

Design and Evaluation of Virtual Realities (Tutorial Notes)

Bibliographic Reference:

Marc Davis, Kevin McGee, and Edith Ackermann. "Design and Evaluation of Virtual Realities (Tutorial Notes)." In: *Proceedings of INTERCHI'93 in Amsterdam, The Netherlands*, ACM Press, 1993.



INTERCHI '93

BRIDGES BETWEEN WORLDS

Design and Evaluation of Virtual Realities

Edith Ackermann, *MIT Media Laboratory*

Marc Davis, *MIT Media Laboratory*

Kevin McGee, *International Media
Research Foundation*

Tutorial Notes

21

Design and Evaluation of Virtual Realities

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Marc Davis, MIT Media Laboratory (USA)

Kevin McGee, International Media Research Foundation (Japan)

INTERCHI TUTORIAL NOTES¹

Amsterdam, Netherlands

April 26, 1993

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AGENDA

Time	Section	Facilitator(s)
INTRODUCTION		
9:00-9:10	Welcome	Marc
9:10-9:20	Who We Are and Why We Are Here <ul style="list-style-type: none">• Psychology and Media Sciences• Storming the Reality Studio• Environments for Societies of Agents	Edith Marc Kevin
GETTING LEVERAGE ON VIRTUAL REALITY		
9:20-9:30	Technical Overview: Intermediaries and Hard Problems	Kevin
9:30-9:45	Virtual Reality and Learning	Edith
9:45-10:05	Leverage Points for the Design and Evaluation of Virtual Realities	Marc
EXERCISE I		
10:05-10:10	Form Groups and Select Reporters	Marc
10:20-10:30	Generate an Inventory of Virtual Phenomena	Marc
10:30-11:00	BREAK	

Time	Section	Facilitator(s)
THE MATRIX		
11:00-11:10	Introduction to the Matrix	Edith
EXERCISE II		
11:10-11:15	Select Virtual Phenomena from the Inventories	Kevin
11:15-11:30	Situate Virtual Phenomena within the Matrix	All
11:30-11:35	And So What?	Edith
DESIGN EXAMPLE		
11:35-11:45	Design Example	All
EXERCISE III		
11:45-12:05	Small Group Design Exercise	All
12:05-12:25	Groups Present	All
CONCLUSIONS		
12:25-12:30	Wrap-Up and Conclusions	All

ABSTRACT

The purpose of this workshop is to enable you to use your own experience for the design and evaluation of virtual realities. The CHI community is engaged in the hard problem of finding criteria for the assessment of computer-human interfaces. In this workshop, we propose an approach to evaluation which differs from the methodologies of empirical psychology and standard testing. To this end, we focus on constructing with you a set of conceptual tools and methods for using your own experience to evaluate and design virtual technologies.

There will be a very general overview of some of the current virtual technologies, as well as an introduction to the kinds of learning that virtual realities afford. Then, through a set of collaborative group exercises, participants will be encouraged to use the expertise they already possess by exploring some of the qualities of virtual technologies in terms of the kinds of experiences they afford. In particular, we will introduce two dimensions for consideration: the technological and the transformational dimensions; and participants will then work with these during design sessions in which they extend existing virtual technologies, and then evaluate the results. Tutorial participants will come away with a set of leverage points for designing and evaluating virtual technologies.

This tutorial is highly participatory. No previous technical knowledge is required of participants.

INSTRUCTOR BIOGRAPHIES

Edith Ackermann is Associate Professor in the Learning and Common Sense Section (Epistemology and Learning Group) at the MIT Media Laboratory. Her background is in developmental psychology. Before she came to MIT at the invitation of Seymour Papert, Edith Ackermann was a collaborator at the International Center of Genetic Epistemology, under the direction of Jean Piaget. She worked in close collaboration with Bärbel Inhelder and Guy Cellérier, at the Faculty of Psychology and Sciences of Education, at the University of Geneva, teaching courses and conducting research on constructivist approaches to knowledge acquisition—in children, adults, and scientists. Her current interest is in the uses of technologies in education. She participates in various projects on the design and evaluation of virtual exploratoria and constructive learning environments for children.

Marc Davis is a Research Assistant in the Learning and Common Sense Section (Machine Understanding Group) at the MIT Media Laboratory. In his current doctoral work, he is building a system called "Media Streams" for annotating, retrieving, manipulating, and repurposing digital video. Before coming to the Media Laboratory, he completed his Master's work in reader-response theory at the University of Konstanz in Germany under Wolfgang Iser. Marc Davis is also participating (with Kevin McGee) in the redesign of the BMW Museum's exhibits about the history of mobility and transportation. He spent this past summer pursuing his research at Mitsubishi Electric Research Labs in Cambridge, Massachusetts. Marc Davis' work is about providing powerful tools for a whole generation of TV viewers (himself included) to enable them to make video a personal and interactive medium.

Kevin McGee is Principle Researcher of the International Media Research Foundation (IMRF) in Tokyo. Before joining IMRF he completed his doctoral work at the MIT Media Laboratory, which focused on a computational model of cognitive development and the implications of this theory for the design of media to facilitate learning. Currently, his major research concerns arise from an attempt to construct environments which afford complex relationships between agents—both computational and human—and between these agents and their environments. More concretely, this involves the study of mind and computational environments. Research into mind proceeds through the study of individuals using computational systems and the development of computational theories of mind (such as the *Society of Mind* theory of Marvin Minsky). The research into computational environments concentrates on the development of agent-based programming languages, evolving systems (artificial life, genetic algorithms, etc.), and frameworks for *embodying* and *making accessible* powerful ideas.

Design and Evaluation of Virtual Realities

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TUTORIAL MATERIALS

Welcome

Today everyone is talking about the coming revolution in computer-human interface which will be brought about by virtual reality technology. The discussion ranges from obscure, highly technical talk of polygons, bandwidth, Polhemus sensors, eyephones, and datagloves to prophetic pronouncements about how VR will change the way we think, live, work, play, and learn. Our goal is to provide you with conceptual tools and methods for *using your own experience* to help you explore and think about, to evaluate and design, virtual reality. We too share in the belief that virtual reality holds the promise to enable radical and positive change in human interface and human life. But we also believe that most people have all the resources they need to envision and analyze this technology in the richness of their own daily experiences in interacting with current technology, each other, and the world. And because we feel that virtual reality does hold such promise we want to encourage, through tutorials like this one, serious thought about this technology by the people who will use it and help shape it—that is all of us.

Today we will not be lecturing to you for two and a half hours about the design and evaluation of virtual realities. To do so would be foolish for two reasons. First, virtual reality is such a new phenomenon that it is far too early for final classifications and systems of analysis which will be adequate for describing this new medium. Second, and most important, we believe that to lecture about design in a tutorial setting is like trying to teach dance as a correspondence course. The experience of working directly on these issues with us and your colleagues today is probably the best way to begin the process of serious thought and activity about the design and evaluation of virtual phenomena. We will explore virtual phenomena in daily life and virtual technology being created today by researchers and practitioners in the field. What we hope to offer you is a way of thinking about virtual reality and a way of *thinking about thinking* about virtual reality (and design in general) which will help you in your work and play with this and other new media.

Who We Are
and
Why We Are Here

Edith Ackermann: Learning and Media Sciences

If I had to define my "intellectual niche" in a few words, I would say that I am engaged in two major enterprises:

1. Studying how people (children, laypersons, scientists) come to gradually make sense of their lives and themselves.
2. Imagining, designing, and assessing settings for children and adults in which they optimize their interactions with the world, while learning about themselves as cognizing agents by exploring, expressing and probing—or validating—their thoughts.

Before I came to the Media Laboratory, I was a psychologist in search of tool-builders who were themselves engaged in exploring *how the tools they build engage the minds of those who use them!* Prior to that, I had studied how children build and appropriate tools, and how tools shape children's minds. In recent years, I became more of a tool builder myself—a very low-tech tool-, toy-, and microworld-designer, indeed!

The focus of the Media Laboratory's Epistemology and Learning Group is: to design computer-based artifacts for constructive learning; to refine the design of these artifacts (programmable construction kits, exploratoria, interactive microworlds) through the analysis of their appropriation and use in different learning cultures; and to invent the appropriate research techniques that allow for such a mutual refinement to take place. Our "users" are children and teachers who live and work in schools, and who—luckily for everyone—also spend some of their time in science clubs, museums, and other "informal settings."

One of the lessons I have learned in the last six years at the Media Laboratory is that the existing experimental techniques (so called "user-testing" and other forms of standard evaluations) are of little use to designers, students, teachers, and media-researchers! Much of my current teaching and research goes into rethinking the mutual contributions of—and boundaries between—learning, teaching, research and design, and to redefine their complementary role in the creation and evaluation of constructive learning environments.

Marc Davis: Storming the Reality Studio

Storm The Reality Studio.
And retake the universe.

—William S. Burroughs, *Nova Express*

As a child I watched a lot of television. Hours upon hours of it everyday. And like millions of other American children I found that this activity, which took up so much of my time and interest, was not even discussed, let alone explored or analyzed in the other activity I engaged in for hours upon hours during the week: going to school. It was as if my entire culture was in a state of denial or suffered from widespread recurrent short-term amnesia. We learned how to write, how to read, how to speak, and manipulate numbers, but the skills that would have connected me to the affective center of my world—and to the engine of my culture's society and economy—were not taught. Today, children and most adults still do not have access to tools for creating, manipulating, analyzing, and playing with moving images and sound. My work is about radically changing that situation through the development of tools (both conceptual and computational) which will enable people to create virtual worlds through the repurposing of media (mass, popular, and personal).

Before beginning my doctoral work at the MIT Media Laboratory, I was studying literary theory and philosophy at the University of Konstanz in Germany. There I realized that if I would have lived during the tremendous revolution in media technology brought about by print, I would have left the academy to go work with Gutenberg. Today, we are in the midst of an even greater transformation in media technology—the transition to a world in which all information is in digital form, and thus manipulable, transmissible, and sharable in ways that were never possible before in human history. In a few short years, we will live in a world in which large amounts of rich data (video, audio, text, numbers) will be able to be accessed, processed, and shared by people around the world. The needed infrastructure in terms of bandwidth, storage, computation, and content will be in place—the challenge is designing the tools, interfaces, and forms of access for people who want to use this technology in their daily lives.

Kevin McGee:

Environments for Societies of Agents

The one-line statement which summarizes my current research is that I am developing virtual environments for societies of agents.

Virtuality

Virtuality has three aspects which interest me: the developmental, the environmental, and the technological (or mind, world, and mediation). First, from the perspective of developmental psychology, the world we live in is always the virtual world of our experiences and concerns. Second, individuals learn, develop, and define themselves in terms of their environments, whether the environment is natural, social, urban, or technological. Third, technology, in the original sense of the word, as a form of knowing-by-doing, is part of the continuing evolution and development of ever more flexible tools which allow us to mediate between mind and world.

Agents

The research on agents is driven by similar concerns. The research on mind is framed in terms of "mental agents", after the Society of Mind theory of Marvin Minsky; the research on environments is framed in terms of computational agents and the development of an "agent-oriented programming" paradigm; and the research on mediation is framed in terms of "interface agents", agents which facilitate the interaction between the workings of the mind and computational tools.

Societies

The word "society" has a double meaning in this context: it refers both to the study of societies of mental agents, and to the development of societies of computational agents. My current research, then, centers on the attempt to develop environments which afford complex relationships between agents, both computational and human, and between these agents and their computational environments. Among others, these concerns include the development of agent-based programming languages, frameworks for making "powerful ideas" accessible, evolving systems (artificial life, genetic algorithms, etc.), and the development of computational theories of mind.

