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Supporting Creativity with Conceptual Modeling Tools

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Abstract: Many of the tools developed within the knowledge acquisition research community to support the knowledge engineer in developing knowledge-based systems are based on methodologies from psychology, education or management designed to support people in developing overt conceptual models. Often the root discipline already has explicit models of the roles of these methodologies in supporting the human creative process. Given the tremendous technical progress in developing a variety of interactive knowledge acquisition tools in recent years it is appropriate to investigate the applicability of these tools to their original domain of application in the root disciplines. This paper reports some preliminary experiments on the application of conceptual modeling tools based on personal construct psychology to support first year graduate students in establishing their research directions and identities.

INTRODUCTION

Human creativity is a puzzle within an artificial intelligence context. We expect creativity to be associated with intelligence, yet factor analyses of intelligence tests and divergent thinking tests suggest that creativity is a distinct factor of ability independent of intelligence (Bolton, 1972). Logically, the puzzle is perhaps resolved if one thinks of it in terms of the difference between the capabilities to perform a task *well*, and those to perform it both well and *differently*. Originality is not valued positively within the current performance paradigms of artificial intelligence research. On the contrary, we have been concerned with systems that mimic natural intelligence, and our evaluations are higher the closer the performance is to established human norms. A highly creative person would not come out well within such an evaluation framework!

However, much of what has been done within the artificial intelligence research paradigm is potentially valuable to creativity research and to the support of human creativity. In the knowledge acquisition community, we have developed many tools designed to elicit expertise (Boose & Gaines, 1988, 1990). These are apparently within the performance framework noted above—to ‘snapshot’ existing expertise. However, we have come to realise as Clancey (1989, 1990) has stressed, that, while the expertise may exist, the overt knowledge that we presuppose to underlie it may not pre-exist. Skilled performance in the neural network that is the brain is not necessarily based on overt knowledge structures. Indeed, there is no basis other than explicit presupposition to suppose that there *are* ‘knowledge structures’ underlying expertise.

Over a period of time, at the knowledge acquisition workshops we have come to view our knowledge acquisition tools, not as transferring knowledge, but rather as supporting the expert in building a model of his or her skill sufficient to emulate it. We no longer presuppose that such a model pre-exists in a form to be ‘transfered.’ Since the roots of most knowledge acquisition tools is in other disciplines, such as psychology, anthropology and management (Shaw & Woodward, 1990), and the original purpose was often to aid people in understanding their own psychological processes, it is plausible that the computational tools developed may serve other purposes. In particular, they may be relevant to aspects of the human creative process.

One of the first psychologists to consider the relationship between convergent and divergent knowledge processes within a cognitive framework was George Kelly (1955) whose *personal construct theory* presents a person as exploring his or her environment, collecting data about the world and constructing a personal reality from which to view it. The repertory grid methodology used in many knowledge acquisition tools (Shaw & Gaines, 1983, 1987; Boose, 1984; Boose & Bradshaw, 1987; Diederich, Ruhmann & May, 1987) stems from this perspective, and supports the elicitation and analysis of the construct system, or conceptual framework, with which an individual operates in his or her own domain.

Kelly analyzes the dynamics of change in a person's construct system in terms of a *creativity cycle* in which convergent and divergent thinking alternate. A system of personal constructs is not fixed, but may vary from one occasion to another:

> There are typical shifts in the sequence of construction which people employ in order to meet everyday situations….The Creativity Cycle has to do with the way in which a person develops new ideas. (Kelly, 1955, pp.514-515).

Kelly sees convergence/divergence as a sequence of loosening and tightening of constructions. A person who uses only tight construing may be very productive but cannot be original. On the other hand, loose construing is characterized by a person's "preposterous thinking" (p. 529) which is unformulated and often preverbal. The structured alternation of these processes is what we perceive as the creativity underlying intelligent behavior. Thus the paradoxical relation expressed at the start of this section is explained in terms of sequentiality—the full scope of intelligence involves not only a high level of performance but the adaptive renewal of the underlying basis of that performance through a process of creative reconstruction.

We are studying the application of knowledge acquisition tools as systems to support the creative component of scientific knowledge processes. This paper presents Kelly's personal construct theory and, in particular, the repertory grid, as a method of eliciting relevant but abstract constructs about the topic, together with semantic nets which are used to produce a concept map of the cognitive structures involved. Hypermedia is used for annotation and explanation, to add notes, diagrams and links to other material during the creativity process. An empirical study has been undertaken of the system in use by ten graduate students in a Cognitive Science course in a university department of Computer Science to explore and elaborate aspects of their research topics. Some initial results are presented.

KNOWLEDGE ACQUISITION TOOLS

There are well over one hundred knowledge acquisition tools named and described in the current literature (Boose, 1989). However, a recent classification of tool architectures has characterized them in terms of four major types (Gaines, 1990):

- Semi-formal elicitation and structuring through hypertext and hypermedia—used to capture raw knowledge at the pre-computational stage—the tool typically being based on a hypermedia system such as Apple's HyperCard.
- Direct editing of knowledge in a semantic network, frame, rule, representation—used with overt, computational knowledge structures directly available from an expert or derived through other tools—the tool typically being some form of graphic knowledge editor for semantic nets.
- Indirect elicitation through critical cases described in relevant attributes—used when the expert cannot provide overt knowledge structures but can provide high quality stereotypical case data—the tool typically being graphic interaction through a repertory grid methodology.

- Inductive derivation of knowledge from data sets of varying quality—used when the expert cannot provide high quality case data but can give access to substantial databases of lower quality data—the tool typically being a derivative of ID3 or AQ11.

All of these types of tools seemed to us to have some *prima facie* validity as potential support for the creative process. Our logic was that tools designed to help an expert make his or her knowledge structures overt could also support students in developing models of their own intuitions. Such tools might counterbalance the weight of existing received knowledge, particularly used by first year postgraduate students attempting to establish their own research directions and personal research identities. The significance of the knowledge acquisition tools and underlying methodologies is threefold: they are *reflective*, reflecting back to the student his or her own vocabulary, nascent knowledge structures, and their implications; they are *adaptive*, capable of being continually edited and refined with little ergonomic cost; they are *operational*, generating knowledge structures capable of being used in the computer for reasoning, simulation and problem-solving.

