24. Designing, Exploring and Interacting: Novice Activities in the Boxer Computational Medium

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Abstract. The Boxer computational medium provides a new educational context. The processes of designing, exploring and interacting in Boxer present a new form of educational activity involving new goals and needs. An account of the experience of novice programmers, both teacher and students, is presented. The research suggests that, during the initial stages, active engagement in the Boxer medium provides new and powerful opportunities for learning for teachers as well as students. In particular, the evolving computer-mediated process makes overt the often tacit interactions, evaluations and assumptions about teaching and learning and supports reflection and reconceptualisation.

24.1 Introduction

A systemic view of the activity—cognitive, emotional and motor—that occurs as users interact with and explore a generic computational medium provides a powerful means of understanding the complexities of learning through exploration in an educational community. The process of designing and adapting a computer-based educational setting that is appropriate for student exploration and responsive to changing needs and goals in open-ended tasks is a powerful learning experience for teachers. The creative process externalises their knowledge and beliefs about the teaching/learning process which are often tacit in more usual classroom interactions. The use of a computational medium as part of their professional work also provides a functional basis for learning a programming language. For students, the presence of an adaptable medium provides new opportunities for personalised, active participation in the construction and evolution of the setting for learning as well as for construction of knowledge. In this paper the term "setting" is used to describe the relationship between a learner and the arena in which learning activities occur (Lave, 1988).

24.1.1 Generic and Specialised Software: Trade-offs

Generic software, such as Boxer, offers the possibility of a new kind of setting for human learning and researching activities. The setting has the potential to provide a rich environment for exploration, creation and invention—a cyberspace through which, with which and within which people may interact, explore, expressively create and reconstruct. Software of this kind has the potential to act within a community to mediate the flow of information and action.

For the novice, the trade off between generic software and more specialised software, at first glance, appears centred around the complexity and reconstructibility of generic media and the immediate instrumental utility and economy of effort in learning to use well-designed specialised software. Complexity is associated with effort in learning how to access the potential power of the system. For the user, the question is: How much do I need to learn in order to use this? The perceived "utility" of a medium such as Boxer is the ratio of value over effort—the value of and uses for programming in the medium and effort entailed in learning to do it (diSessa, 1986). Although capabilities such as reconstructibility are arguably beneficial in the longer term once programming skills are developed, in the beginning, maintenance of user motivation and exploratory activity depends on user perceptions of utility and their ability to gain access to the opportunities offered by the medium.

The possibilities for expressiveness and reconstruction are key elements of Boxer's utility. They also represent key differences between generic *computational media* (diSessa, this volume), such as Boxer, and more specialised exploratory educational software in mathematics and science such as *Algebra Supposer* (Educational Development Centre/Sunburst Inc.), Cabri Geometry (Laborde, this volume) or *Relab* (Bolt, Beranek and Newman Laboratories Inc.). Cabri Geometry represents an example of specialised software of the most sophisticated pedagogical design that aims to *constrain* the activities of the user in ways which facilitate particular insights and knowledge development in a specific knowledge domain—Euclidean geometry. Like most specialised software, the design takes little account of the difference between geometrically naive and more expert users. However, it is designed in ways that minimise difficulties in access and maximise the potential of the medium to focus students' attention on aspects of selected domain knowledge.

24.1.2 Approaches to Overcoming the Utility Barrier

Although computers have changed the ways in which most scientists and mathematicians work, computer use in mainstream curricula in mathematics and science is still marginal (Crawford, Groundwater-Smith and Milan, 1990; Kaput, 1992). Exploratory software constructed by experts has not been easy to incorporate into the system of activities and purposes that constitute educational institutions. The lack of enthusiasm about exploratory activities in schools has continued in spite of the growing recognition by researchers of the benefits of self-directed exploration as a learning activity. There is a growing gap between educational practice and recent theories of learning and human development. There is also a growing gap, in technologically advanced countries, between computer use in schools and in the wider culture. It seems that the utility barrier for software in educational settings lies less in the complexity of learning to use it than in the perceived utility of computer-based exploratory experiences as a basis for learning. The fact that at present most educational practice is still firmly focused on practices derived from paper and pencil technologies and transmission models of learning means that autonomous learning through exploration with computers is still not viewed as educationally useful by many teachers and administrators.

Approaches to reducing the utility barrier in specialised software have focused largely on embedding recognisable information and "intelligence" in the system and/or simplifying the interface. The recognisable purpose of educational software often involves tutorial structures that "teach" what has always been taught in recognisable ways. Specialised exploratory environments are constructed by experts to allow safe and fairly limited exploration in a prescribed setting. In Piaget's (1964) terms they seek to provide an environment that "we set up for them," a computer-based "sandpit" for intellectual activity and development. The best of them are "user friendly" and easily accessible though there is generally little provision for adaptation by the user. In more generic media, such as Logo or Boxer, the construction of "microworlds" (e.g., Edwards, this volume) potentially allows the same level of guidance and constraint for users and reduces the necessity for them to learn to program in a complex medium.