Getting Leverage On Virtual Reality

Technical Overview:

Intermediaries and Hard Problems

Important Goals for VR Research

- Eliminate intermediaries
- Facilitate working on hard problems

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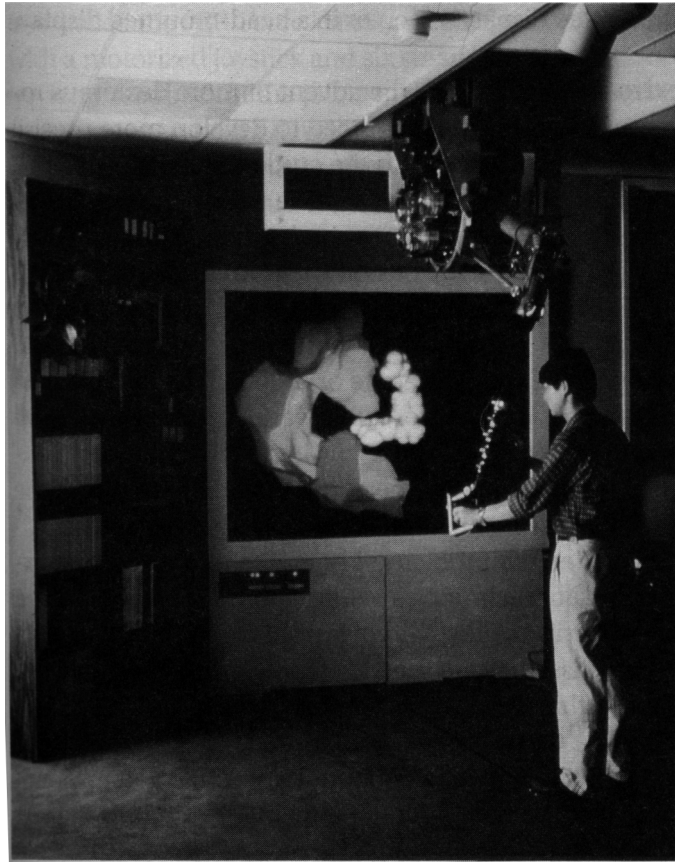
The general assumption is that in most cases the architect is an unnecessary and cumbersome (and even detrimental) middleman between individual, constantly changing needs, and the continuous incorporation of these needs into the built environment. The architect's primary functions, I propose, will be served well and served best by computers. In this sense [I am talking] about a new kind of architecture without architects (and even without surrogate architects).

—Nicholas Negroponte,
The Soft Architecture Machine

The alternative to the dependence of a society on its schools is not the creation of new devices to make people learn what experts have decided they need to know; rather, it is the creation of a radically new relationship between human beings and their environment.

—Ivan Illich,
In Lieu of Education

Although our tutorial is mainly concerned with providing theoretical tools, the following pages present a quick overview of some of the existing technology. The function of this section is two-fold. On the one hand, it should serve as brief introduction for those who are not familiar with the technology. On the other hand, it locates the technology within a broader framework which we will discuss in greater detail.



**Hard and Interesting Problems:
The Argonne Remote Manipulator**

[illegible][illegible]

[illegible][illegible]

[illegible]



Objects to Transform With: Architectural Walk-Through

[illegible]

Objects to Transform With

In this tutorial we will focus on one particular aspect of the design of "objects to think with": transformation. Indeed, we could say that our particular interest here is the development of "objects to transform with."

Indeed, the degree to which it is possible to transform a system substantially effects the extent to which it is possible to use the system to work with "objects to think with."

Take, for example, the ability to go beyond conventional CAD/CAM renditions of buildings and actually create architectural walk-throughs. A user's ability to transform a virtual space as a result of "inhabiting" it greatly increases the degree to which problems in architectural design become "objects to think with."

[illegible]

There are many barriers which prevent people from being able to work on the hard problems which interest them. Some barriers include: the cost of the activity; the level of danger of the activity; the age, race, or gender restrictions; the physical requirements; or the fact that the tools, materials, or concepts are represented in ways which are alienating.

Age. Many of the reasons why it takes so long for people to “grow old enough” to participate in society stem from the nature of the tools and materials they have access to. The future opportunity for very young people to communicate and work with others via the personal computer seems inevitable. We feel, however, that this is only the beginning. In March of 1993, we hosted a panel discussion under the heading *VR for 2-Year Olds: Designing a Future Learning Environment*. The emphasis here was on seriously exploring which barriers to social and intellectual participation could be lowered or eliminated through the use of this technology.

[illegible]



Technology Barriers

We are all familiar with the limitations of technological development. To use a mundane example, untold hours of the preparation of this very tutorial manual were spent waiting for scanned images to scroll on a screen. Machines are always too slow, have too little storage, and only do what we *tell* them to do instead of what we *mean* for them to do.

However, the example of waiting for scanned images serves a double purpose. It is both an example of how the technology is too primitive ("low-tech"), but it is also an example of how the technology is too advanced ("high-tech"). It is too high-tech because the capability of scanned images tempts us to suffer many hours of exasperation when a simpler, more low-tech approach such as drawing and Xeroxing might be more appropriate.

We always trade off between advantages of a technology as it stands in relation to what it has effectively replaced and the disadvantages of what it is not yet able—or may never be able—to do.

The Polhemus Tracker is just one of several competing position/orientation trackers. Where other systems use mechanical, optical, or ultrasonic methods, the Polhemus Tracker generates a magnetic field. However, magnetic sensors—unlike mechanical systems—have a problem with accuracy. Mechanical systems, on the other hand, are usually unwieldy.

[illegible]

Play

We believe that some of the greatest changes that will come from human-computer interaction will result from the ability to *play* in ways that were previously impossible.


Most of us living in the post-industrial West separate work and play. This distinction is partly the result of the spatial separation of work, school, and home—a separation that has been a reality for most people since the print revolution. However, computational media are beginning to make this separation less and less necessary. Not only will the new media bring these activities back together, they will contribute to a process of actually redefining the activities themselves.

In fact, the concept of "telepresence"—where individuals don full-body suits and remotely operate robots or equipment—might someday stand the paradigm which replaces school. Rather than having medical students learn about operating by using one medium and actually do it in another, we might see the two media converge into one, thereby eliminating unnecessary intermediaries and providing tools for working on the hard and interesting problems.

[illegible]

Virtual Reality and Learning

Virtual Reality and Learning



assimilation

accommodation

ADAPTATION

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The most fundamental subjective experience is the extension of Self thrown into the object focused, accommodating one's own self to 'become' the object itself.

(Sayeki 1989)

Human development is a history of successive emergences from embeddedness in order to relate better.

(Kegan 1982)

All intention wants to complete itself in saying.

(Merleau-Ponty 1962)

These three quotes capture a paradox which is central to our concern about VR and learning. The first talks about the importance of immersing oneself in the object of inquiry; the second talks about the growth as successive emergences from embeddedness, the third talks about people's need to recast their experience—the cognitive dance between diving-in and stepping-back.

Piaget defined intelligence as adaptation, or the ability to maintain a balance between stability and change, closure and openness, tradition and innovation, or, in his own words, between assimilation and accommodation. Becoming-one with a phenomenon (getting immersed) may lead to a momentary sense of loss (drifting away from oneself) but allows for change and innovation (openness to variations). Imposing one's order upon the world may lead to momentary separation (setting boundaries) but allows for the building of cognitive invariants (or the ability to grant the world an existence beyond one's current relation with it).

KNOWING

- To know is to relate
- To relate is to interact

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- # KNOWING
- To know is to relate
 - To relate is to interact
-
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KNOWING

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KNOWING

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[illegible]

Indeed, interaction is not (always) direct manipulation of physical objects.

There are times when people act directly, yet on symbolic objects, and other times, when they act symbolically, yet on physical objects. There are even times when they refrain from acting altogether, by running scenarios in their head, or thinking (internalized action).

By mediating their intervention through the use of models, simulations, and other transitional spaces, people become able to both explore real issues in make-believe worlds, and play around with virtual or make-believe objects through "real" manipulation.

Far from distancing the subject from personal experience, such a mediation allows a closer, more direct, and personal exploration of intangible ideas. It provides a way to make intangible ideas tangible.

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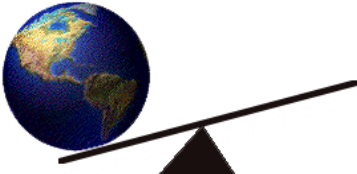
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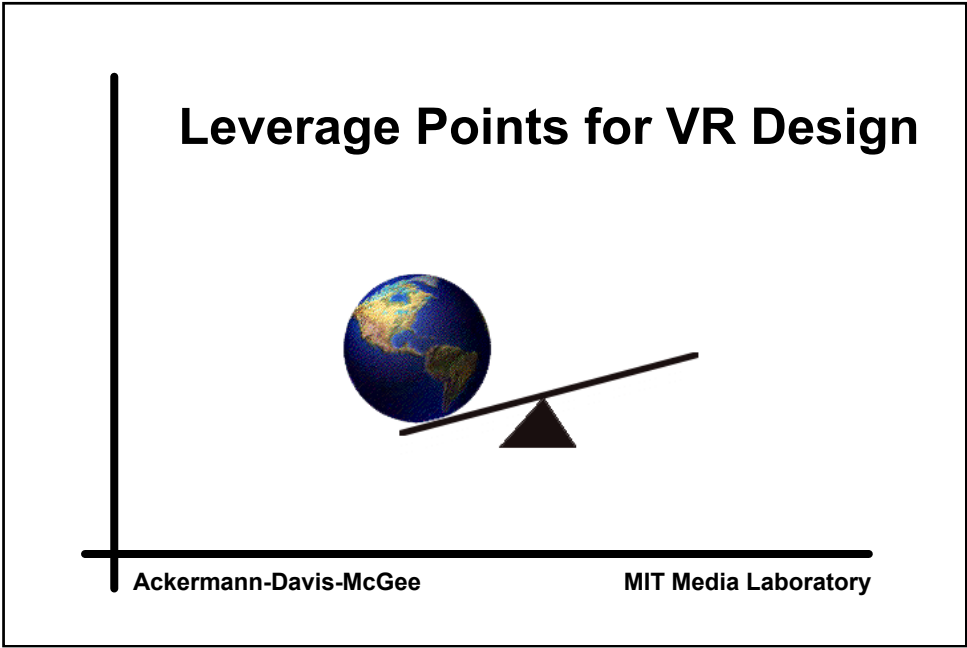
Leverage Points
for the
Design and Evaluation
of
Virtual Realities

Leverage Points for VR Design

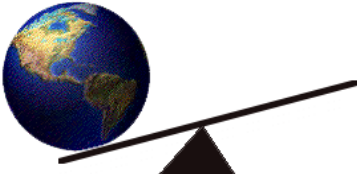


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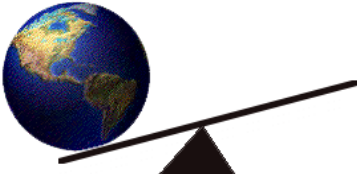


Leverage Points for VR Design



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Leverage Points for VR Design



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TRANSFORMATION

- Objects of Transformations
- Transformations
- Properties of Transformations

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- 
- # TRANSFORMATION
- Objects of Transformations
 - Transformations
 - Properties of Transformations
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TRANSFORMATION

- Objects of Transformations
- Transformations
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TRANSFORMATION

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Why is transformation a useful concept?

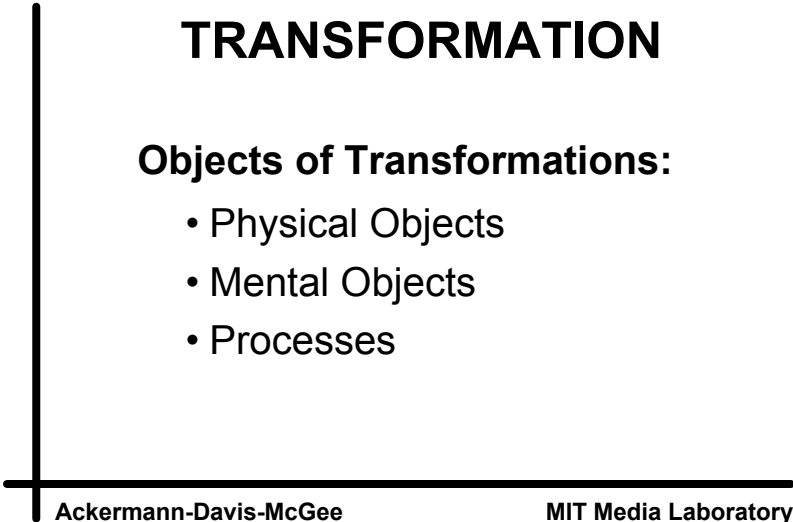
We think about transformation as bi-directional, as a system with feedback in which an agent through its activity in the world transforms an object. Through the process of transforming the object the agent transforms itself.