In the early 1980's we reported the application of computer-based repertory grid tools as computer-assisted learning (CAL) tools to track the creativity cycle in a student's learning progression (Shaw & Gaines, 1982). We had already suggested that such tools could be used to derive the conceptual models underlying expertise in developing expert systems (Gaines & Shaw, 1980), and demonstrated their role in eliciting accounting expertise at an early expert systems conference (Shaw & Gaines, 1983). Boose (1984) presented parallel research in an industrial context at AAAI'84, and repertory grid methodologies and tools have since become routine items in the knowledge engineer's toolkit. In particular they have been greatly extended in both the richness of knowledge representation and the quality of interactive computer support and online computer analysis and its graphic presentation.

It has seemed to us as we enter the 1990's that the wheel has come a full circle and that it is time to test the tools developed for specialist expert system development as general *knowledge support systems* with applications to creative thinking at all stages of the educational, scientific and artistic process. We have at our disposal the original repertory grid tools, now greatly enhanced and integrated with hypermedia systems and a range of expert system shells (Gaines, Rappaport & Shaw, 1989; Gaines & Linster, 1990). We also have a graphic knowledge editor designed on the one hand for ease of use through simple MacDraw-like editing features, but on the other hand implementing a well-defined visual conceptual language supporting both Kelly's construct hierarchies and Brachman's KL-ONE conceptual structures (Gaines & Shaw, 1990). In the context of this paper, it is particularly interesting to note the way in which the graphic knowledge editor is able to support the concept maps already used within the educational system to help students elucidate and communicate their ideas (Novak & Gowin 1984).

The remainder of this paper briefly introduces the basic ideas of personal construct theory, gives an overview of the tools, illustrates their application in the hands of a graduate student, and summarizes our preliminary experience with ten students experimenting in their use.

PERSONAL CONSTRUCT THEORY

George Kelly commenced his studies as an engineer but moved into clinical psychology and developed a radically different approach to the subject that emphasized the questing nature of the individual and the idiosyncratic content of our models of the world. Kelly put forward the idea of an individual as what Shaw (1980) terms a *personal scientist*☐ using *personal constructs* as filters through which people perceive events:

> Man looks at his world through transparent templets which he creates and then attempts to fit over the realities of which the world is composed. (Kelly, 1955, pp.8-9)

He emphasizes the epistemological status of these constructs in predicting and controlling the world and their ontological status as personal conjectures rather than reality-derived absolutes:

> Constructs are used for predictions of things to come, and the world keeps on rolling on and revealing these predictions to be either correct or misleading. This fact provides the basis for the revision of constructs and, eventually, of whole construct systems. (Kelly, 1955, pp.14)

Making explicit the construct structures in use and identifying their strengths and weaknesses is a key process in aiding a person's coping with a complex world. In general we may expect many problems of knowledge, decision and action, both fundamental as in science and applied as in management, to be related to the construct systems in use. In particular we may expect the development of cognitive structures to be related to the construct system through which the person is viewing the world.

Kelly suggested the technique of the *repertory grid* to represent the repertoire of constructions that the individual has acquired from his personal observations of the world. A repertory grid or "construction matrix" is essentially a two-way classification of data in which events and abstractions, or constructs, are interlaced. In his own terms:

> ...it expresses one's own finite system of cross-references between the personal observations he has made and the personal constructs he has erected. (Kelly, 1965, p. 291)

The personal observations are known as *elements*. Elements were originally constituted from the role titles of significant people in the life of the particular individual. The personal constructs are bipolar dimensions which group the elements into varying clusters according to their similarities and differences within the individual's frames of reference. Kelly used the repertory grid as a tool to assist with psychotherapy, using significant others as elements. Since its introduction, it has been used in many settings to probe the construct systems of psychiatric patients, student teachers, effective managers, knitwear inspectors, rivet selectors in the aircraft building industry, and the conceptual structures of students and experts. The elements may be people, things, events, or experiences, which are related to the particular problem or purpose for using the grid.

THE REPERTORY GRID TOOL

RepGrid is a knowledge support system providing an integrated set of tools for elicitation and analysis of elements and constructs in a given domain. It combines a number of different techniques, including element and construct elicitation and clustering, and is linked to an inductive rule generation program. It runs on the Apple Macintosh family of computers to provide a highly interactive and graphic knowledge acquisition environment. At the heart of RepGrid is an object-oriented knowledge base in which knowledge is formally represented as a multiple-inheritance digraph of classes, objects and properties.

The main tools in RepGrid are shown in Figure 1:

- *Elicit* accepts specifications of elements within a domain and provides an interactive graphical elicitation environment within which a person can distinguish elements to derive his or her constructs within the domain. The resultant conceptual system is continuously analyzed to provide feedback prompting the person to enter further elements and constructs.
- *Exchange* extends this to share elements and constructs between people and allows the terms in the conceptual system derived from one person to be used by another in order to determine whether the two conceptual systems are different in any way. It can also be used by the same person looking at changes in their own conceptual structures over time, for example, after reading a specific book, or exploring a particular domain.

- *Process* gives access to clustering tools for the analysis and display of the conceptual systems elicited: FOCUS shows the system as a hierarchical structure; and PrinCom as a spatial map.
- *Socio* processes results from several people to reveal the similarities and differences in their conceptual systems, or the same person at different times, construing a domain defined through common elements or constructs. It can be used to focus discussion between people on those differences between them which require resolution, enabling them to classify them in terms of differing terminologies, levels of abstraction, disagreements, misunderstandings, and so on (Shaw & Gaines, 1989).

RepGrid is coupled through an inter-application protocol with Apple's HyperCard, and to inductive analysis tools deriving rules from cases represented in the grids. It exports the grid data as class definitions, properties, constraints, entailments and instances to a variety of object-oriented knowledge-based system shells. In particular it exports to our KRS knowledge representation server, a KL-ONE-like system with associated graphic knowledge editor.