Supporting teachers in developing an understanding of the educational potential of new computer-based exploratory environments is more difficult. The current Explorers Project[1] is one example of the recognition of the gap between the current theories of learning as represented in recent software and curriculum documents and the "theories of action" (Argyris, 1993) of administrators, teachers and students in educational cultures. The project aims to support the use of new exploratory software by teachers through the use of interactive video and electronic mail to create a "community" of software users. The PRINT[2] Project takes an alternative approach and aims to enhance the ownership and use of educational software by supporting teacher authorship and customization of software—to blur the distinction between programmer and educational user (Eisenberg, this volume). That is, rather than supporting teachers in using software programmed by experts, the project aims to support teachers in constructing useful software themselves. Boxer, has the potential to blur the distinction between programmer and user even further—to

[1] Bolt, Berenek and Newman, Inc., 1993.
[2] PRINT Project, Department of Education, Dortrecht, Netherlands.

make it possible for the process of constructing software to be part of the educational process both for teachers and their students. As diSessa (this volume) states: "within the context of a fully functional computational medium, each application may need add only a few specific capabilities to be useful...teachers and students may get into the development act—and new pieces of software are not only very easy to appropriate, but are likely to be much better adapted to circumstances."

24.2 Boxer as a Medium for Exploratory Learning

Boxer is a complex and powerful system which has the advantage of reconstructibility and the "glass box"[3] transparency of inspectable programs (Crawford and Kay, 1991, 1992). The illusion is created that what you see is what you get. The closeness between interface representations and internal representations means that user familiarity with the interface generally provides an insight into the internal representation of the system. Objects, or boxes, can be customised and copied in ways that encourage participatory design of the immediate environment and more explicit microworlds. The text base of the interface presents a familiar medium and the box metaphor provides a powerful and accessible representational basis for making, inspecting and modifying computational objects.

As an exploratory environment Boxer has the potential to mediate negotiations between teachers and students about expectations, constraints and guidelines for a task or project. Boxer, as a "reconstuctible computational medium" (diSessa and Abelson, 1986), provides a suitable environment for the investigation of the processes whereby teachers and students explore, design, construct and reconstruct an intended "setting" for learning (Lave, 1988). Aspects of the relationships between the system, students and teacher-designer are more overtly negotiated when objectified as part of the organisation of the learning environment. Similarly, the domain knowledge that is objectified as part of a microworld or a program is organised and represented in new ways. Mathematical notions such as variable and function are embedded in the structure and organisation of the programming language. In addition to objectifying many normally tacit processes, Boxer is powerful and flexible enough to support data collection about programming activities by keeping records of transactions at the interface.

24.2.1 Boxer as a Changing Context for Learning

In an educational setting, Boxer presents the possibility for a *reactive environment* in the sense used by Resnick (this volume) when he describes the characteristics of the "patches" in Star Logo. That is, the actions and ideas of the people involved are transformed through their programming to *become* the educational environment. Their actions build the environment, customize it and in part define its meaning and

[3]Debra Feinstein, 1989, Glass Boxes: Lifting the Veil on Information, Benchmark/Spring Edition, 12-15.

potential. Traditionally the context of learning has been viewed as a static physical environment that forms a stable background to the activities of people. In Boxer, there is the potential for the setting to be transformed by the activities of people working in, through and with the medium. The nature of a computer-based setting may be overtly transformed by the actions of the users.

24.2.2 Integrating Teaching and Learning

The process of creating a new educational setting might be considered as a part of a teacher's professional work. It is also a powerful learning experience. In Fischer's (1993) terms the working and learning are integrated. Teachers learn as they work to construct an environment that represents their knowledge and beliefs about how students learn and provides an opportunity for students to learn selected domain knowledge. The blurring of the distinction between programming and interacting with the medium allows the possibility that knowledge—about learning processes, domain knowledge (e.g., in mathematics) and programming knowledge—is constructed by teachers through their activities in the medium.

24.3 Initial Interaction with the Boxer Medium

The focus of the research reported below has been on initial interaction with the Boxer medium in exploratory projects: that is, the complex system of activities and interactions that emerges as a teacher seeks to design and responsively modify an exploratory computer-based learning environment and the students explore the possibilities of the setting, tinker with it and use it to pursue their own projects. The choice to focus on novice programmers of Boxer was based on evidence that the ways in which people initially approach a computer-based medium have a powerful effect on later use (Schoenfeld, Smith and Arcavi, 1990; Thomas, 1993).

Most research on Boxer has reported student activity after some experience—usually one year—and considerable input from expert programmers (e.g., Noss and Hoyles, 1992). In contrast, the account below reports a microanalysis of introductory access to Boxer for teachers and students who are all novice programmers. Thus, exploring the interface was a major part of the initial activity. Boxer became the central element in a learning experience for all concerned—an expanding space to explore, play and grow in—a space where we collectively tried out our ideas and converted them into objective organisation of the interface. As such, this is a very different account from the one that might be expected when Boxer is used by experts in an established culture of Boxer users.