What makes virtual reality so interesting is the potential to have greater control not just over what kind of objects we transform, but of the properties of the transformations themselves.

What does it mean to talk about the properties of transformations? Are these properties of the transformation itself or of the state of the transformed object? Transformations become accessible to us in that they become tangible or object-like. To become tangible, transformations must be recorded. A recording of the activity of transformation must be left behind as a tangible trace. Recording is what allows a process to become an object which itself can be transformed. Transformations are recorded either in the object of transformation itself, which bears the trace of the transformation as a record of its own history (like the erosion of a mountainside over millennia), or the transformation is recorded in some other medium (like a film or a computer simulation of a process which can be replayed and altered).

[illegible]



TRANSFORMATION

Objects of Transformations:

- Physical Objects
- Mental Objects
- Processes

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- Physical Objects
- Mental Objects
- Processes

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[illegible]

objects, like the famous shoe phone of Maxwell Smart.

[illegible][illegible][illegible]

TRANSFORMATION

Transformations:

- Copy/Paste/Cut/Erase...
- Divide/Compose...
- Substitute/Invert...
- ...

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TRANSFORMATION

Transformations:

- Copy/Paste/Cut/Erase...
- Divide/Compose...
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TRANSFORMATION

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Virtual technologies allow us to combine and play with transformations of physical, mental and procedural objects. The computer has already made some physical transformations much easier and changed our relationship to the physical world. For example, words can be transformed through copy, cut, paste, and erase without using carbons, scissors, glue or white-out. Because we have the ability to work with words in a virtual rather than a physical manifestation, we begin to think about transforming other physical objects into virtual ones. For example, with a CAD/CAM system, we move back and forth between manipulations of physical and virtual objects.

This is a prelude to transformations which enable virtual/imaginary objects to be manipulated physically. Virtual reality's most significant contribution may be its ability to make the objects of the imagination tangible and shareable. Examples of these types of transformations abound in children's play. A stick becomes a magic wand. A broom becomes a hobby horse. A corrugated box becomes a TV. These are examples of one of the most powerful types of transformation—one which VR may make even more powerful—*bricolage*. A bricoleur, as discussed by Derrida, citing Levi-Strauss, is "someone who uses the 'means at hand,' that is, the instruments he finds at his disposition around him, those which are already there, which had not been specially conceived with an eye to the operation for which they are to be used and to which one tries by trial and error to adapt them, not hesitating to change them whenever it appears necessary, or to try several of them at once, even if their form and their origin are heterogeneous—and so forth." (Derrida 1978)

_____Rap

music_____

_____scratch

video_____

_____compilation

films_____

_____photo composi-

ing_____

_____using a coke

can_____

_____ for a doorstep

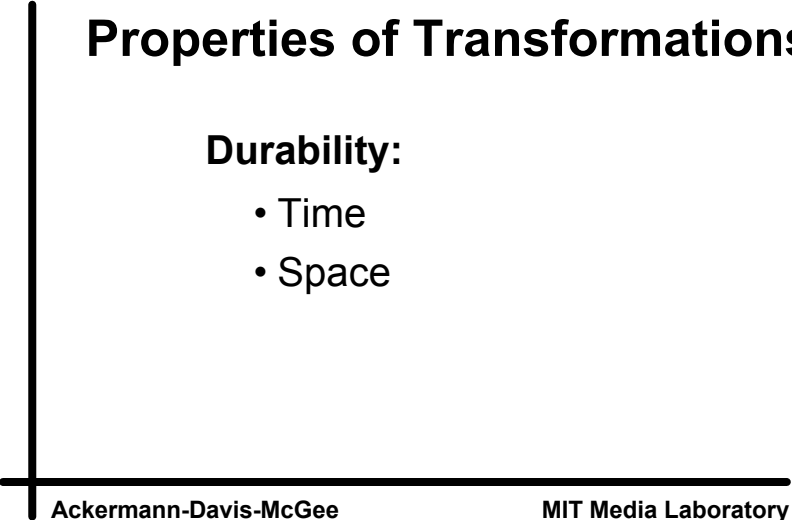
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Properties of Transformations

Durability:

- Time
- Space

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- Time
- Space

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[illegible]

[illegible][illegible][illegible]

Properties of Transformations

Accessibility:

- Permissions
- Conventions
- To Self
- To Others

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Properties of Transformations

Accessibility:

- Permissions
- Conventions
- To Self
- To Others

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- # Properties of Transformations
- Accessibility:**
- Permissions
 - Conventions
 - To Self
 - To Others
-
- Ackermann-Davis-McGee MIT Media Laboratory

Properties of Transformations

Accessibility:

- Permissions
- Conventions
- To Self
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Properties of Transformations

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Properties of Transformations

Propagation in a System:

- **Propagations**
 - **none**
 - **local**
 - **global**

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Properties of Transformations

Propagation in a System:

- **Systems**
 - **dynamic/static**
 - **modular/uniform**
 - **self-regulating/non-self-regulating**

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[illegible]

Systems, in which transformations propagate, can have various underlying properties which afford different types of interactions, transformations, and experiences.

Static systems don't change, whereas dynamic systems can change or be changed. Examples of static systems include crystal lattices, inert gases, grids, materials at absolute zero, and certain social and political philosophies.

Dynamic systems can have a steady-state, evolve, cycle, or decay. Transformations can affect changes in dynamic systems, or make static systems into dynamic ones. Examples include economic cycles, organisms, and ecological systems.

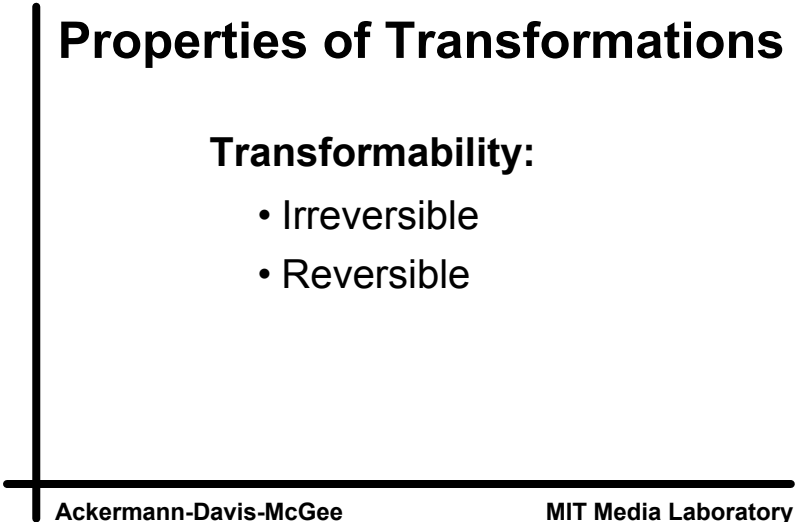
Modular systems have reusable parts with specific differentiated functions which can be used to construct new systems. LEGO and object-oriented programs are examples of modular systems.

Uniform systems may have highly dynamic, yet homogeneous components. For example, uniform cellular automata can exhibit highly dynamic phenomena.

Self-regulating systems involve feedback which results in dynamically changing but stable state. For example, a thermostat is a self-regulating system which maintains a stable temperature.

Non-self-regulating systems have no feedback, only linear causality. Examples include machines which transfer force but do not have feedback, like a lever, or systems which transfer information but do not have feedback, like bureaucracies.

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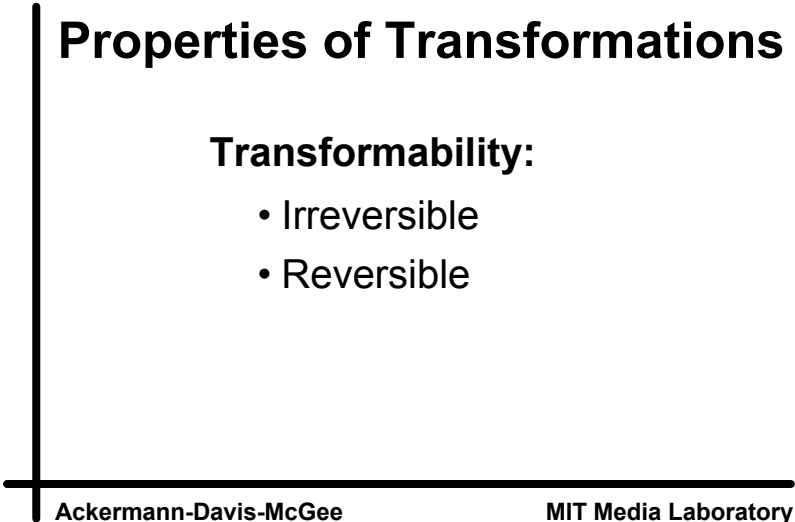
Properties of Transformations

Transformability:

- Irreversible
- Reversible

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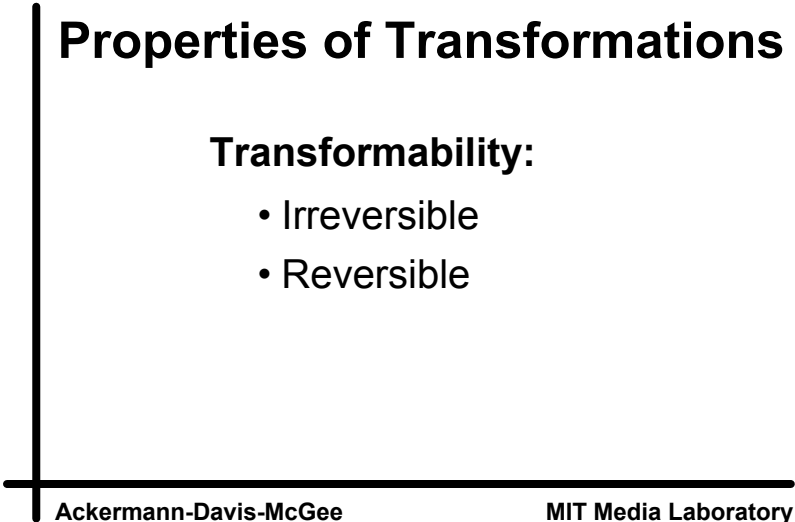
Properties of Transformations

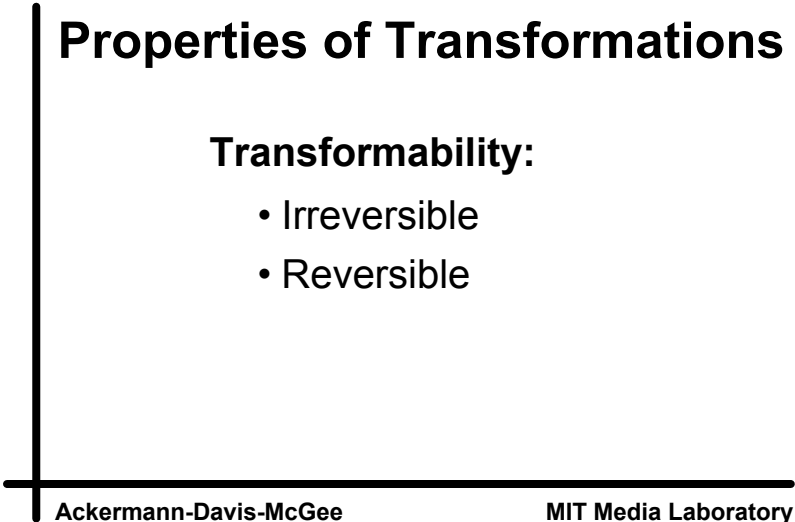
Transformability:

- Irreversible
- Reversible

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- 
- # Properties of Transformations
- Transformability:**
- Irreversible
 - Reversible
- Ackermann-Davis-McGee MIT Media Laboratory