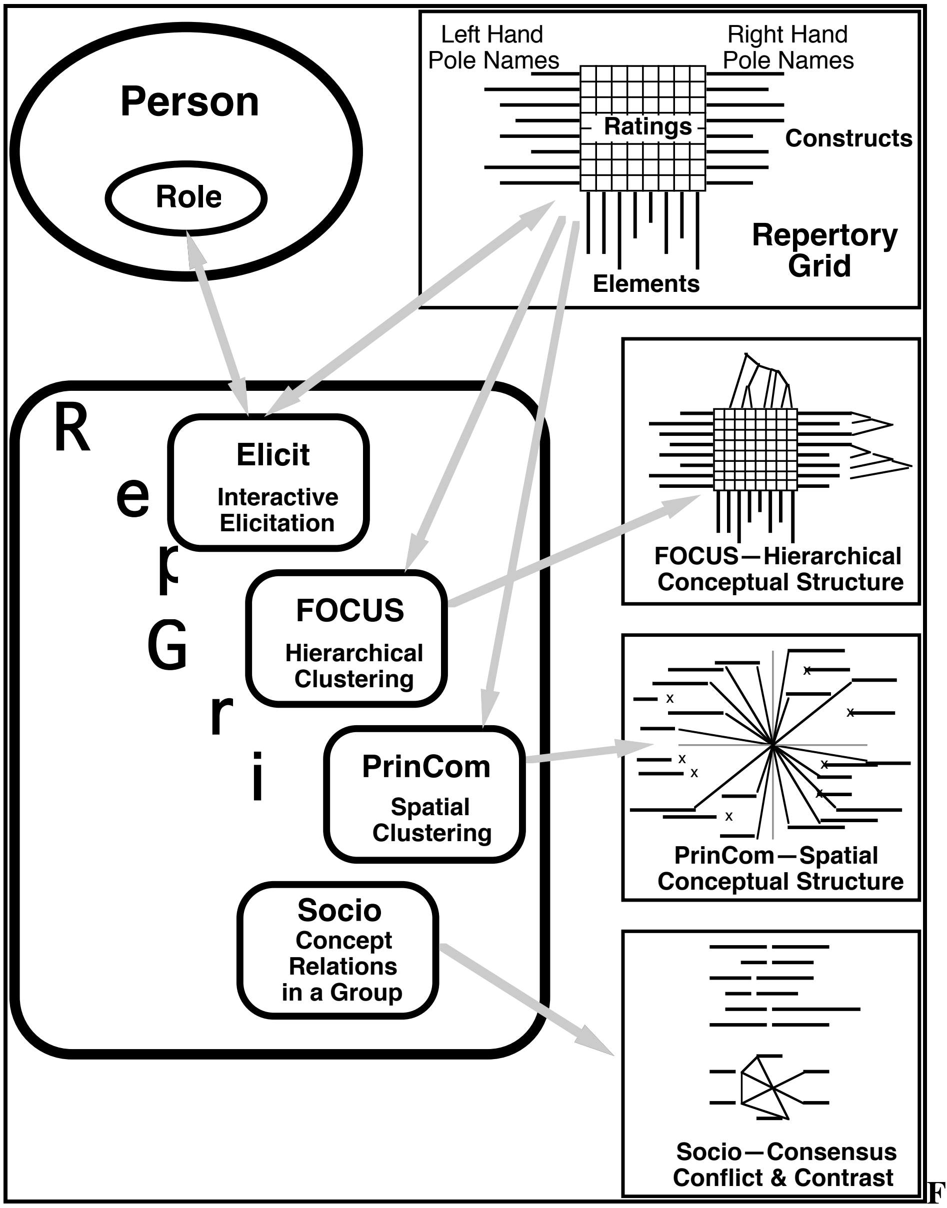
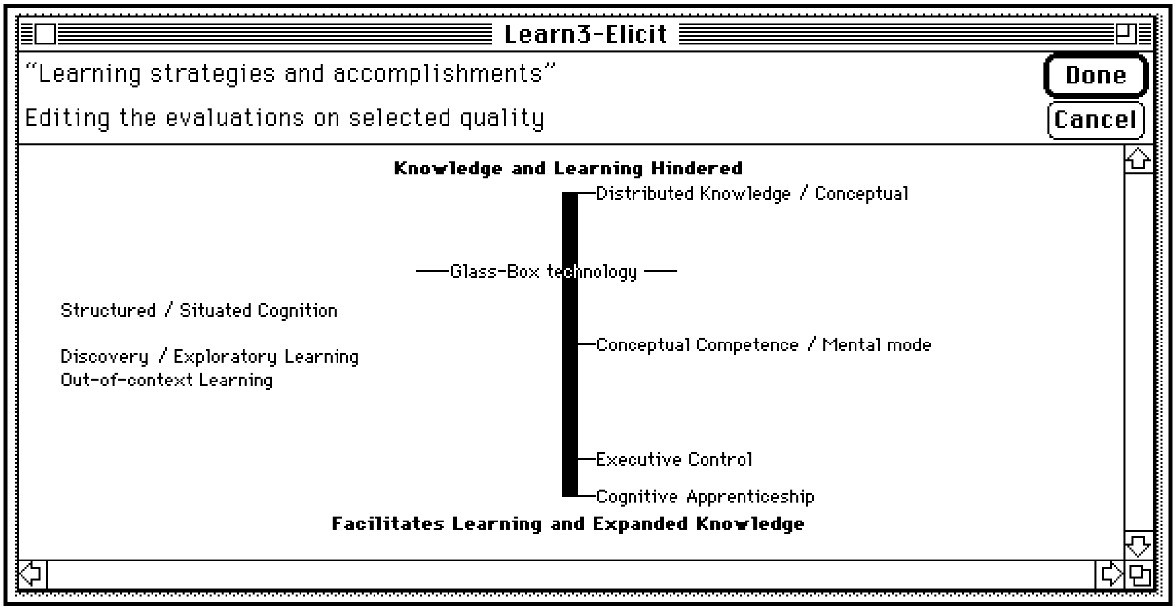


Figure 1 RepGrid Functionality

The ten graduate students were given access to RepGrid and associated tools for some two months with the assignment of developing their research ideas for their MSc research. Figures 2, 3 and 4 give examples of the interactive graphical elicitation of constructs using RepGrid by a graduate student organizing her framework of learning strategies as exemplified by some of the publications from the Institute for Research on Learning in California.