Issues surrounding the trade-off between easy access for the learner by means of a simplified interface and a focus on domain knowledge, and the advantages of participatory design and customisation of the learning environment, with less immediate and less specialised access to domain knowledge, were a critical focus of the study. Should learning be contextualized in a microworld (Edwards, this volume)? Should the learners learn through creating their own environment (Pratt, 1992)? What are the costs and benefits of each approach?

A second related trade-off became a major issue in the study and deserves some discussion. It is the trade-off between independent exploration and support in the form of constraints and guidelines. After all, why explore? What motivates people to tinker, or solve problems? What are the benefits of exploration in terms of learning? What cognitive processes are demanded by exploration? What are the characteristics of an exploratory setting? How much guidance can and should be given to students? How should the distribution of activity be negotiated between teachers and students? How should teachers and students interact via the Boxer medium?

24.4 Activity Theory: Learning through Action

The notion of Activity, as proposed by Russian psychologists, is useful for thinking about the processes involved as humans interact symbiotically with a computer system in processes involving exploration and inquiry. "Activity" implies active intellectual engagement and personal involvement as well as the connotations of physical action that come with the word in English. The Activity theorists (Leont'ev, 1981; Davidov and Markova, 1983) describe the fusion of knowledge, thinking, feeling and action as a basis for cognitive development. In their interactive and systemic model of cognition, "Activity," either physical, emotional or intellectual is stimulated by subjective perceptions of needs or expectations in any context and subordinated to subjective "images" of the goal of any action. For the Activity theorists, activity occurs first in a social context and is later internalised to create new cognitive structures that will form the basis of future consciousness and activity. Knowledge is socially constructed and interpersonally mediated within a cultural environment and, through action, is converted into objective organisation.

24.4.1 Actions and Operations

Within any Activity, Leont'ev and his compatriots make a distinction between "actions" which occur in cases of conscious decision-making, planning and novel problem solving and "operations" that are the often automated, routine procedures that are tools that usually form part of any Activity. They note that operations require little intellectual effort and are not usually available for change and review. Luria (1973) describes the "simultaneous processes" based in the parietal occipital lobes of the cortex that are involved in conscious actions. He suggests that such processing results in concept development and "matrices of community relations" that form the basis of later consciousness. Crawford (1986) found that simultaneous processes were associated with interpretation, representation, extrapolation, problem solving, self-evaluation and programming tasks. The Activity theorists take a systemic view of group actions. Engestrom (1990) uses the term "activity system" to describe the processes occurring when people act in a group, each with their own subjective needs, expectations and goals, as in the case of the teachers and students working with Boxer.

24.4.2 Designing the Scope of Activity

When teachers design any learning environment and provide scaffolding they usually act to reduce the intellectual demands on students by reducing the complexity of the actions to be undertaken. Teachers may also act to increase the scope and complexity of the environment if they judge that students are ready for a greater challenge. Similarly, in programming a computer-based environment they choose which aspects of the environment the students will focus on—what guidance or constraints will be provided—what kinds of learning activity will be encouraged. These choices are influenced in turn by their conceptions of the system and the learning task at hand.

Traditionally teachers have helped students by "showing them how to act." That is, they do the interpretation, decision-making, tinkering and planning and reduce the intellectual effort of the student to memorising other peoples' actions. This approach is clearly not appropriate in the design of exploratory environments. Scaffolding has the effect of reducing the scope and enhancing the predictability of student learning. By making the task manageable, it also reduces frustration. However, scaffolding has an effect on the quality of learning outcomes. Decisions about the scope of student action and the need for teacher-designed scaffolding might be considered as involving a judicious distribution of the actions within a learning community.

Activity theory provides a basis for thinking about the learning outcomes of the design and use of an exploratory environment. Which actions must be carried out by the teacher?—the students? What effects do the actions have on the knowledge and capability of each person? What operations would be useful to develop at an early stage? How is teacher awareness of the knowledge domain or the Boxer software changed in the process of the design activity? What demands does the context make on the student for actions?—for operations? What are their perceptions of their needs?—or the expectations of the setting? What is the history of those perceptions? Is prior knowledge available as a basis for future action? What is the perception of the goal of the task? What does the student need to know to explore in the environment?—about the domain knowledge?—about Boxer programming?

24.4.3 Activity Systems

To Activity theorists, explorations such as those using Boxer involve an activity system which includes the computational medium as one element. That is, as people explore and construct using Boxer, Activity occurs in a social context, using a humanly constructed medium; the process forms cognitive structures that become the basis of future awareness, exploration, reconstruction and interpretation.