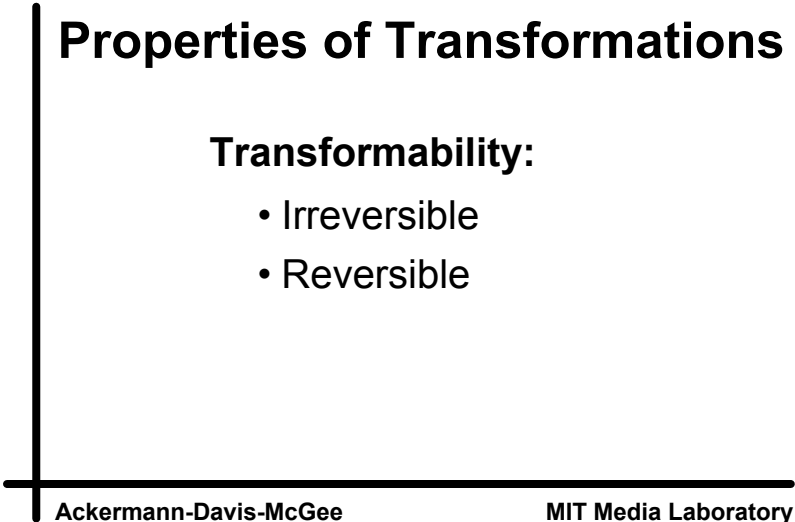
Properties of Transformations

Transformability:

- Irreversible
- Reversible

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Properties of Transformations

Transformability:

- Irreversible
- Reversible

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Exercise I:

**Generating an Inventory
of
Virtual Phenomena**

In order to develop a working familiarity with the leverage points:

- 1) We will now form small groups.**
- 2) Each group will select one individual to be the reporter.**
- 3) As Marc goes through the leverage points, each group will quickly generate examples of corresponding virtual phenomena.**

Leverage Points:

Virtual Phenomena:

[illegible]

Leverage Points:

Virtual Phenomena:

[illegible]

Leverage Points:

Virtual Phenomena:

[illegible]

The Matrix



[illegible][illegible]

Exercise II:

Situating Virtual Phenomena

within the

Matrix

In order to play with our inventories of virtual phenomena we situate some examples within the Transformation/Tech Matrix:

- 1) Each group selects 3 of the examples of virtual phenomena generated in Exercise I. Select those which you find particularly interesting or unusual or useful.**
- 2) Write each selected example on one notecard.**
- 3) After selecting the 3 examples, a member from each group will come to the board and situate the notecards within the Transformation/Tech Matrix.**

Design Example

The tutorial facilitators will now select one example from the board and move it into each of the other three quadrants of the Matrix. By playing with the location of this virtual phenomenon we will sketch out how it might be redesigned in relation to the changes in its level of technology and its transformative power.

Exercise III:

Small Group Design Exercise

As the facilitators demonstrated in the previous design example, each group will imagine possible design variations of one example as they move it within the Transformation/Tech Matrix. By focusing in this way on the qualities of one virtual phenomenon, we seek to enrich our understanding of the design of virtual realities:

- 1) Choosing from the examples on the board, each group spends 20 minutes redesigning one example so that it will fit into the three other quadrants. In other words, if the group chooses an example which is high-tech/low-transformation, the design problem is to envision how it might change if it was high-tech/high-transformation, low-tech/low-transformation, or low-tech/high transformation.**
- 2) At the end of the 20 minutes, each group will present the results of their design session.**
- 3) We will conclude the tutorial with a group discussion of the design sessions.**

Conclusions

Our purpose, in **conducting this tutorial** is twofold:

- 1) We hope that participants play with and thereby transform the boundaries of what they think virtual realities are, or might be, by comparing and contrasting a range of familiar and less familiar examples of virtual phenomena drawn from their own experience.
- 2) We wish that each and every participant walks away with leverage points for assessing *the qualities of virtual realities in terms of the experiences they afford*. Our hope, too, is to open up the discourse and practice of human-computer interface design so as to enable people of non-technical backgrounds to have leverage in the design and evaluation of virtual realities.

For those of you who will be asked to “report” on this tutorial we suggest that the best way is to do the tutorial again with people in your organization—to engage again, with them, in the process of playing with and working out leverage points and exercises for the design and evaluation of virtual realities. What we hope you will take away from this tutorial is a greater facility with a process through which you may transform your relationship to virtual realities.

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- Fox-Keller, E. (1983), A Feeling for the Organism: The Life and Work of Barbara Mc Clintock, New York: Freeman.

In her book on Nobel Prize Barbara Mc Clintock, Evelyn Fox-Keller eloquently shows that even "hard" science can be practiced the "soft" way, and that a rigorous scientific approach, as practiced by Barbara Mc Clintock, does not necessarily imply a removed, analytical, and purely abstract way of thinking.

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In *The Evolving Self*, Kegan develops the view that becoming embedded and emerging from embeddedness are both essential to reaching deeper understanding of oneself and others. To Kegan, human development is a lifelong attempt on the part of the subject to resolve the tension between getting embedded and emerging from embeddedness. In a similar way, I think of cognitive growth as a lifelong attempt on the part of the subject to form and constantly reform some kind of balance between closeness and separation, openness and closure, mobility and stability, change and invariance.

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This paper addresses "the consequences of two types of experience which may be designated as *direct experience* and *mediated experience*, and analyses "their partial equivalence and differing potential roles in the intellectual development and acculturation of children." The authors claim that: "a clearer conception of the processes involved in direct experience ("learning-by-doing") will help to better examine the manner and extent to which mediated experience (or symbolic activity) ("doing-as-if"), may complement, elaborate, and substitute for that direct experience."

In the authors' view, learning through contingent experience is crucial and "may be facilitated through rearranging the environment to render the consequences of activity more obvious. Structured environments, simulations, toys, and automating devices of various sorts (microworlds) have the advantages of both extending the range of a child's experience and making the relations between events observable and otherwise comprehensible".

The authors further suggest that people not only construct and reconstruct their worlds (through action), but that they endlessly cast and recast their actions, to themselves and to others (through narration).

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Sayeki challenges the largely held view among psychologists and educators, that anthropomorphism is a primitive or childish way of understanding natural phenomena, which causes many misconceptions or erroneous judgments. In contrast, the author claims that anthropomorphism underlies people's understanding of their environment, in all stages of development (including scientist's understanding of nature).

One of the most fundamental subjective experience is, in his view, people's ability to "throw themselves into the object focused", accommodating their own self to "become" the object itself. In Sayeki's words: "In almost every intellectual activity, such as seeing, knowing, and reasoning, there seems to exist an implicit agent who gets involved in some meaningful activity, and we put ourselves in position of such an agent. This agent, an extension of self, is the source of our activity of knowing, and will be called "kobito" (Japanese for "little person"). Anthropomorphic epistemology describes how people understand their environment in terms of their kobitos' activities.

Reprinted Papers

Virtual Reality as Mass Medium

Presented by:

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ELECTRONIC IMAGING INTERNATIONAL '91

HYNES CONVENTION CENTER

BOSTON, MA

SEPTEMBER 30-OCTOBER 3, 1991

Abstract

It is the thesis of this paper that VR is the next revolution in mass communications. There are a number of well-known technological obstacles to the realization of this: bandwidth, cost, processing power, and so on. However, there are other non-obvious, "human" problems facing developers and users of VR technology which are not strictly technical and which will determine its success, acceptance, and usability: conventions of representation, powerful interface metaphors, paradigms of interactivity, protocols for group use, and environments for making and re-appropriating tools. We conceive of these various issues in terms of frameworks, access, and connectivity, and illustrate them with examples from other media and from popular culture.

Virtual Reality as Mass Medium

Introduction Virtual reality has definitely captured the popular imagination, but is it trivial trend or total transformation? We believe that VR will be as ubiquitous and important a technology as television and Nintendo, it will be cheap, easy, fun, and an important part of people's lives, and it will transform the way people work and play. However, some thought must be given to how we make, use, and envision this technology which is changing all of our lives, because none of this is going to happen if we limit ourselves to thinking of VR as an imaging technology. We need to understand it as the next revolution in mass communications.

The reader may be confused at this point as to why we are talking about VR as a *mass* medium. Mass communication is historically associated with *broadcast* media, such as newspapers, radio, and television. However, when we say mass media, we mean massively *interactive* media, telephones and email being the two most prominent examples. In our conception, what is important about mass media is that they shape,

and are shaped by, popular culture, and have the potential to create new forms of social interaction by connecting large numbers of people. Such media facilitate the creation of new social institutions and forms of culture.

VR promises to be the dominant mass communications medium of the next century. In our century, telephones, radio, television, and computer networks have all contributed to bringing people together. In the next century, media will not be *what* bring people together—they will be *where* people come together. We now live in front of TV; we will soon live *in* VR.

VR, as we conceive it, is the latest attempt to subsume all previous media. It is not clear to what degree it will be a full-sensory environment, nor is it clear how many of our social interactions we will want to carry out within it. However, we do see it as revolutionary because it will be the first medium to combine powerful forms of personal interactivity with mass distribution and access.

VR is a technology of the imagination. Imagination is the prototype of an imaging technology. Within the imagination we manipulate, transform, and process images and other cognitive forms. But we have difficulty sharing the artifacts of our imaginations with other people. In fact, the entire history of media technology can be seen as an attempt to externalize the human imagination: to give it form and to structure it in durable, reproducible, and manipulable representations which we can share with others. But just as the imagination gains its power through being structured, shared and communicated, so too, VR needs powerful frameworks for the communication and manipulation of digital media.

If we look at the prototypical medium—language—we see it provides the structure for imagination. However, saying this is rife with potential misunderstandings and logical errors. Imagination does not *precede* or *give rise to* language—language and imagination come into existence at

the same time. They define each other. They cannot exist without each other. So too with all subsequent media. *The invention of each new medium is concurrent with the invention of a new form of imagination.* If media give the imagination form and makes it accessible to us, then VR needs to be researched and developed within the context of the theory and history of media technology.

VR is a medium. The term "virtual reality" is somewhat of a misnomer; VR is not about reality—it is about mediation. Most researchers emphasize that VR is a tool for representing and manipulating *reality*. Without getting into a discussion about whether or not there is single, coherent reality, it is nonetheless important to agree that the human imagination—and its artifacts—mediates the world for us; we shape and understand the world through our mediations. Consequently, our experience of reality is always already *virtual*, that is, mediated by media.

When we think of VR as a medium, it becomes clear that the project of trying to represent all of reality is misguided. This is helpful for two reasons. In the first place, you can't do it. It is computationally too expensive to represent *all* aspects of the world. As Rudy Rucker [Ruc89] says, the world is as complex as it is because "God has the budget." In the second place, even if you could represent all of reality, you wouldn't want to. Media shape the way we understand our world, our bodies, and ourselves. They establish *conventions of representation*—conventions that make one painting appear "stylized" and another "realistic," one poem "abstract" and another "concrete," and one image a "scientific visualization" and the other a "processed image." It is conventions, abstractions, and representations that make reality intelligible and useful.

When we think of VR as a medium, it also becomes clear that VR is powerful as a means of communication. Communication is only possible if there are shared conventions of understanding.

Conventions are precisely what need to be developed if VR is to become a mass communications medium—a medium we use to understand, construct, and envision our world. If we want to understand VR as a technology for manipulating and communicating the artifacts of the human imagination, we should shift our focus to an entirely different set of issues than the familiar technical ones, and turn to disciplines that study them: media, communications, and the arts.

VR is old news. People have been living in virtual worlds for 5,000 years. Every medium is a virtual world. Not yet virtual reality, but a virtual world. Theatre, books, music, film, dance, and amusement parks all create artificial worlds of the imagination. However, throughout the history of media, these virtual worlds, though engaging, have remained, for the most part, separate. So for as long as people have been creating and using media, they have been experiencing the advantages and limitations of virtual worlds.