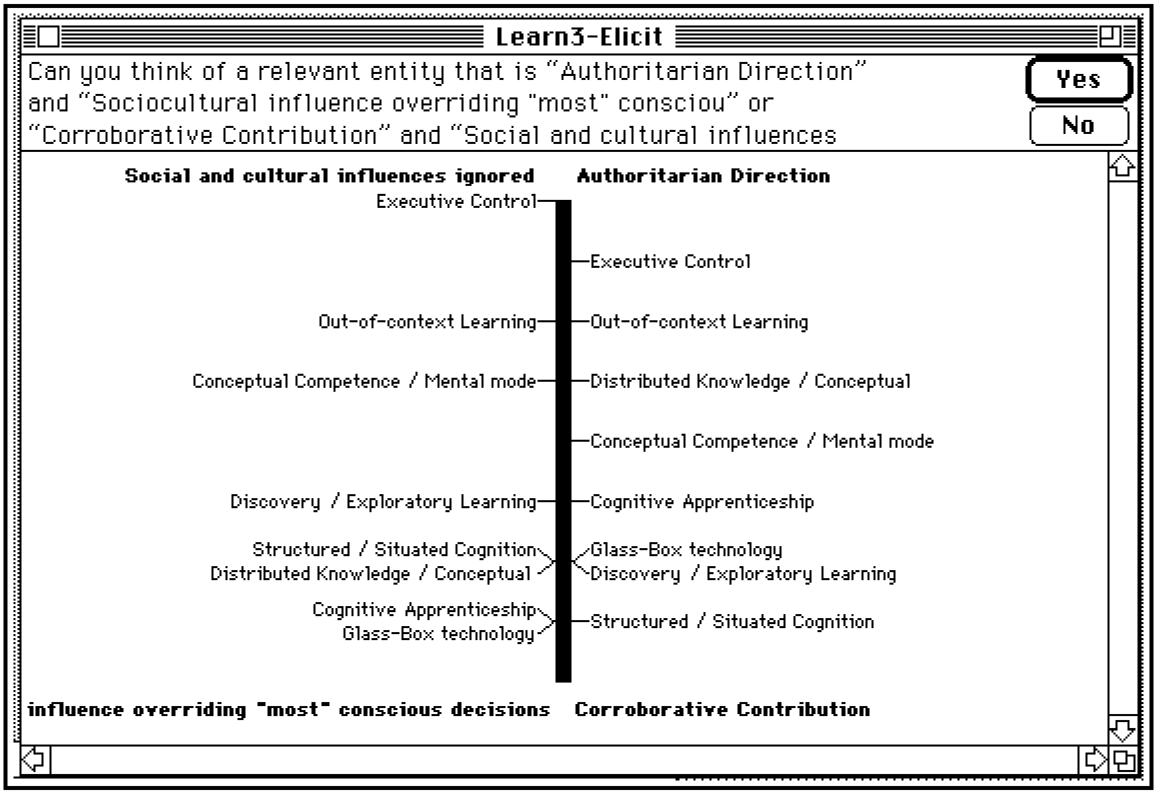
Figure 2 shows a construct in process of elicitation, with the elements listed on the left and being dragged on to the dimension of the bipolar construct *Facilitates Learning and Expanded Knowledge — Knowledge and Learning Hindered*. Figure 3 shows two constructs which are highly matched, showing the placing of the elements on each, and inviting the student to think of a new element which would reduce the match level.



"Learning strategies and accomplishments"

Editing the evaluations on selected quality

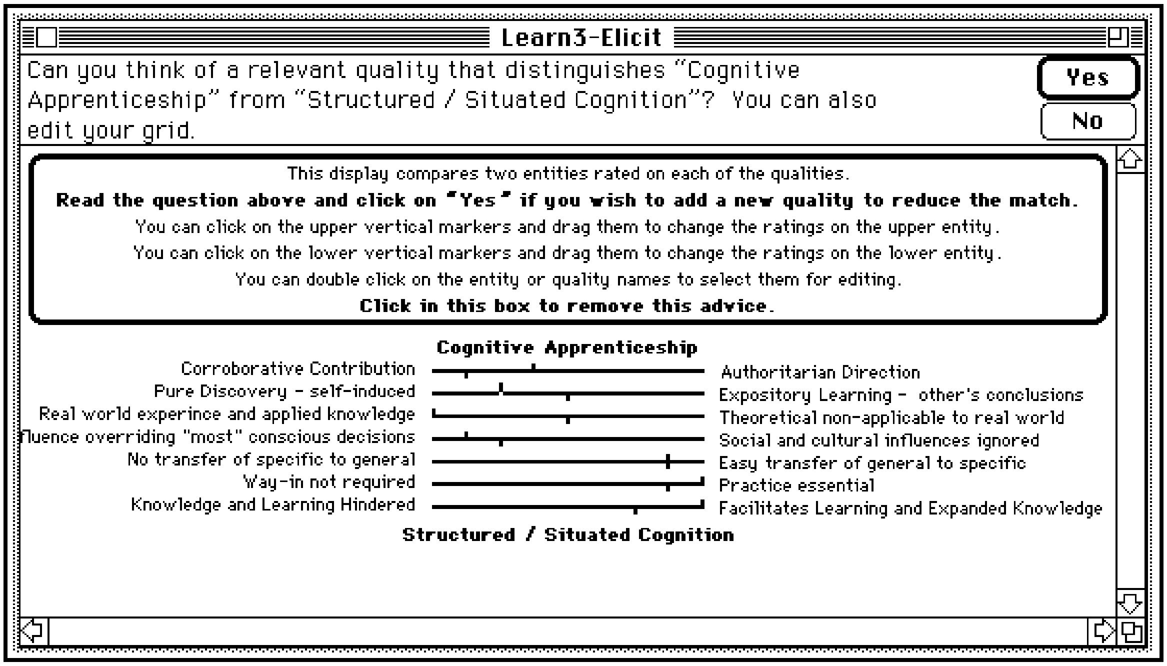
Figure 2 RepGrid Construct Rating



Can you think of a relevant entity that is "Authoritarian Direction"
and "Sociocultural influence overriding "most" consciou" or
"Corroborative Contribution" and "Social and cultural influences

Figure 3 RepGrid Construct Match

Figure 4 shows a similar situation with two elements which are highly matched. The marker sticking up refers to the element *Cognitive Apprenticeship* and the marker sticking down to the other element *Structured / Situated Cognition*. Elements and constructs can be moved or changed at any time.



Can you think of a relevant quality that distinguishes "Cognitive Apprenticeship" from "Structured / Situated Cognition"? You can also edit your grid.

This display compares two entities rated on each of the qualities.

Read the question above and click on "Yes" if you wish to add a new quality to reduce the match.

You can click on the upper vertical markers and drag them to change the ratings on the upper entity.

You can click on the lower vertical markers and drag them to change the ratings on the lower entity.

You can double click on the entity or quality names to select them for editing.

Click in this box to remove this advice.