This viewpoint raises questions about the characteristics of the cultural experience of learning and its objective results. Epistemologically, the action of memorising and reproducing old knowledge appears to result in knowledge that is available for reproduction but not innovation, review or re-representation in the form of objective organisation. There is also some evidence (Crawford, Gordon, Nicholas and Prosser, 1993) that extensive experiences of this kind are also associated with conceptions of knowledge as rules and statements and of learning as memorisation for most students. On the other hand, automated intellectual tools are often valuable as a means to such a complex activity as exploration. In either case, knowledge about effective strategies and tools, arising from experience, influences later learning.

In contrast, experience of actions that involve constructing, creating, designing and innovating result in knowledge that is available as a basis for further actions of the same kind (Harel, 1991). Experiences in active exploration lead to knowledge that is available and useful in further exploratory activity—experiences in decision making lead to capabilities in decision making. In other words, there appears to be a relationship between the quality of the Activity of any individual or group within any educational setting, or activity system, and the quality and potential of the resulting knowledge as a basis for future action.

24.5 Investigating Boxer as a Medium for Exploration

Exploration involves actions as well as operations. To develop an environment in which exploration would be perceived by students as functional, appropriate and motivating it seemed necessary to pay attention to their needs and goals in relation to the system and the social context.

In order to explore confidently students need some basic understanding of the system and some support. According to the Activity theorists further understanding about the Boxer medium will be developed through the process of exploration. Earlier research supported this hypothesis but suggested that the scope of technological understanding that develops in this way is determined by learners' purposes in using a generic computational medium (Bornholt, Crawford and Summers, 1993). Also, there is evidence that initial well-established routines (operations for Activity theorists) continue to be used long after they cease to be efficient or even functional (Schoenfeld, Smith and Arcavi, 1990; Thomas, 1993) Therefore, the exploratory environment in Boxer needs to be seen by novices as useful and enticing for meaningful tasks while also supporting the acquisition of necessary knowledge about the computational medium—Boxer. Care is needed in the introduction of initial procedures as these are likely to become robust habits. Necessary information needs to be accessible and presented in ways that will make it comprehensible and available for later use. The inspectability of the Boxer system and the naive realism are both assets in this respect.

However, the Boxer medium is only one element in an activity system in which exploratory activities are carried out. Exploration has been found to occur only when it is perceived as necessary and functional (Thomas, 1993). Motivation and the will to explore depend on security and commitment to the task and task demands. Collaboration is a powerful basis for supporting risk-taking and the independent learning behaviour that is necessary for exploration. The conditions for exploration clearly arise from the "setting" (Lave, 1988)—the relationships between the learner and other elements of the learning context. The social organisation of the context, the learner's approach to the computer system and the nature of the task all seem likely to influence the quality of action or exploration.

24.5.1 The Focus of Research

Because of the reconstructive capability of Boxer and the relative inexperience of the teacher, one aim in this project was to create a consultative and collaborative environment in which both teacher and student collaborated to make meaning within the system within the course of other self-selected exploratory projects. Further consultation and collaboration occurred between the teacher and the author as the environment was adapted between each session to better meet student needs.

The unit of analysis, in the study, was the *activity system* containing the teacher-designer, the student and the computer. The focus has been on the initial responses of novice Boxer programmers to exploratory tasks. The research addresses the question: How can Boxer be explored from a position of virtual ignorance? An aim of the exploratory projects was to facilitate the development of understanding of the notion of a variable and operations on a variable. An exploratory environment was designed initially and used cooperatively with a student for four one-hour sessions. The sessions were videotaped and also records were taken of student activity in the form of screen dumps and an *inputs* box which invited statements about the task from both teacher-designer and student and incorporated them into a database. At the end of the first four-hour session, some further modifications were made to the environment. A second student then began initial use of Boxer for a further four, one-hour sessions. Further modifications were made at the end of the second series. A project diary was also kept by the teacher-designer. C-Video was used to analyse the videotapes.

This small study has yielded valuable information about the processes of computer mediated interaction, the initial responses to Boxer, and the interactive system of activity that is mediated by a computer-based medium like Boxer.

24.5.2 Designing the Initial Environment

Designing the initial environment was posed as a project for the teacher-designer, Bill (name supplied). This involved exploring the environment with a view to creating a suitable educational setting and proved to be an intense learning experience for the teacher-designer (Crawford and Lambert, in press).

First, as mentioned above, the process of mediated activity, in a social and computational environment, makes some of the usually complex and tacit interaction processes overt (see, Crawford and Kay, in press). The necessity to plan for student activity mediated through Boxer, provided an externalised focus for analysis of the problem and heightened awareness of prior conceptions, influences and any gaps between the design intentions and student actions.

For example, Bill had an image of Boxer that was largely influenced by early experience with hypertext and some recent experiences with Logo. It became clear that this conception of Boxer strongly influenced initial attempts to use the medium and was modified through negotiation with the students.