People have also been doing VR research for 5,000 years. From the beginning of art and technology people have been trying to solve the problems of mass communications and virtual reality. Every communications medium has created virtual worlds and has shaped us in the process. For example, with the advent of movable type, the printed book became the dominant metaphor for understanding the world: nature was a book, human life a story, and to understand people was to "read" them. Likewise, in our own time, the computer has given us a new way of visualizing the world and ourselves: biological and social processes are understood as computational ones, and in cognitive science as in popular culture, the brain is a computer.

The visual and performing arts, painting, theatre, cinema, and music, have developed conventions for the structuring of imaginary environments, for transitions, emphasis, and juxtaposition, which are able to focus and expand our

attention and experience. These techniques offer an important resource of design ideas for VR makers, not only because of their effectiveness, but because they form the core of our methods of understanding; they are the language of the popular culture [of our imagination] which VR must respond to if it is going to take hold and survive.

New technologies create new metaphors, and these new metaphors drive us to consider new kinds of problems and to develop new technologies to address them.

VR is new news. VR research, in its current form, promises several important developments above and beyond "traditional" VR technologies.

One development is that VR will subsume all previous media. Media theorist Marshall McLuhan argued that each new medium takes an older medium as its content—VR takes *all* previous media as its content. Photography subsumed painting, film subsumed photography (and phonograph), television subsumed film (and radio), multimedia is subsuming television (and computers), and VR will subsume multimedia (and telephones).

Another development is that as a digital medium, VR, on the one hand, will allow us to more easily record, manipulate, and communicate information, and on the other hand, it will provide a common representation for the content of all media thus allowing media to be translated into each other. Take music, for example. With digital representations we can create meta-instruments, which allow us to sample, manipulate, and share any sound. If I want an oboe sound in a piece I am creating, I can sample it rather than having to produce it. Furthermore, I can manipulate it in multiple ways; among other things, I can modify the sampled sound itself as well juxtapose it with different sounds. Finally, if I am working with a collaborator in another city, we can work together in a virtual studio.

VR will also allow us to re-integrate the artificially separated worlds of work and learning. There have been a number of historical analyses that show the relationship between the advent of the book and the separation of work and learning [Ill81, Ber83], as well as the separation of people into "children" and "adults"—a separation which did not exist until the middle of the 17th century [Ari62]. With current communications technologies, certain elements of the population are marginalized. We accept specific forms of presence and mediation and do not accept others. We personally know several software consultants who are barely in their teens, at least one of whom has had the unfortunate experience of physically showing up at a client's firm only to be dismissed as a "kid." However, as long as they run their consulting companies out of their houses and conduct most of their business over the net and via telephone, they are treated as the professionals they really are. One might automatically assume that this advantage will be lost in VR when everyone can see everyone else. However, we believe that since people will be able to represent themselves in so many different ways, age, gender, and race could be used less and less as metrics of competence.

Finally, VR can effect powerful transformations on our social institutions through the creation of virtual communities—both in terms of virtual workplaces and in terms of the demographics of society. We already see the effect that email and networks have had on the limited community that has access to them until now: people continue to log in even when they are on vacation, it is possible to be more flexible about when, or if, one comes to work on a certain day, and so on. Imagine how making VR as common as the telephone and extending the capabilities to include images ("video phones," "virtual windows," and "visual teleconferencing"), sound/speech, and graphic representations will affect people's work habits and the way they choose to live. The automobile created the suburbs: people migrated both out of the cities and

away from the farms. What kind of neighborhoods and boroughs will VR create?

VR is newsworthy. There are a lot of people currently working on the technological problems of VR. Some well-known practitioners include Myron Krueger [Kru91] who has been developing "artificial realities" for artistic and aesthetic experiences; Jaron Lanier [TBB⁺90] who is working on the development of navigation tools for cyberspace; Frederick Brooks [Bro90] whose development team is creating virtual tools to help biochemists; Scott Fisher [FT90] who is currently working on "telepresence" technology; and Eric Gulichsen [Gul87] who is trying to make VR cheap and accessible to everyone.

There are also a host of people who have been and are developing powerful theoretical frameworks that are directly relevant to understanding the social and intellectual consequences of VR. Among these researchers is Marshall McLuhan [McL66] who has probably done more than any other theorist to make popular the idea that media should be taken seriously as a subject of study; Ivan Illich [Il88] who is probably the most probing analyst of the relationship between media and societal transformations; Roland Barthes [Bar77] who extended the syntactic, semantic, and pragmatic work of earlier semioticians to develop a powerful theory that accounts for the way meaning changes in changing contexts; Jean Baudrillard [Bau83] who has provided an entire theoretical vocabulary for understanding the relationship between reality and simulation; Umberto Eco [Eco86] who extends the work of McLuhan and Baudrillard to computing, media, and contemporary popular culture; and Brenda Laurel [Lau91] who is drawing on the history of representation and narrative—particularly theatre—in order to develop theoretical frameworks for understanding and enriching the human-computer relationship.

Many of us at MIT's Media Lab are developing VR-related technologies, while attempt-

ing to integrate technological with theoretical research. Dave Sturman's work is based, in part, on the insight that the strength of datagloves does not lie so much in *direct manipulation*, but rather in the development of different gestural languages and hand manipulations that provide leverage over the more traditional computer interface paradigms; Margaret Minsky has been developing haptic (tactile) interfaces for virtual environments in order to better understand how textures, for example, can be used for data navigation and representation; Mike McKenna, Steve Pieper, Steve Drucker, Tinsley Galyean, and Michael Johnson have, individually and as a group, been developing underlying representations for graphical and cinematic elements, as well as intelligent agents, for virtual environments; Mike Travers has applied social theory to the development of systems for computer-supported cooperative work in order to create virtual environments that facilitate, among other things, casual interaction; Marc Davis is developing systems for the annotation of multimedia content which address the need for the representation, manipulation, and repurposing of complex, large data in interactive narrative structures; and Kevin McGee is doing research on the integration of work, play, and learning by developing a networked microworld. We believe that these examples illustrate the power and effectiveness of combining the technological with the theoretical.

VR's problem space. What are some of the important problems that need to be solved in order for VR to become a reality? There are three main problem areas that need to be addressed: frameworks which make VR an intuitive, compelling, and transformational medium; access for the widest possible spectrum of users; and forms for connectivity and interaction which support community life.

- We need *frameworks*.

VR can only succeed if it makes use of powerful conventions of representation. The

organizational and stylistic strategies which make the arts compelling, meaningful, and intelligible to us need to be combined with the intuitive and reliable design aspects of well-made interfaces, machines, and tools. We need languages for representing, manipulating, and constructing data which not only have useful grammars, but engaging rhetorics and poetics as well.

- We need *access*.

The development of VR needs to take into account individual styles of working and learning, cultural differences, and issues of race, class, and gender in order to make sure VR is accessible to a wide spectrum of users.

- We need *connectivity*.

Although this is a technical problem, it also a social and psychological problem. We need to facilitate people's ability to connect to things that matter to them: other people, tools, information, resources, and entertainment. We need to address the deep cultural needs for a sense of community and a *rapprochement* between work and learning.

We can learn the most about frameworks, access, and connectivity by looking at popular culture and the history of media.

VR is rooted in popular culture. Popular culture gives us significant clues about what people find important and the properties that they demand of a medium or artifact. Look at "America's Funniest Home Videos," phone sex, CDs, and talk radio. Clearly these touch on people's interests and drives: humor, sex, music, politics. Many of them also function as forums or channels of communication and interaction.

Perhaps the most pervasive and significant pop-culture phenomenon of recent years has been

the extraordinary success of Nintendo games (so successful, in fact, that it has become a generic name for video games). Popular phenomena don't just manufacture desires, they point to what people find important. The success of email is in response to the need of a rapidly expanding research community; the success of VCRs is in response to people's need for more control over what they watch and when they watch it; the success of personals is in response to the disappearance of adequate social situations for meeting people; talk radio and community access TV give people the chance to conduct public political discussions; and the success of comic books, science fiction "fan-zines," CNN, and USA Today is the result of people wanting information that is personally relevant and approachable rather than proscriptive and normative. What needs will VR meet in popular culture? It seems that VR speaks to two intertwined needs: the need for community—access and connectivity—and the need for frameworks that structure our activities and help us make them meaningful—fantasy being perhaps the most compelling example.

Think about what makes Nintendo so popular. Among other things, it is a shared experience. There are magazines, clubs, and television shows. People can participate in the culture of Nintendo. They can talk about it at school or the office, trade game cartridges with their friends, exchange strategies and tips, and play together. Most importantly, members of the Nintendo community have a common language for talking about their lives in terms of the games they all play. Nintendo also offers a rich environment for fantasy. The multitude of characters and their various challenges provide powerful vehicles for role-playing, identification, and transference. They create a virtual world in which players can explore and act out their problems, concerns, and desires.

We can already see where Nintendo is going—and, to some degree, what VR will be like—by looking at networked games. These games,

called MUDs (for “multi-user dungeons”) are an extension of earlier board games (notably *Dungeons & Dragons*) and computer text-adventure games (like *Zork*). To enter MUDs, individuals log into remote computers and find themselves in simulated worlds. Players are able to give themselves names, to look around, to interact with the environment by touching things, picking things up, talking to people, and by building extensions to the environment. Some of the characters in these environments are simply the result of programming—other characters are other players, logged in remotely from their computers. MUDs create a shared space of the imagination, a zone of interactive imaginary play in which groups of people can come together. Like comic books, Nintendo, movies, and MTV, they speak to, and articulate, a structured space for satisfying our deep cultural needs for community and fantasy.

We need to develop VR so it will become integrated into and change people’s lives: so it will allow us to communicate with each other and facilitate desires we already have. VR must become a part of popular culture. It is a truism that pornography drove the VCR industry. However, it did more than drive it. Popular culture not only drives technologies—it sustains them and makes them worth having. It may be argued whether pornography is what makes the VCR worth having (though for some people it is), but it is certainly the case that a widespread demand for music, entertainment, political information, and religious writings continues to make the CD, the movie, the magazine, and the book worth having. VR must address the needs and desires expressed in popular culture, while at the same time providing the technology for articulating, communicating, and satisfying those needs and desires. And, of course, as with every other medium, sex will drive this one too.

VR is rooted in the history of media. The history of media—of the different conventions

they developed and the social consequences they had—is full of important examples that can help us understand and satisfy people’s need for frameworks, access, and connectivity.

- All media structure our lives and perceptions by establishing frameworks and conventions. For example, the first close-up of a woman’s face in a movie literally sent audience members screaming from the theatre in fear. Similarly, in early movies, if a character was going to ride an elevator to another floor, the camera would continuously (without cuts) follow him into the elevator, show him telling the elevator operator which floor he wanted to go to, show him standing in the elevator, and then follow him out when it got to his floor. Film makers simply couldn’t rely on audience members to understand what was happening if the film cut from a man entering an elevator to the same man walking out of an elevator. Conventions of seeing have to be cultivated and developed in order for audiences to understand and make use of media.

Perhaps the clearest contemporary example of this is the spreadsheet. By building on the strengths of the computer’s ability to handle computation, the spreadsheet totally transformed the way we work with numbers and data. On the other hand, the word processor, though it has certainly had a powerful effect on the way we work with text, is often cited as an example that has so far been unsuccessful in re-framing our relationship to the written word. One of the things we can learn from this is that it is often not enough to merely transfer an existing framework to a new technology. This is something we have to be acutely aware when we consider VR.

- Access has mixed effects. Depending on the types of access we have, the effects can

be positive or negative. Think of the telephone answering machine which was supposed to liberate us from being tied to the telephone and thus give us more free time. Now we call in for messages, play phone tag all day, and spend more time on the phone than ever before. Conversely, the video camera was once feared as the ultimate surveillance tool the state could use against its citizens. Now with the proliferation of the camcorder, we keep tabs on the state—as in the Rodney King incident, in which a passerby videotaped the violent beating of an African-American motorist by a group of police. In this case, access to individual tools (the camcorder) produced something compelling enough to provide access to corporate tools (the television networks). This is not always the case, and we will do well to learn from the cases where important information is withheld as well. It remains to be seen what unintended effects VR will have. What is certain is that they will be momentous.