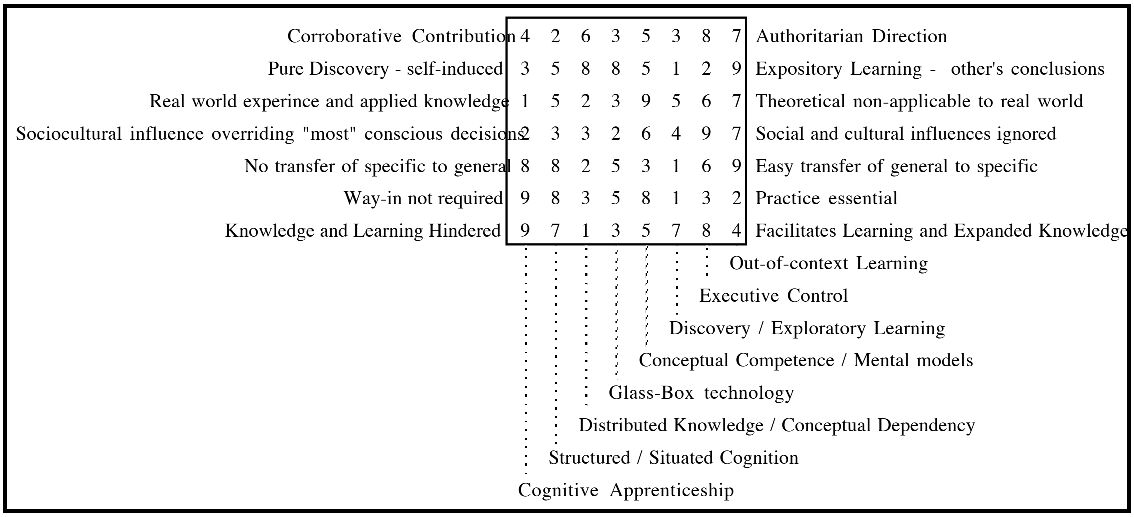
Cognitive Apprenticeship

Corroborative Contribution	Authoritarian Direction
Pure Discovery - self-induced	Expository Learning - other's conclusions
Real world experince and applied knowledge	Theoretical non-applicable to real world
luence overriding "most" conscious decisions	Social and cultural influences ignored
No transfer of specific to general	Easy transfer of general to specific
Way-in not required	Practice essential
Knowledge and Learning Hindered	Facilitates Learning and Expanded Knowledge

Structured / Situated Cognition

Figure 4 RepGrid Element Match

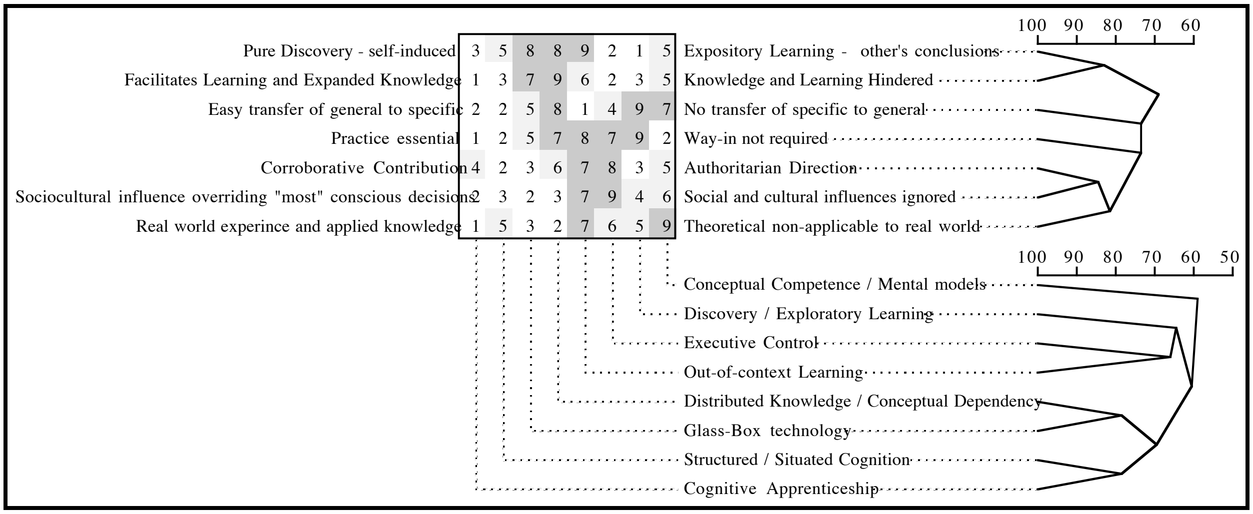
Figure 5 shows the display of the final grid with the constructs as rows, the elements as columns and the rating position of an element on a construct represented by a value from 1 on the left to 9 on the right. That is, if we look at the last construct *Cognitive Apprentice* is on the pole *Facilitates Learning and Expanded Knowledge* whereas *Distributed Knowledge / Conceptual Dependency* is rated as *Knowledge and Learning Hindered*. The element *Conceptual Competence / Mental Models* is rated a 5 which puts it at neither pole. The others are not at extremes of the poles, but are characterized by a part of both.



	Cognitive Apprenticeship	Structured / Situated Cognition	Distributed Knowledge / Conceptual Dependency	Glass-Box technology	Conceptual Competence / Mental models	Discovery / Exploratory Learning	Executive Control	Out-of-context Learning	
Corroborative Contribution	4	2	6	3	5	3	8	7	Authoritarian Direction
Pure Discovery - self-induced	3	5	8	8	5	1	2	9	Expository Learning - other's conclusions
Real world experince and applied knowledge	1	5	2	3	9	5	6	7	Theoretical non-applicable to real world
Sociocultural influence overriding "most" conscious decisions	2	3	3	2	6	4	9	7	Social and cultural influences ignored
No transfer of specific to general	8	8	2	5	3	1	6	9	Easy transfer of general to specific
Way-in not required	9	8	3	5	8	1	3	2	Practice essential
Knowledge and Learning Hindered	9	7	1	3	5	7	8	4	Facilitates Learning and Expanded Knowledge

Figure 5 RepGrid Display

Figure 6 shows the focused grid with the clusters on the right, and the values shaded in groups for easier interpretation, and Figure 7 shows the principal components analysis of the same data. The actual data values are also available, such as the match values and the factor loadings.