The following personal goals in the initial learning of Boxer were reported by Bill in a diary of his experience:

1. developing a MM [*mental model*] of the keyboard aspects of the interface,
2. organising the visual work space, i.e., fitting related things on the screen at the same time so that I could **see** their relationships,
3. understanding "between box" relationships (particularly with variables),
4. scoping within hierarchically structured programs,
5. using *dynamic* variables (italics added).

He felt he needed to develop a mental model of where key commands were located on the keyboard. He also felt the need to develop ways to organise the work-space visually so that he could see the relationships between things on the screen. At the time Bill's perceived order of conceptual development of Boxer understanding was:

1. simple direction commands (e.g., `fd 20`),
2. using "nested" boxes,
3. using variables,
4. using dynamic variables,
5. using box names to form inter-box links.

Most interestingly, despite his recent experiences of exploring Boxer—of tinkering, trying things out, experimenting to see how things worked—Bill was aware of his new knowledge as series of instrumental commands and procedures. That is, over a very short period of time, his earlier actions had become operations and were conceived as tools that might be useful if taught to a student. Those qualities of the experience that were associated with the needs, expectations, frustrations and goals of the initial exploration were forgotten. Also, initial attempts to create an environment in which mathematical ideas might be explored revealed difficulties in applying conceptions of mathematics derived from a fairly traditional school experience in a programming environment. The issues involved in representing mathematical ideas in a computer environment are discussed in Abelson and diSessa (1986).

24.5.3 Initial Responses from a Student

An initial screen layout was devised by the teacher-designer using information and materials to hand. These involved examples of simplified "challenge tasks"[4] which were placed in nested boxes so that only the task at hand could be seen at each stage. The result was a big bare screen with one task box and one data box on it called *Task1!*

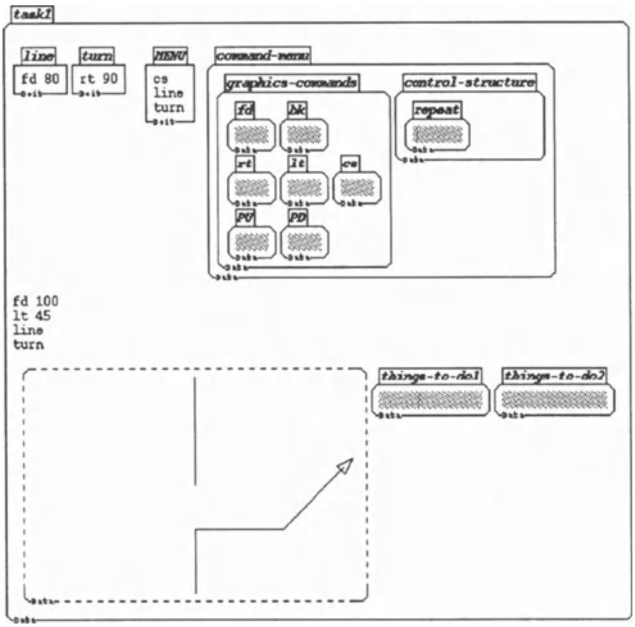

Figure 1. Screen display for *Task1*.

Figure 1, above, shows the result of opening *Task1*. The command library has the expected commands that will be needed. Each command box contains a plain English explanation and, if appropriate, a working example.

A challenge task was presented and data boxes containing hints and examples left lying around. The hints and examples were largely ignored by the first student Sally (name supplied). The first issue to arise in the negotiations about computer-mediated exploratory environments and independent learning became apparent. What seemed like a good idea for the designer-teacher in the light of his experience and goals, was not perceived as relevant by the student. This was at least in part because Sally came to the first Boxer session with her own preconceptions based on experience with Macintosh interfaces. She also recalled her knowledge as a

[4]Challenge tasks were originally part of demonstration boxes supplied by U. C. Berkeley.

series of operations that she was accustomed to carrying out. She started to compare the new medium with her previous experience. "Can I copy?"...."How can I undo?"...."It's very messy"...."It doesn't autowrap"...."How do I select this box?"...."Is there any way to make it faster?" She also had considerable difficulty manipulating boxes largely because of her habit of double-clicking. After twenty-one minutes, she still needed to ask how to open a box and name it.

It became clear that early access to Boxer would be greatly facilitated by provision of easily accessible information about operational commands. However, the transcript of the student's second session contains continuous references to difficulties in *communicating* with the Boxer system. "It didn't understand"....."It didn't do what I wanted it to." After thirty-seven minutes of the session, the teacher expressed sympathy with the communication difficulties in terms of "It's giving you a hard time."

The essentially negative response appears at least in part due to the frustration of a switch from a medium where she had experienced considerable success (Hypercard on Macintosh) to a new medium which was initially difficult because her previous knowledge had to be relearned. Similar resistance to changes in programmable tools were reported by Benyon, Crawford, Kay and Thomas (1991) among students using a new editor. In each situation, the potential benefits of the new medium were only appreciated after the initial gap in facility with automated basic commands was overcome.