- We often overlook peoples' need to connect with each other. For example, there is the well-known story that ARPANET was originally designed to connect researchers to the mainframes of larger institutions. One of the minor features of the system was something called "electronic mail." We all know what happened to that "minor feature." Users created conventions of interaction, forums for debate, and built bulletin boards, news groups, and news services. In effect, they built an entire culture around and with this technology.

There are many other insights we could derive from these examples, but three in particular are worth mentioning. First, each medium has to teach its use. Second, new media always have unintended effects. Finally, people appropriate media to their own ends. As we develop VR technology, we should keep these insights in

mind and continue to look for more ideas and lessons from popular culture and the history of media.

Conclusion We believe that technological innovation is enriched when it is informed by an understanding of the way people making meaning, the strengths and weaknesses of a medium, the history of successful innovation, and the theoretical underpinnings of media, communications, representation, and popular culture. Of course it is possible to build powerful tools without any grounding in theories of representation, the history of media, or studies popular culture. Those of us who develop technical systems do so for a variety of reasons, and there is always some part of the bigger picture which we ignore because we don't know or care about it. However, it is our belief that the story about email provides a perfect example of how to take into account the ideas we talk about in this paper. VR must be constructed in a way that facilitates its appropriation by the culture at large. This will be the right thing for two reasons. First, it means we don't have to solve—or even work on—all the problems; the architecture of our systems just has to allow users to work on the problems we didn't recognize or have the capacity to work on. The second reason is by far the more important one. If VR is going to be the next revolution in mass communications media, if it is going to realize the dream of externalizing and sharing the human imagination, then VR research needs to respond to popular culture and not lose contact with the people who use, make, and study mass media.

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Pathways into a Child's Mind: Helping Children Become Epistemologists

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Presented at the symposium
Science Learning In The Informal Setting

Sponsored by and held at
The Chicago Academy of Sciences
Chicago, Illinois
November 12-15, 1987

PATHWAYS INTO A CHILD'S MIND: HELPING CHILDREN BECOME EPISTEMOLOGISTS.

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ABSTRACT

Helping children become epistemologists means helping them construct tools for acquiring knowledge. It means encouraging them to build, probe and enrich their models or descriptions of complex phenomena. I will analyze environments in which children are invited to discover a "world," to keep track of their discoveries, and to build comprehensible descriptions for themselves and for others. I will show how the construction and use of notational systems can foster the understanding of complex phenomena.

INTRODUCTION

Helping children become epistemologists means helping them develop heuristics -- models and strategies -- for acquiring knowledge. It means, in other words, helping them gain knowledge on how to gain knowledge about themselves and their environment.

We all agree in this assembly that "hands-on" activities are essential to learning. There is no knowledge without experience and no experience without personal engagement. Learning occurs, moreover, through probing and confronting one's current theories in one way or another. One could say that growth requires feedback, and feedback requires engagement and action. Thus both action and evaluation of the effects-of-an-action are essential to learning.

I will focus my talk on ways of alternating "hands-on" with "heads-in" activities so as to foster understanding in dealing with complex situations. I want to emphasize the importance of multiple approaches to -- and descriptions of -- a problem are a key to learning.

A rich learning environment is an environment which provides opportunity to wander in and out of a problem, in the same way one wanders in and around a city in order to uncover its various facets. Wandering in and out of a problem implies such things as looking at the problem from different perspectives, getting immersed in the problem ("diving" into it or "getting in touch" with it), getting out of the problem and looking at it from a distance. It implies expressing and shaping one's understanding by building models or descriptions of the situation as one goes along, by probing these models or descriptions, and by sharing them with others. Manipulation in itself is insufficient for learning. Acting upon a

situation is surely essential, yet it is equally important to know when to stop-and-think in order to evaluate what has been done in light of what we want to do next, or *vice versa*.

CHILDREN AS EPISTEMOLOGISTS

Epistemology is the study (logos) of knowledge (episteme). When applied to ourselves, epistemology is best defined as the search for methods and foundations which enable us to gain assurance about the validity of our current beliefs. When applied to others, epistemology becomes the study of how other people (scientists or children) build methods and foundations which enable them to gain a more accurate knowledge of their environment and selves. The notion of "accuracy" -- or validity -- of knowledge is certainly complex. I use it here in a broad sense. It can refer both to personal usefulness (or functionality) and to the systematic search for absolute truth.

In our everyday life, we all have a commonsense knowledge about people and things around us and we know quite a bit about our own ability to deal with these people and things. This commonsense knowledge serves as a grid through which we interpret the world and by means of which we organize our activities. To use Piaget's words, our commonsense knowledge is the "assimilation frame" through which we give meaning to things and by means of which we monitor our activities.

As long as everything works smoothly and we get what we want by doing what we do, there is no need for a great deal of reflection or justification. It is when dissatisfaction or doubt arises that a new level of reflection is required. Doubt arises in a variety of situations which are different for different people. For example, doubt might arise when we are no longer sure about the value of a thought, when we are repeatedly contradicted in our beliefs, or when we don't get what we want by doing what we do. More generally, doubt arises when we perceive a discrepancy between a desired and a current state. Perceiving a discrepancy calls for change and sets in motion a search for new and more accurate strategies in order to decrease the gap.

Like researchers, children need to develop their own methods of investigation and of validation for coping with their doubts. Helping children become epistemologists means giving them an opportunity to explore, build, express and shape their own theories, through different media, and communicate them in a comprehensive manner. It is, again, by shifting between **doing**, **reflecting** and **expressing** that children develop the ability to enrich their current knowledge.

A rich learning environment is a setting in which the shifting between these activities is encouraged in ways which are meaningful to the child and not imposed in a purposeless manner by the adult.

THE CLINICAL METHOD AS A TOOL FOR LEARNING AND TEACHING

It is my belief that the clinical method of investigation in the Piagetian tradition offers a rich model to think about teaching and learning both for the child and for the adult. Provided it is well conducted, the clinical setting actually becomes an ideal learning environment for both participants. It enables the adult to find a pathway into the child's mind and thus to gain insight into the child's ways of thinking. And concurrently, it enables the child to develop, probe and express his or her own theories about a phenomenon, which happens to be a good way to optimize them.

The clinician's first job is usually to design an experiment that is both conceptually rich and meaningful to the child. The clinician tries to create a "microworld" (Papert, 1980) that embodies and thus reveals the concepts s/he wants to study, and that includes a problem the child is truly interested in tackling -- a problem in which the child gets deeply involved. Once the task is designed, the clinician leads the child through the problem, while being guided by the child's own approach. It is difficult to set rules on how to be or become a good clinician. It is easier to describe what a clinician should not do. The clinician should never try to teach the right answer to a child nor to pull the child toward the right answer in a more or less subtle fashion. Neither should the clinician evaluate the child's performance in relation to performances of other children who might come up with the correct answer. If a child "makes an error", which is to say, if a child solves a problem in a way different from an adult or an older child, the purpose of the clinician is to uncover the originality of the child's reasoning, to rigorously describe its coherence and to probe its robustness or fragility in a variety of contexts (Piaget, 1963).

What a clinician typically does in order to gain access to children's deep theories is to vary the constraints of the situation ("What you did until now is great, now what if we changed the situation?"), to invite the child to make guesses and to express his guesses in various ways ("What do you think will happen? Can you show me? tell me? make a drawing?"), to have the child probe his guesses experimentally ("Let's try!"), to have the child explain why a given guess was confirmed or disconfirmed ("Did you expect what happened? What did actually happen?"), to propose counter-suggestions ("Another child I saw the other day thought that...what do you think?"), to have the child explain her/his point of view to a younger child ("Could you explain what you think is right to a younger child?").

It is precisely because the intention of the adult, in the clinical setting, is not to teach the right answer but to understand the coherence of the child's thinking that the clinical interview becomes, almost paradoxically, a privileged learning situation. Learning takes place through a shared game of reframing the problem, of proposing alternative views and of modifying the constraints.

Learning takes place because children are encouraged to shape their own thoughts through different media, for different

purposes and from different viewpoints, because children are encouraged to adopt different roles. It is my strong belief that proposing variations provides opportunities for building coherence. Proposing variations helps children who are ready for it to uncover the hidden link or the "theme" behind the variations. If the child is not ready for this insight, giving a right answer won't provide it.

CONSTRUCTION AND USE OF NOTATIONAL SYSTEMS

To illustrate my point I will give an example from a series of experiments we conducted at the University of Geneva in 1982-83 on children's development of representational systems. The purpose of the research was to study children's ability to build, modify and use modelling tools. I will focus on the design of the experiments rather than on the results. I hope to show that it is possible to design microworlds in which the process for gaining deeper understanding -- through discovery and justification -- can be presented in a way that is meaningful to the child.

All situations deal with the building (and using) of notational systems or instructions for (from) oneself and for (from) others.

Experiment 1: "taking notes for oneself"

The first experiment is a study by Annette Karmiloff-Smith (1979) which served as a basis for a series of further experiments on spatial notation. In Karmiloff's experiment 63 children from age 7 to 11 are given a "toy territory" in the form of a roll of wrapping paper. On the inside of the roll is drawn a long curvy road with forks, dead-ends and landmarks (Fig. 1).

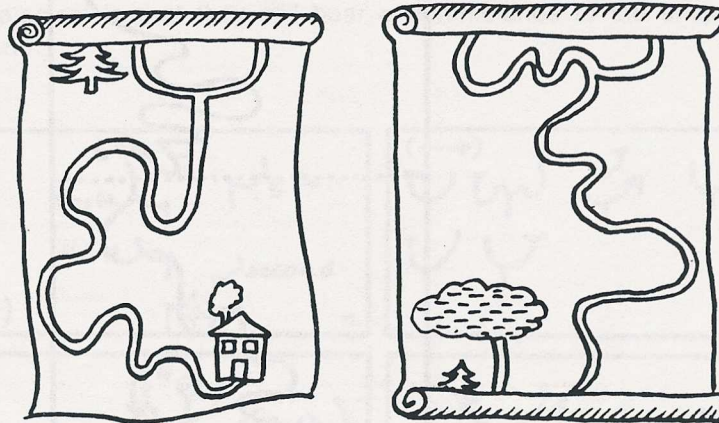


Figure 1. Since the paper rolls itself up, only a small part of the road is visible at once, in the same way only a small part of the landscape is visible when one drives through with a car.

Each child is asked to drive a toy car from a starting point (house 1 at the bottom of the route) to an endpoint (house 2 at the other end). While finding her/his way through the territory, the child is encouraged to take notes so that next time when s/he passes s/he will be able to get through at once, without errors. Children are given a choice of various sized papers. The experimenter does not specify what form the notes should take.

This task was designed to analyze the spontaneous forms of notation children generate and, above all, the spontaneous modifications children introduce to improve their notations during the session. Children can run through the roll as many times as they like.

In her version of the experiment Karmiloff came up with five types of notational systems. It should be stressed that these types are not a function of age. Karmiloff called them figural representation, figural schematization, analogical abstraction, non-analogical abstraction, linguistic notation.

1. Figural representation. Children usually begin by indicating only the correct side of each fork (the path to be taken). No "wrong way" is shown in the drawings (Fig. 2). Such notations happen to be almost impossible to read for a second run. Once the children become aware of this difficulty, they end up indicating crossings and dead ends. The exact shape of the road is still maintained.