Pure Discovery - self-induced	3	5	8	8	9	2	1	5	Expository Learning - other's conclusions
Facilitates Learning and Expanded Knowledge	1	3	7	9	6	2	3	5	Knowledge and Learning Hindered
Easy transfer of general to specific	2	2	5	8	1	4	9	7	No transfer of specific to general
Practice essential	1	2	5	7	8	7	9	2	Way-in not required
Corroborative Contribution	4	2	3	6	7	8	3	5	Authoritarian Direction
Sociocultural influence overriding "most" conscious decisions	2	3	2	3	7	9	4	6	Social and cultural influences ignored
Real world experince and applied knowledge	1	5	3	2	7	6	5	9	Theoretical non-applicable to real world

Conceptual Competence / Mental models
Discovery / Exploratory Learning
Executive Control
Out-of-context Learning
Distributed Knowledge / Conceptual Dependency
Glass-Box technology
Structured / Situated Cognition
Cognitive Apprenticeship

Figure 6 RepGrid FOCUS

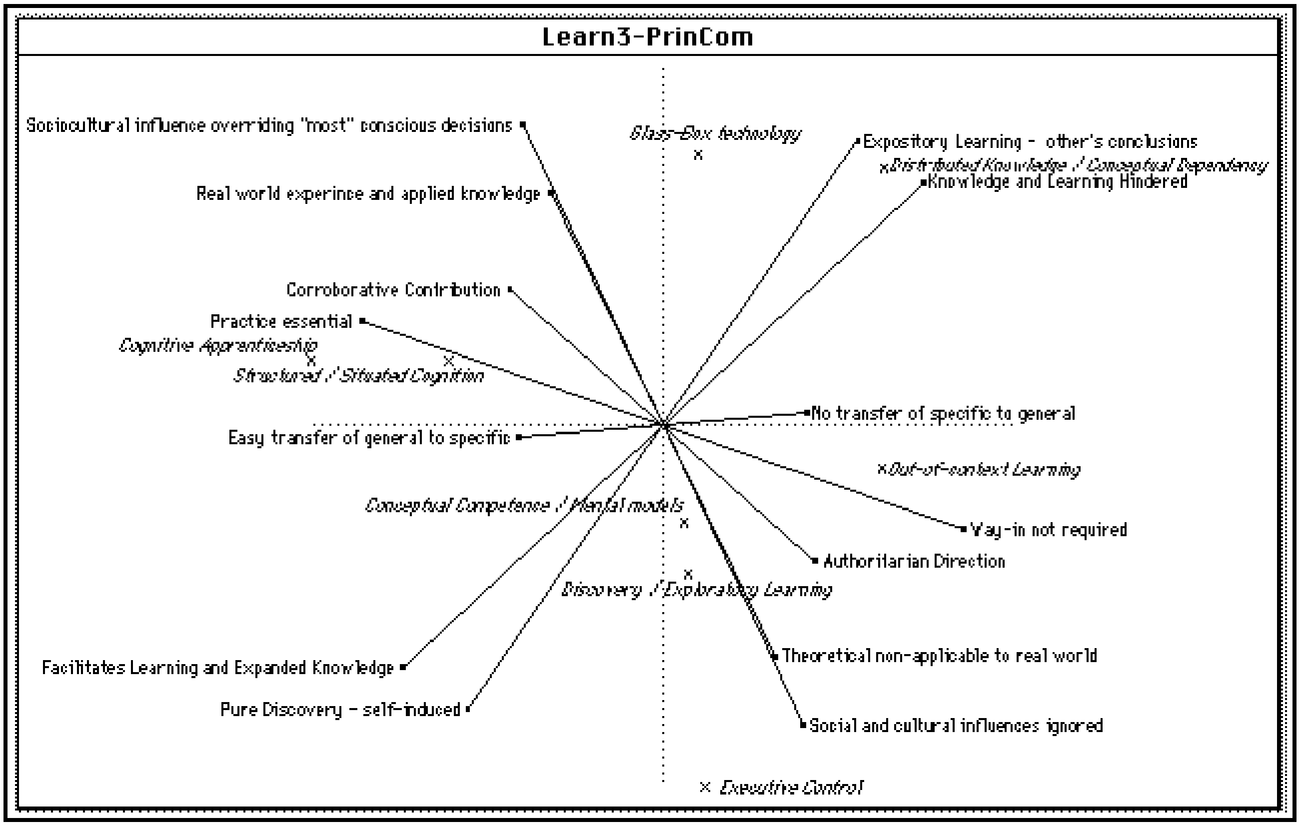


Figure 7 RepGrid PrinCom

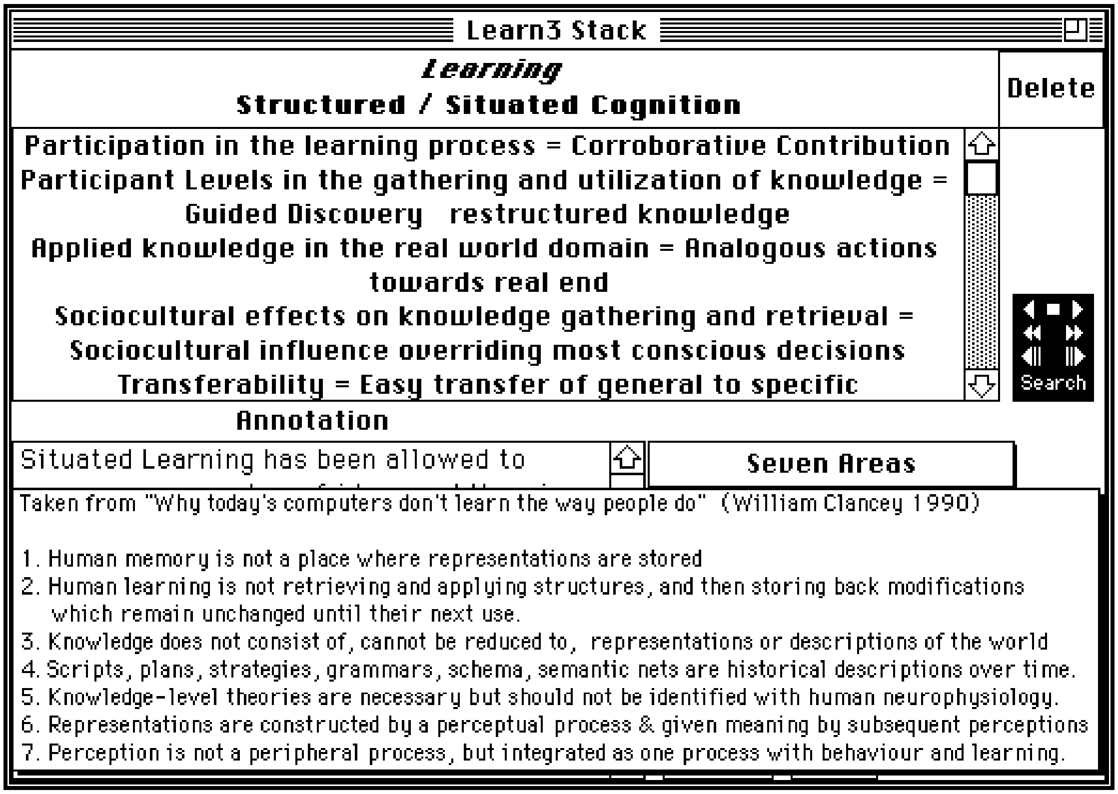
Using the example described above the single output variable was used *Towards a Perfect System*, that is, the construct *Facilitates Learning and Expanded Knowledge — Knowledge and Learning Hindered* with the middle point described as *Limited Knowledge and Learning Gain*. Some of the rules produced by the induction system (Gaines, 1989) were:

