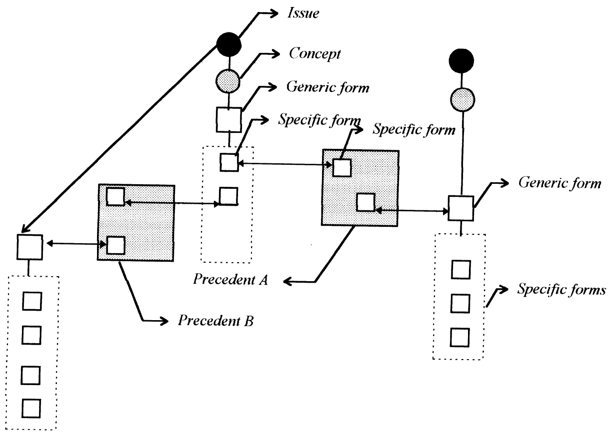

Figure 10 Development of concept (d): exploratory browsing in a design precedent

and the actual production of design artifacts. But if we are design educators, we must find means to supplement traditional pedagogy by educating the designerly thinker as well as the maker of designs.

In the brief example above, we refer to the development of conceptual understanding, one of the most significant categories. In the following section we evaluate how the acquisition and the explication of knowledge structures through computational modeling and the use of the technology, have contributed to design learning.

5.2 *Evaluation of computer implementation*

Venues of design education, the class-rooms or the studios, are the spatial institutionalization of educational theories. The class-room may provide a spatial situation for directed analytical education in problem solving, while the studio is traditionally viewed as providing the creative ambiance of design making. How is it possible to spatialize the exploration of cognitive phenomena and the modeling of cognitive processes?

The issue of the learning content of place and the role of the relevance of the learning environment was raised by Habraken[17]. In our case we have elected to exploit the computer laboratory as a design learning environment which we have termed as *Cognitive Design Media*[18]. This form of teaching through the development of systems is based upon educational experiences in constructionist theories. The practical techniques of this methodology focus on the development and the design of computational systems which can represent the cognitive models. This has proven to be a powerful, stimulating and innovative educational medium for the acquisition of knowledge. This way, the computational system supports both the learning

17 Habraken, N J 'Tools of the trade' Lecture given at the Faculty of Architecture and Town Planning, Technion, Israel, November (1997)
18 Oxman, R E (http://arrivka.techunix.technin.ac.il/~rivka/designstudies/education)

process and the potential re-use of this knowledge and the creative and learning increment of their work can be evaluated comparatively.

On the basis of our work we believe that this new venue has proven itself as a medium for design education. We should consider the significance of the venue and the medium from the point of view of their contributions to educational performance, and in comparison to conventional media and venues. The enhancement of collaborative, versus competitive, motivations of students are significant and may be enhanced in group modeling. The ephemeral nature of the results of conventional educational activities can be compared to the potential value of knowledge permanence in the research-related character of this approach.

6 Summary and conclusions

It is now possible to demonstrate that the derivation of design knowledge through constructive processes, in itself, provides a medium for design learning. Though the observation of the process of construction we have identified such phenomena as *depth of understanding* of the task in the development of modeling skill, and the efficiency in modeling representation. A growing level of complexity in the representation indicates the acquisition of a deeper understanding of relevant concepts and the mastery of their interactions in design thinking; the sophistication of integrating and implementing concepts in complex structures may be interpreted as considered an indication of metacognitive insight which is perhaps an indication of a high level of general knowledge regarding the interaction of knowledge in design strategies.

This approach transcends the educational logic of conventional venues of the classroom and the studio. It suggests that special design learning environments must be developed which can enhance and supplement formal education and foster personal development in design learning. As for the potential of future applications of this methodology, we believe that the resulting relationships between cognitive models of design, design domain knowledge and the incorporation of computational technology has theoretical and practical implications for design education in the broad spectrum of design domains.

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