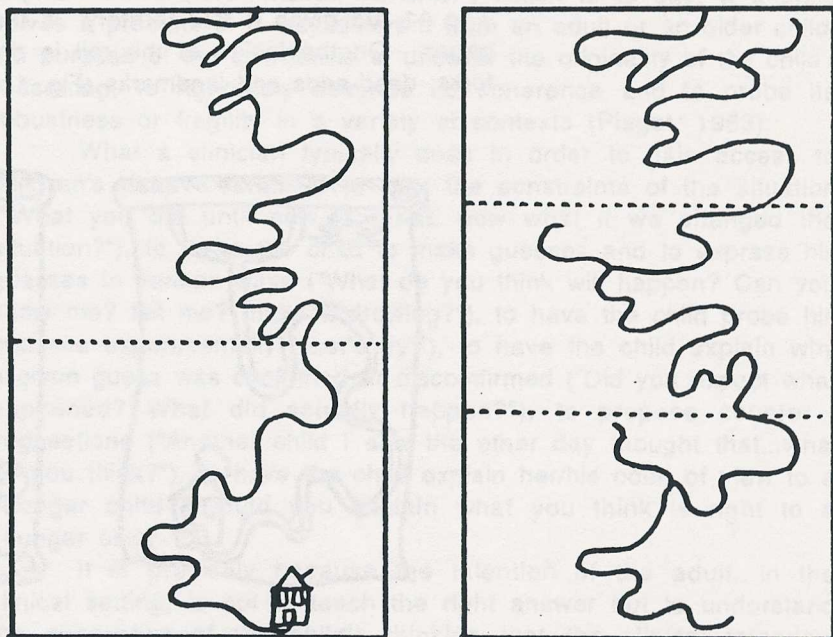


Figure 2. Children draw a miniature map including all curves of the road. The purpose is to reproduce the exact shape of the road. The use of topological clues is rare. The drawings often cover a large number of pages.

2. Figural schematisations. Children of this group begin to schematise the road between two forks. The shape of the road is no longer the main property to be represented (Fig. 3). In a second run, after having read their own indications, children usually improve their first notations by indicating which directions to take. Some children indicate the dead-ends (Fig. 3c and 3d).

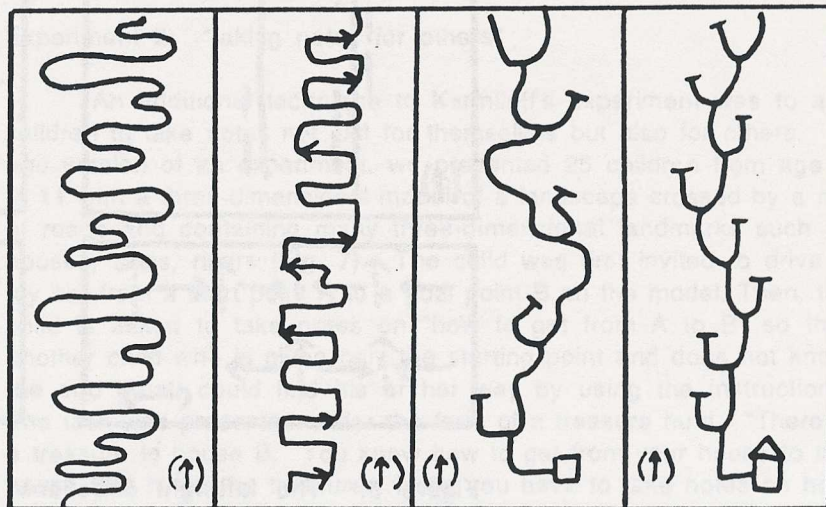


Figure 3. The arrows in parenthesis indicate the direction of drawing.

3. Analogical abstractions. In these notations only the forks (decision points) are represented (Fig. 4). The instructions remain analogical in that they still bear a resemblance to the shape of the route.

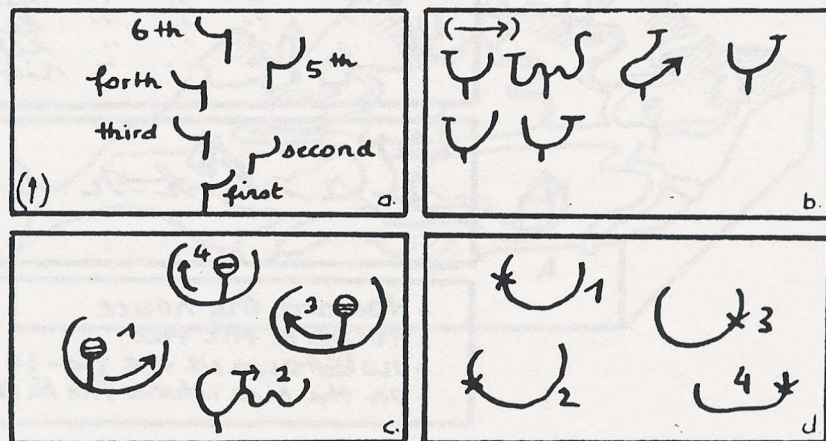


Figure 4. The sequence of decision points is either mentioned by numbers or implicitly suggested by the order of the drawing (4b).

4. Non-analogical abstractions. The signs used in these notations in no way resemble the shape of the actual road. Decision points are marked by arrows or other conventional signs (Fig. 5).

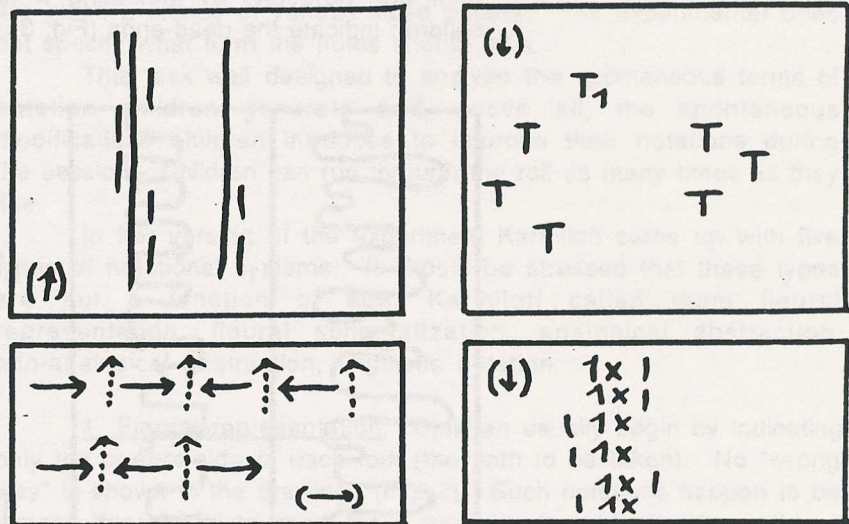


Figure 5. The left/right directions are often distinguished and marked spatially (Fig 5 c)

5. Linguistic notations. These notations consist of a string of written instructions (Fig 6). The sequence of instructions is usually given by the order of writing (from left to right), or else under the form of a list (from top to bottom).

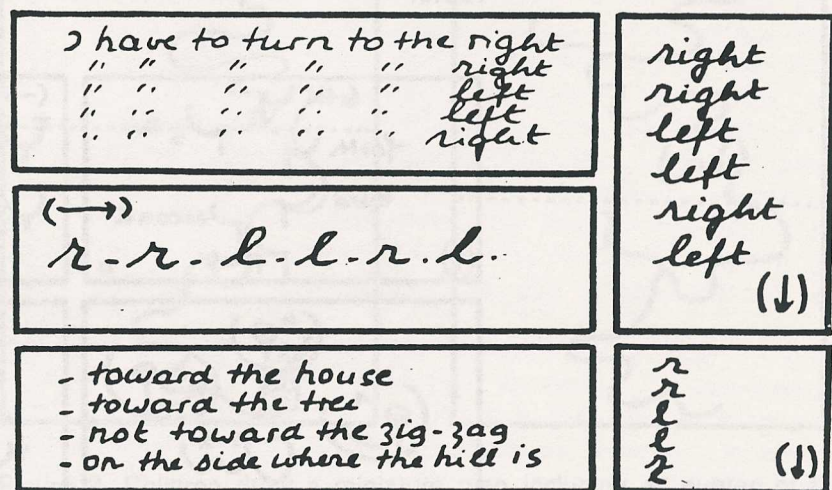


Figure 6. In their verbal notations, children often use the landmarks.

6. Conclusive remark. No matter what form of notation children first adopted, they all improved their initial attempts in the second run. They did so for sake of economy, or else because they experienced difficulty in reading their own instructions. Improvements include a clear indication of the route to be taken at each fork as well as of the sequence of forks. Improvements also include a progressive schematisation of the path between two forks and a mention of the routes not to be taken. Landmarks are only used in verbal notations.

Experiment 2: "taking notes for others"

An additional technique to Karmiloff's experiment was to ask children to take notes not just for themselves but also for others. In one version of an experiment, we presented 25 children from age 4 to 11 with a three-dimensional model of a landscape crossed by a net of roads and containing many three-dimensional landmarks such as houses, trees, rivers (Fig. 7). The child was first invited to drive a toy car from a start point A to a goal point B on the model. Then, the child is asked to take notes on "how to get from A to B" so that another child who is given only the starting point and does not know the end point, could find his or her way by using the instructions. The task was presented under the form of a treasure hunt. "There is a treasure in house B. You know how to get from your house to the house that hides the treasure. Now, you have to take notes on how to get there because you will have to leave instructions for a good friend who does not know which house hides the treasure. You have to write down all she needs to know so that she can easily find her way to the treasure." As in Karmiloff's study, the experimenter does not specify what form the notes should take.

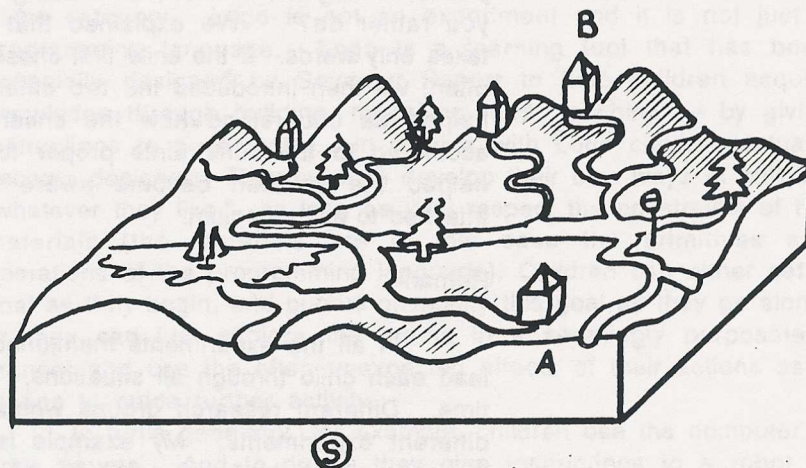


Figure 7. The child is seated on S. House A is the starting point. House B is the goal.

All the experiments on "taking notes for others" converge in showing that small children do not differentiate between taking notes for themselves and for others. Younger children, around age 4 or 5, say that they would do exactly the same for someone else. Older children, from age 6 upward, usually recognize that they should give more explicit instructions to someone else "because they don't know what's going on." Yet these children do not always know how to be more explicit. They express this difficulty by saying "oh, that's gonna be hard." The two main improvements we find, once children become able to modify their notes for others, are indications of the directions not to be taken and the use of landmarks as references.

Experiment 3: "the reverse path"

A second addition to the initial experiment was proposed by D. Maurice (unpublished paper, 1983). Maurice asked children how they would have to modify instructions so that they -- or someone else -- could easily find their way back from the goal to the starting point. This addition was introduced to study how children deal with spatial reversibility. It leads to the discovery that all of the "left-right" instructions have to be reversed. Another solution to the problem is to write a meta-instruction telling "just systematically reverse all lefts to rights and vice versa."

Experiment 4: "conveying information through a variety of media"

A third addition to the initial experiment was to ask children to give instructions through different media. In a series of experiments designed in collaboration with C. Giddey and D. Piguet (unpublished papers 1983) we proposed to 50 children from age 5 to 12 that they use a telephone, a letter, or a telegram. We asked each child: "If you could choose between talking to your friend on the phone, writing her a letter, or sending her a telegram, which would you rather do?" We explained that a telegram travels fast but takes only words. If the child first chose the phone, which happened often, we then introduced the two other media. These experiments helped us understand how the children modify their instructions according to the constraints proper to each medium. They also helped the children become aware of the different constraints attached to each medium.

Remark

In all the experiments mentioned so far, we did not actually lead each child through all situations. Our goal was another at the time. Different research groups worked with different children on different experiments. My example is, in this sense, limited. It serves to illustrate "what could be done" to create a rich learning environment rather than "what has actually been done." In the context of this conference the example remains useful in that it stresses the potential richness of the clinical attitude as a way of leading a child through a problem -- by proposing a variety of

perspectives and approaches but without pushing toward a correct solution. The example remains useful in that it reminds us that being interested in children's ways of thinking -- and trying to find pathways into their views of the world -- is the best way to optimize their own thinking, and therefore to foster learning.