- Knowledge is *hindered* when there is *limited* master teaching
- Knowledge is *hindered* when there is both *cooperative* participation and *expository* learning
- *Limited* knowledge gain occurs in purely *theoretical* environments
- Pure *discovery facilitates* knowledge gain
- *Analogous* learning supported by applied practice *facilitates* learning

THE HYPERTEXT TOOL

Students were provided with a skeleton HyperCard stack that supported inter-application communication with RepGrid. When this stack is running at the same time as RepGrid a popup menu cursor appears as one mouses over element names and construct pole names in graphic screens such as those of Figures 2 through 7. Mousing down when this cursor appears brings up a popup menu that offers a link to HyperCard. Selecting this transfers to the HyperCard stack at the card corresponding to the element or construct, creating such a card if it does not already exist.

The upper part of such annotation cards is predefined as shown in Figure 8 to show the grid name, element or construct names, and possible construct values or actual element values. The lower part contains a scrolling text area to the left for annotation and an open area to the right for buttons linking to further annotation. Facilities for linking to subject matter video disks are also provided.



Learning
Structured / Situated Cognition

Participation in the learning process = Corroborative Contribution
Participant Levels in the gathering and utilization of knowledge = Guided Discovery restructured knowledge
Applied knowledge in the real world domain = Analogous actions towards real end
Sociocultural effects on knowledge gathering and retrieval = Sociocultural influence overriding most conscious decisions
Transferability = Easy transfer of general to specific

Annotation

Situated Learning has been allowed to

Taken from "Why today's computers don't learn the way people do" (William Clancey 1990)

1. Human memory is not a place where representations are stored
2. Human learning is not retrieving and applying structures, and then storing back modifications which remain unchanged until their next use.
3. Knowledge does not consist of, cannot be reduced to, representations or descriptions of the world
4. Scripts, plans, strategies, grammars, schema, semantic nets are historical descriptions over time.
5. Knowledge-level theories are necessary but should not be identified with human neurophysiology.
6. Representations are constructed by a perceptual process & given meaning by subsequent perceptions
7. Perception is not a peripheral process, but integrated as one process with behaviour and learning.

Figure 8 Element annotation card with additional annotation showing

All the students made heavy used of the hypermedia annotation facilities to annotate their elements and constructs and to add additional material such as background notes and diagrams. Since the supplied annotation facilities were designed to operate through a well-defined protocol leaving the full functionality of HyperCard open and available, several of the students took the opportunity to use the hypermedia tool for their own purposes. One student presented his complete final essay on this project in the stack embedding in it buttons that linked to examples, diagrams and references.

THE KNOWLEDGE EDITING TOOL

The knowledge structures developed in RepGrid can be exported to a variety of knowledge-based system shells as class, property, constraint, object, value and rule definitions. In particular they may be exported to the graphic editing tool associated with our knowledge representation server, KRS (Gaines, 1991). Figure 9 shows the grid concepts and rules shown above exported to KRS and graphed as a semantic net.

KL-ONE-style knowledge structures are difficult to edit because they are require the 'top-down' definition of general concepts and their stepwise refinement to more specific concepts. The grid methodology is a way of developing them 'bottom up' from cases. The KRS graphic knowledge editing tool further supports this approach. Knowledge structures can be developed and edited using drawing tools providing a natural visual language. The structures can extend across multiple screens supporting modularity and libraries. Structures can be freely duplicated and definitions may be fragmented across screens. The consistency of the definitions is determined only when they are compiled into a formal knowledge structure and inconsistencies are graphically highlighted.

The grapher is highly interactive. Objects, and groups of objects, may be dragged to new locations and the lines remain connected. Objects may be double-clicked to select them for editing—both text and object type may be edited. Popup menus associated with each object enable the connecting lines and arrows to be entered simply. The visual language used in Figure 9 is precisely defined. Concepts are ovals, primitive concepts are ovals with small horizontal lines inside each side, individuals rectangles, roles (and annotation) unboxed text, rules rounded-corner boxes, constraint expressions rounded-corner boxes with small horizontal lines. The interpretation of the arrows is overloaded but well-defined by the types of the objects at their head and tail. Lines without arrows connecting primitive concepts denote that the concepts are disjoint, and connecting roles that they are inverse. The knowledge compiler traces concepts and individuals through their outgoing arrows, builds a dependency table for concepts, highlighting circular links that it will not use, and generates concept definitions and individual assertions which are passed to the server.

All of the students exported their grid data to KRS and graphed it from various perspectives. However, this was done toward the end of the course and few of the students did much further development within KRS. The exception was one student who was very much taken by the graphic editing tool in its own right and used it directly to develop a number of different classifications of material in his research area of instructible systems. He remarked that he preferred the visual language of the graphic knowledge editor to the textual approach of an outliner and suggested a number of ways in which the tool could be improved as a knowledge outliner.

Ausubel (1969) proposed concept maps as a tool in education for both developing students' creativity and assessing their changing conceptual structures during the learning process. Novak & Gowin (1984) have reported extensive use of concept maps in the educational system, and Hunter, Stahl & Novak (1990) have developed CMap, a computer-based conceptual map tool.

The graphic editor in KRS may be seen as a rather more elaborate and formally based version of such a tool, and it would be interesting to see its impact in use by those in the educational system already using concept maps.