Papert (1980) discusses person-computer interaction in terms of *speaking* mathematics to a computer. In these sessions the utility barrier was being socially defined as a communication problem. Support for exploring in Boxer seemed likely to require a renegotiation of the relevance of the information available and provision of more information about Boxer commands.

Sally had no previous experience of Logo but had been studying high-school mathematics for two years and so was familiar with the notion of a variable. Like the teacher-designer, she had difficulty in using this idea in a Boxer context even when exploring the *Poly* box (graphics box with staged tasks for constructing polygons). Further, the box metaphor, that is a fundamental aspect of the design of Boxer, although very powerful, appeared to distract Sally from looking at the relations between boxes.

24.5.4 Adapting the Environment

The screen layout within each task box was amended to include two new boxes, *working-bits* and *models*, containing working examples of individual commands and examples of pieces of program thought relevant to the set tasks. Also, the nested arrangement of boxes for the first two sessions was changed so that an initial choice of boxes and tasks was offered.

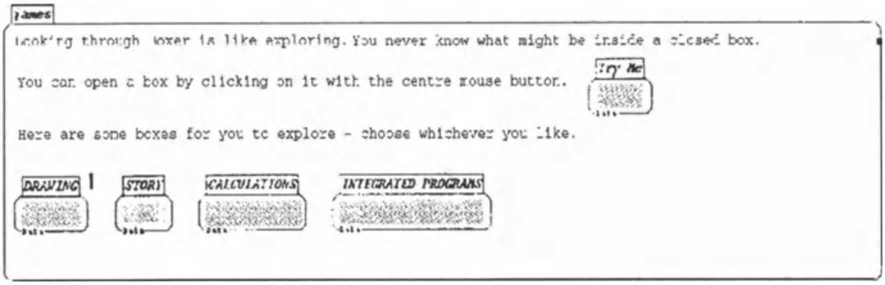

Figure 2. Adding working models to the environment.

24.5.5 A Second User Response

The second student to interact with the environment was James (name supplied). He had limited experience of Logo at school, but these experiences strongly influenced his initial approach to Boxer. Although a choice of boxes was offered, James merely opened them and closed them all and returned to the most familiar graphics box. He proceeded to pursue his own project (making waves—he is a surfer!) and was content to keep the scope of his activities largely within his existing knowledge of Logo. His interest in Boxer was limited to finding out any differences between what he knew of Logo and the Boxer language. He used the *model* box and the *bits* box within the *drawing* box to accomplish this goal. Thus, for James the exploration was confined to transforming knowledge of Logo into a Boxer environment and building a simple pattern. Interestingly, unlike Sally, he had no difficulty using the notion of a variable in Boxer. This is perhaps a result of his previous Logo experience which he reported as involving "making patterns with the turtle." Because he set himself a relatively simple task, James found his existing knowledge, derived from his Logo experience, generally functional. Despite encouragement he did little exploration.

James needed some encouragement to use the *input* box as a diary of his project but eventually he gave a succinct account of his goals and plans at the end of each session. His response was a valuable lesson in the futility of the teacher-designer trying to do the customisation for the student ahead of time and second guess needs and interests.

24.5.6 The Evolving Exploratory Interface

The constructability and reconstructability of Boxer, means that, at even the simplest level, the trade-off between utility and complexity is not black and white. Boxer can be customised to suit the needs of different users. The potential for participatory-design and customisation seems a considerable advantage especially in the case of exploratory environments. Security, confidence and ownership seem important aspects of an environment for independent exploration. Boxer allows the possibility of an evolutionary functionality in the system as users modify it to suit their developing needs and the consensual expectations of the user group. Bodker (1989) describes an "activity flow" as a software system is included in an activity. Because of the ease of reconstructibility the Boxer environment seems likely to evolve as it is used by a group of people. Not only does the activity of a group of users, working together on exploratory tasks in Boxer, seem likely to change their conceptions and cognitive structures but also to have objective results in terms of the form of the Boxer interface.

In creating an exploratory environment it seems important to provide choice and to support independent learning behaviour (Crawford, 1992). In initial activities in Boxer, choice can be achieved by providing a number of "worlds" of different kinds and either setting open-ended challenges or negotiating exploratory projects on an individual basis. If a particular kind of domain knowledge is considered important then the choices may be constrained to facilitate similar experiences for all users of the system. The tension between teachers' needs to be accountable for and in control of the content of the curriculum and the benefits of student-centred exploratory activities is not confined to computer-based environments.

24.6 Designing for Exploration

Our experience suggests that the process of facilitating independent learning behaviour in a Boxer context necessitates addressing some of the difficulties experienced by novices so that greater independence can be achieved in early sessions.