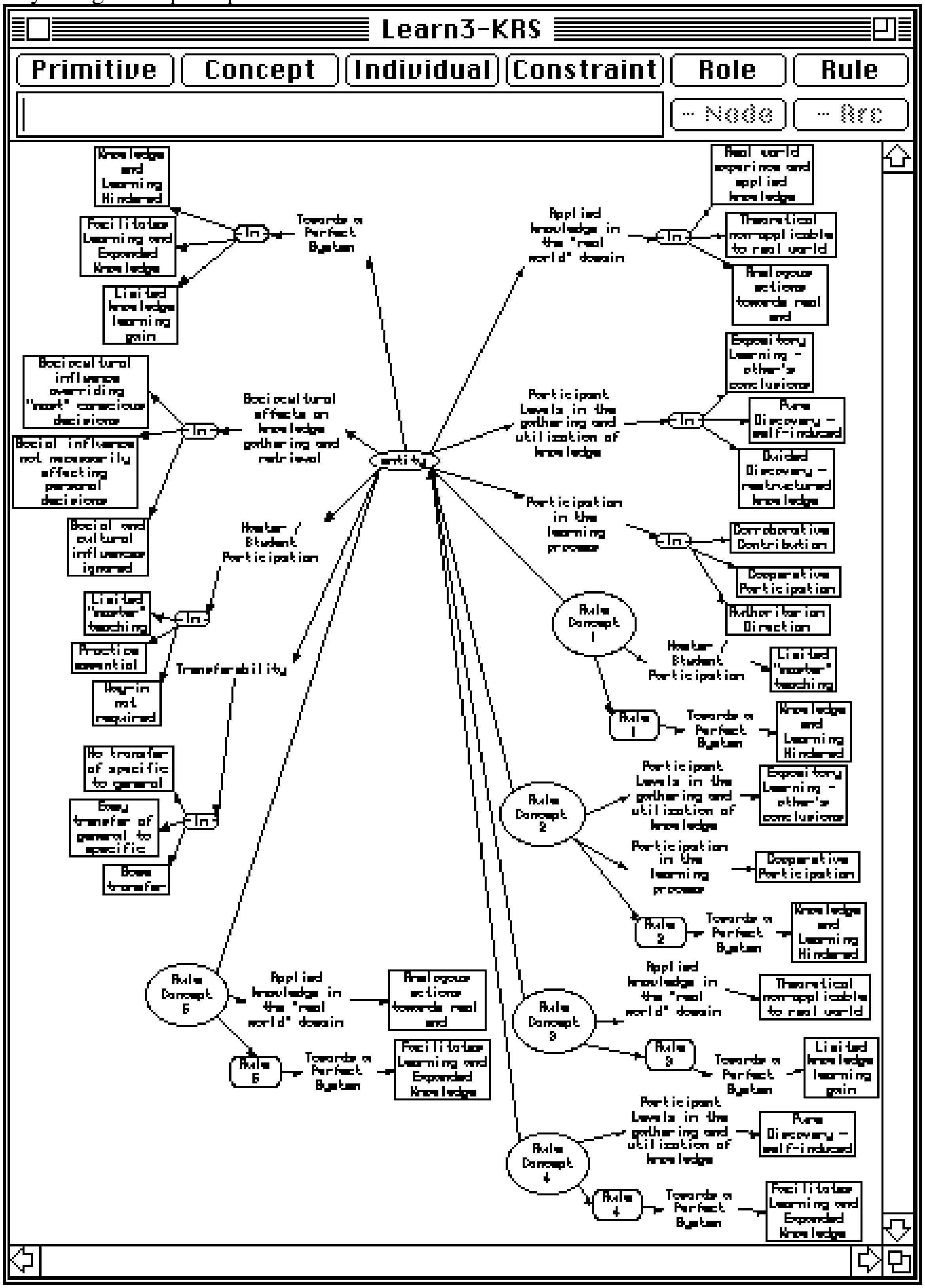


Figure 9 Grid and Induced Rules Exported to the KRS Graphic Knowledge Editor

SOME RESULTS

The students in the Cognitive Science course were encouraged to choose a topic which was closely related to their area of interest and their research project. We have already seen one grid in the general area of situated cognition; others included theories of mind, psychological paradigms and instructible systems. Figure 10 summarizes the research topics, domain chosen for elicitation, outcome in terms of material produced, and major comments of the students on the course.

	Research Topic	Chosen Domain	Outcome	Student Comments
1	open	learning strategies	grid, knowledge structure, stack	
2	open	situated cognition	grid, knowledge structure, stack	
3	instructible systems	instructible systems	2 grids, exchange with Socio analysis, 7 knowledge structures, stacks	prefer KRS to an outliner for developing ideas
4	expository writing support tools	psychological paradigms	2 grids, knowledge structures, stack	presented results as a HyperCard stack
5	cognitive science	theories of mind	grid, knowledge structure, stack	would like to use this for my thesis
6	intelligent tutoring	Pascal statements	grid, stack	
7	open	computational learning	grid, knowledge structure, stack	
8	genetic algorithms	computer games	grid, knowledge structure, stack	
9	machine learning	induction systems	grid, knowledge structure, stack	learned a lot more about induction systems doing this sort of structuring
10	complexity of computation	fast food	grid, knowledge structure, stack	concepts in research field are already defined and not suitable

Figure 10 Summary of Student Experience

It can be seen that not all the students chose topics associated with their research, and it is suspected from more detailed discussion that this was a form of cognitive defense in the same way that avoidance of a primary topic is in a clinical context. There was no pressure to conform since, from an educational point of view, we were primarily concerned to introduce the students to tools within a cognitive science framework that modeled conceptual structures. The fact that they could be used for a variety of practical purposes within the lifeworlds of the students was incidental. The tools continue to be available in the Department and it will be interesting to see whether they are further used by the students concerned in the future development of their research topics.

CONCLUSIONS

What has been reported here is very much a preliminary, informal investigation of the application of tools developed within the knowledge acquisition community to support the creative process in education. Although the underlying methodologies go back many years, it is only in very recently that these tools have reached a level of usability, and deliverability on personal computers, that makes it feasible to introduce them into the educational system. There is still much to be done in the total ‘packaging’ of such tools for the non-AI community.

We see the support of the human creative process and the support of experts in forming overt models of a basis for their skilled performance as closely related topics. The Kellyan model of creativity puts it strongly in cognitive terms that gives formal foundations to this view. Even if this is only part of the story and there are dimensions to creativity well outside the cognitive paradigm, there seems to be enough within it to make the enterprise worthwhile.

The converse is also true—that what is missing within our current modeling and overt knowledge frameworks may be a major weakness in the cognitive and artificial intelligence paradigms. The very attempt to add the support of creativity to the objectives of our general support of knowledge processes may lead to new insights, methodologies and tools that are valuable across a wide range of problems.

ACKNOWLEDGEMENTS

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