First it seems possible and desirable to simplify some basic procedures. For example, novices clearly find the complexity of finding, reading and saving files daunting. In the beginner explorer environment (shown below in Figure 3) steps have been taken to simplify these processes. A list of files is available in a box that can be opened within the work space. The *read-name* and *save-name* boxes simplify the processes of reading and saving boxes. This form of modification seems certain to influence the students' conception of file organisation in Boxer. However, it is calculated to refocus their attention within the domain and on the boxes and the relationships between them. A closet in the same space contains the necessary programs and is available as a resource for those who wish to know more.

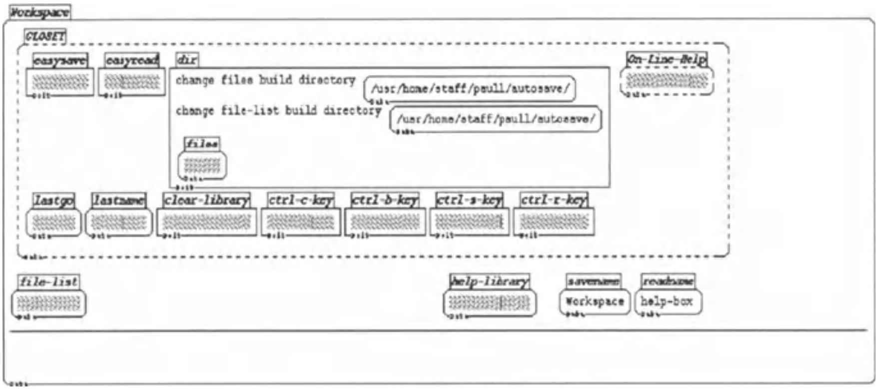

Figure 3. Aids to access.

The command library, has now been replaced by an evolving *help-library* box which automatically records the information that has been asked for in the work space. Experience, so far, suggests that the process of providing relevant information close to where it will be needed (as in the case of the *models* and *bits* boxes) is initially beneficial. Novices appear to find the "box is a container" metaphor very powerful and are reluctant to move outside the current box in search of information. Opening, expanding and shutting boxes remains problematic for a long time especially when the Macintosh-inspired "double click habit" persists.[5] Also, users' inability to structure the screen layout accurately makes multibox management difficult. The notion of working bits as dynamic illustrations of command function appears much more accessible to novices than the somewhat enigmatic responses in "computer science-ese" that are obtained from using the `apropos` command that is available as part of the Boxer medium.

An independent and self-directed role, appropriate for exploratory thinking and learning, requires that the novice is not totally dependent on an expert person at each of the frequent points of difficulty and in order to learn each new command. This means being able to ask for information within the system and to receive interpretable responses. For novices the use of natural language to interrogate the system appears highly desirable as a form of support.

[5]Editor's note: Several of the start up difficulties noted here are artifacts of the use of a workstation Boxer—with its lack of pulldown menus, dependence on the underlying Unix file system and other Macintosh incompatibilities—with Macintosh-familiar subjects. A Macintosh Boxer is now available.

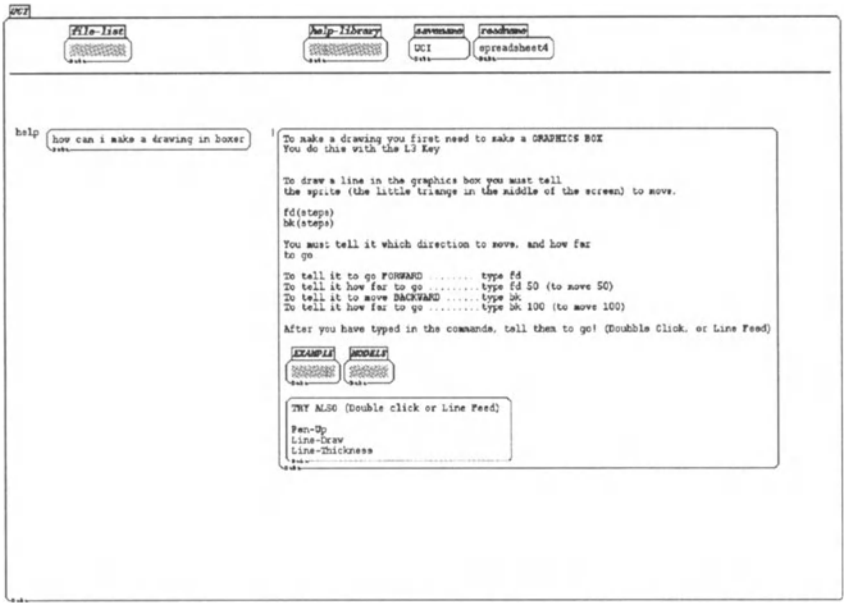

Figure 4. Natural Language help function.

To be able to pose a question in natural language is often difficult in itself though helpful in clarifying a point of difficulty. To be able to use natural language to seek "help" also fits with student conceptions of communicating with the machine either in the imperative (in the form of commands) or to seek assistance about how to use commands (through questions). An online help function was designed to meet these requirements. Details are shown above in Figure 4.

Finally, it seemed desirable for both teachers and students to keep a list handy of the commands currently in use and the questions asked. The `question data box` (qdb) command now provides a list of questions asked in the current work space and the names of the boxes where the information is stored in the work-space *help-library* box. Where possible the box names are the same as the necessary command names. If the enigmatic box name prompt is insufficient, the student knows that the full help response will be stored in a box of the same name in the *help-library* box above.

24.7 Evolving Activity in a New Medium

The account of one teacher's experience of creating an exploratory environment in Boxer highlights a number of issues that challenge current educational practice.

First, it became clear that the teacher-designer's knowledge of mathematics and mathematical representation was not in a form that could easily be used as a basis for creating an exploratory computer-based learning environment. Bill's knowledge of a variable derived from teacher-centred, textbook-based, paper and pencil exercises needed to be reviewed and relearned before it could be used as a basis for a supportive environment for student exploration and learning. Creating an exploratory environment in a computer-based medium presented a further challenge. However, the new context for activity also provided some of the solutions to Bill's initial difficulties. The act of creating a context, engaging in the process of solving an educational problem, provided a form of investigatory project in itself. Bill became a learner as well as a teacher. His creative activities formed a basis for the development of his knowledge of mathematics.

Second, although Bill had espoused current theories of learning, much of his understanding of how children learn was tacit. The process of using Boxer as a mediator in communication between Bill and his students presented a new form of Activity in which his ideas about teaching and learning were necessarily made explicit as part of the design process. In addition, the process of designing for exploration motivated him to pay attention to the ways in which students interpreted and responded to the tasks he set within the environment. The whole process was reviewed by watching videotapes and discussing possible solutions between each session. It became clear that although lack of knowledge of Boxer was an issue in the process, it was not the only challenge. Bill was often surprised by student responses and needed to review his assumptions about teaching and learning. In a computer-based context the usual constraints on students were removed. They felt free to speak openly about their frustrations, needs and goals. They raised questions that stimulated further learning and necessitated objective responses in terms of the organisation of the work-space.

Finally, the process of creating an exploratory environment with Boxer provided a motivating project as a basis for learning about the computational-medium itself. Thus, learning to program became a means to an educational end. From the beginning Boxer was a central element in the creative activity for both Bill and his students. The interface shaped their understanding and interacting in various ways. As they learned, the work-space evolved with them providing tangible evidence of their activity. The challenge of learning to program Boxer provided a basis for reflection and reconceptualisation of the teaching/learning process and the mathematics. Through the challenge presented by a new environment, a new form of educational activity evolved.

The initial ideas about utility have changed. It now seems important to ask: Useful for what? The process of learning to act in a new medium presents challenges. But it also presents new opportunities. There were difficulties in learning to represent information in a computational medium and in teaching and learning using Boxer. However, this new environment necessitated a major review of educational practice and learning outcomes. In the past, changing teaching practice has been difficult. It has also been difficult to overcome the limits of teachers' mathematical knowledge, gained through traditional school curricula, as a basis for teaching through investigation and exploration. This research suggests that learning to use a computational medium, such as Boxer, provides a powerful basis for teachers' professional development.

24.8 Conclusions

Generic software, such as Boxer, has powerful potential to mediate activity and reconceptualization for both teachers and students. It also makes overt the *activity flow* as teachers learn through designing, planning and organising information and students attempt to gain access to the system and learn through exploring chosen environments and constructing their own. That is, there are shifts in the nature and focus of cognitive processes as learning occurs. It also supports flexible negotiated distribution of activity between all participants in a learning culture.

Results suggest that the trade-offs between:

- complexity and reconstructibility versus immediate instrumental utility
- the utility barrier of participatory design of the environment versus immediate access and focus on the domain knowledge,
- independent activity by the user versus supportive constraints

are not clear. In fact, the very process of participating in constructing and responsively reconstructing the computer-based environment, in a tangible way, supports and makes overt the more tacit social negotiations in a learning culture. The activity of construction and reconstruction is also clearly a powerful means to reconceptualization of domain knowledge for teachers as well as their students. This study supports Pratt's (1992) finding about the power of designing microworlds and programming activities as a basis for learning.

Boxer is capable of supporting an evolutionary and personalised work space which expands according to user demands and needs—an expanding and reacting sandpit to explore, play and grow in—a source of feedback about learning, purposes and needs. In such a context, knowledge, technology and action are entwined. The ideas and concepts of all participants are converted into the objective organisation of the interface in ways with reflect the complexities of the learning culture. In turn, the evolving interface provides a flexible medium for further exploration and learning. Even for complete novices, the reconstructible medium can become personalised as an artifact of and for learning activity.

Acknowledgments

I would like to acknowledge the inspiration and encouragement that I have gained from James Uther, Paul Lambert and others in the small Boxer group at The University of Sydney. I am deeply indebted to their creativity and enthusiasm.

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