OTHER EXPERIMENTS

Many other experiments have been conducted on children's development of notational systems.

At MIT, Jeanne Bamberger studied children's construction of musical notation. Children were asked to build a tune or a rhythm and to put on paper what they did, so that they -- or someone else -- could replay the tune or rhythm the next day. Children were then asked to read notes written by other children (Bamberger 1980).

In Geneva, Piaget and his collaborators designed a series of experiments to study children's ability to count and measure. Counting and measuring both require the construction of representational systems which keep track of some discrete or continuous quantities. What are numbers if not a means to keep track of the totality of elements in a collection? What is a measuring tool if not a way to keep track of the duration of an event or the dimensions of a volume?

Like any other notational system, numbers and measuring tools help us remember and reconstruct events -- in this case "the same amount of something" -- elsewhere. Counting as well as measuring require that some features within a context be captured, transcribed onto a given media, transported and kept invariant during the transportation, and ultimately reused as a means to organize -- or as a grid to read -- the event to be reconstructed or compared.

In some ways, a computer environment like Logo fits in this same category. Logo is not an experiment and it is not just a programming language. Logo is a learning tool that has been especially designed by Seymour Papert to help children acquire knowledge through building, modelling, and "teaching" -- by giving instructions to a computer. In playing with Logo children actually become designers. They learn to develop their own ways of building "whatever they like," as long as they respect the constraints of the materials (the materials are in this case the primitives and operations of the programming language). Children can either set a goal as they begin, and pursue or modify this goal as they go along, or they can just explore the media in a seemingly purposeless manner and use the often unexpected effects of their actions as a means to guide further activity.

In turtle geometry, for example, children use the computer to draw figures. And to do so they give instructions to a robot or screen turtle that executes the orders by drawing figures on the floor or on a computer screen. The instructions need to be given in a language understandable by the computer. They have to be explicit and precise. Children need to translate their intuitive descriptions

of movements in space into a series of rotations and translations with specified numerical values. Before typing their commands on the keyboard, children are often encouraged to play turtle, that is, to personally act out the trajectories they are planning to teach the turtle. They are also encouraged to tell someone else -- another child or adult who "plays robot" -- to walk or dance a given figure, by executing the orders. Playing turtle means, in other words, making use of the practical knowledge one has about one's own movements in space as an initiation to teaching others, and teaching others as an initiation to programming a computer. Each step requires a different and more specific description of the movements to be executed.

CONCLUSION

Both designing (or modelling) and teaching (or explaining to others) are useful strategies for acquiring knowledge. Thus, both learning-by-doing and learning-by-telling should be encouraged in schools and promoted in other more informal settings. Designing and teaching are both windows onto -- and expressions of -- children's ways of thinking. By giving children an opportunity to explore and build, and to express through a variety of channels what they think-and-do about a given phenomenon, one gains insight into their theories. Concurrently, one provides the children themselves with an opportunity to gain insight into -- and control over -- their own current view of the world, and therefore to enrich it. A rich learning environment is an environment that offers freedom for exploration, reflection and expression, while at the same time providing care and support. It is not an easy matter to decide when support is needed and what care is all about. It is nevertheless possible to help children become better learners by recognizing the deeply constructive role of trial and errors, of personal discovery and appropriation, and by appreciating children's work and achievements for what they are and not for what they ought to be from an adult's standpoint.

ACKNOWLEDGMENTS

I would like to thank the Chicago Academy of Sciences for having invited me to speak at the symposium "Science Learning In The Informal Setting". I would like to thank Guy Cell  rier, Heinz von Foerster, B  rbel Inhelder, Jean Piaget, and Seymour Papert for having given me the taste and the tools for looking beyond children's actions and immediate answers to uncover the richness of their beliefs, theories and views of the world. I would like to thank my assistants, my students and the children for having changed our research program into a rich experience. I owe a very special thanks to Linda Marquardt and Paul Heltne for their assistance before, during and after the symposium.

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Seymour Papert was named LEGO Professor of Learning Research in 1988.

He is the inventor of the Logo computer language. Seymour Papert joined Massachusetts Institutes of Technology in the early 60'ies. He is one of the founders of the M.I.T. Media Laboratory, and has been the Director of its Epistemology and Learning Group since it was established in 1985.

What is constructionism, and what does it have to do with Piaget?

Constructionism is a theory of education developed by Seymour Papert of M.I.T.¹⁾ It is based upon a theory of knowledge created by the Swiss psychologist Jean Piaget (1896-1980). Papert worked with Piaget in Geneva in the late 1950'ies and early 1960'ies.

A theory of knowledge is a set of ideas that try to explain what knowledge is and how it develops in people's minds. For example, one such theory states that knowledge is innate. Another theory states that knowledge is a mere reflection of experience. Piaget's theory states that people actively construct knowledge - that is, they construct robust systems of belief - out of their experience in the world. For this reason he called his theory constructivism.

Piaget's aim was to understand how children construct knowledge. He devised many ingenious tasks and questions that revealed what sorts of knowledge structures children build at different ages. For example, he discovered that young children believe that water changes its amount when poured from a short, fat glass into a tall, skinny glass. Older children, who structure their knowledge in a different yet equally coherent way, say that the amount of water remains the same even though it looks like there's more.

Piaget did not see himself as an educator, but as an experimentalist. Seymour Papert, on the other hand, wanted to use what Piaget learned about children as a basis for rethinking education. He wanted to use Piaget's theory of knowledge to form a theory of education.

How to think about education depends on how you think about knowledge. For example, if you think knowledge is innate, then education consists of drawing this knowledge out of children by asking them to perform tasks or answer questions that require this knowledge. Alternatively, if you think knowledge is simply a reflection of outer experience, then education consists of furnishing children with the "right" experiences, showing them the "right" way to do

things, and telling them the "right" answers. Conventional education is largely based on these types of theories.

But if you believe, as Piaget and Papert do, that knowledge is actively constructed by the child, then education consists of providing opportunities for children to engage in creative activities that fuel this constructive process. As Papert has stated, "Better learning will not come from finding better ways for the teacher to instruct, but from giving the learner better opportunities to construct". This view of education is what Papert call *constructionism*.

The theory of constructionism states that learning happens especially well when children are engaged in constructing a meaningful product, such as a sand castle, a poem, a machine, a story, a computer program, or a song.

Thus constructionism involves two types of construction: when children construct things out in the world, they simultaneously construct knowledge inside their heads. This new knowledge then enables them to build even more sophisticated things out in the world, which yields still more knowledge, and so on, in a self-reinforcing cycle.

Creating better opportunities for learners to construct has led Papert and his research team at M.I.T. to design various sorts of *construction materials* for children, as well as settings or *learning environments* within which such materials can best be used.

What are some examples of good construction materials for learning?

Most art materials make good construction materials. Paper, cardboard, clay, wood, metal, plastic, soap, and all kinds of "junk" that people might otherwise throw away, are great to build with. Papert first began thinking about constructionism in the late 1960'ies, after observing a group of students become deeply and actively engaged in creating soap sculptures in an art

class over several weeks. He then began to wonder why mathematics classes were so unlike these art classes.

In most math classes, students are given a demonstration of a problem-solving technique or are shown the format of a mathematical proof. Then they are typically assigned problems (not of their own choosing) which they must solve, and they do this with varying amounts of success. Such a class is dominated by instruction, not construction.

In most art classes, on the other hand, students are involved in creating something personally meaningful. Though they may all be using the same medium (such as soap), they do not all work on "the same thing". Elements of fantasy, imagination, and creativity contribute to the quality and uniqueness of the finished product, which bears the personal touch of its creator.

This is not to imply that instruction is always bad. Instruction is like a strong medicine. If it comes at the right time and at the right dosage, then it can indeed be helpful. But if administered at the wrong time (against the learner's will) or at the wrong dosage (too much or too little), then it can be a hindrance or even intellectually poisonous!

Papert's contemplations on that soap-sculpture class led him on a many-year journey to design a more constructable mathematics. Long before he invented the word "constructionism", the ideas existed in his mind as "soap-sculpture mathematics". He knew he would have to work with media more sophisticated and powerful than simple art materials to create such a mathematics.

In the 1970'ies, Papert and his colleagues designed a computer programming language called Logo, which enabled children to use mathematics as a building material for creating pictures, animations, music, games, and simulations (among other things) on the computer.

More recently, in the mid-1980'ies, members of his M.I.T. team developed LEGO TC Logo, which combined the computer language Logo with the familiar LEGO construction toy. LEGO TC Logo enables children to control the structures they build out of LEGO elements. Children program a

computer to make their constructions move, or walk, or light up, or respond to various stimuli. The resulting "behaviors" of such machines can be arbitrarily complex.

With LEGO TC Logo, children are engaged in three types of construction:

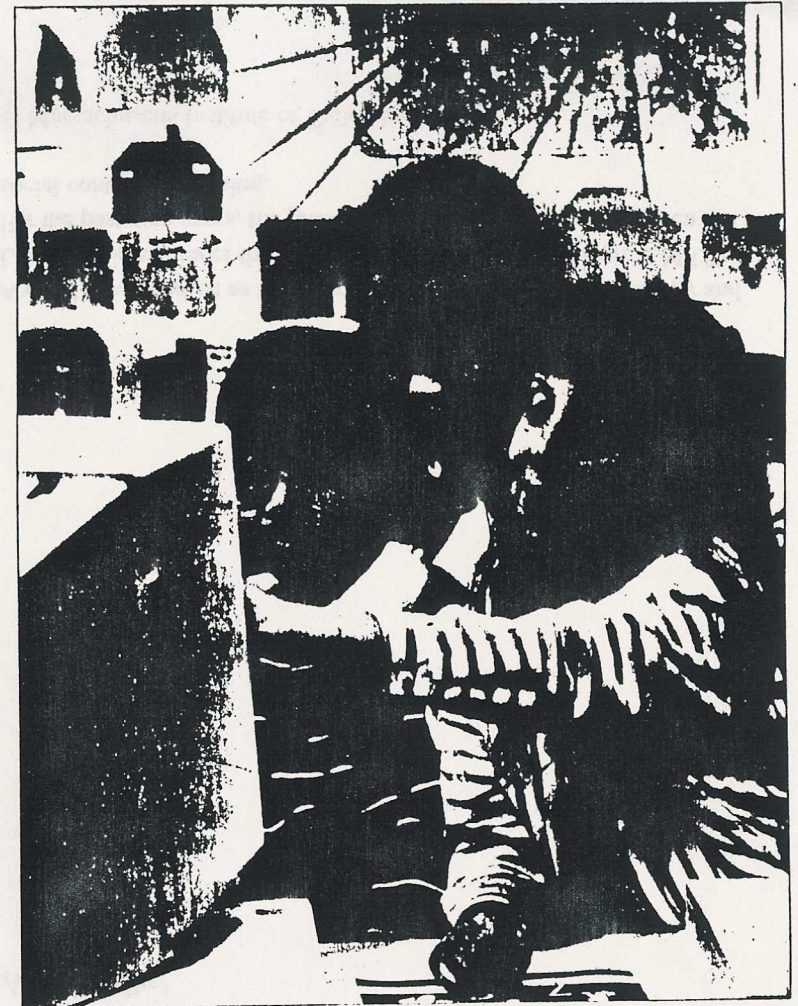
- (1) they are building structures out of LEGO elements;
- (2) they are creating programs on the computer; and
- (3) they are constructing knowledge in their heads as a result of these activities.

Moreover, when using LEGO TC Logo, children learn much about science and design by being scientists and engineers, just as they learn about mathematics by being mathematicians when using Logo. This is something very different from simply learning about science or math.

What is meant by a good learning environment?

Good building materials certainly aid constructionist learning. But they are not the whole story. Equally important is the learning environment or social context within which construction of knowledge (i.e. learning) takes place. Good learning environments try to maximize three things: *choice*, *diversity*, and *congeniality*!

Again, the theory of constructionism holds that learning happens most powerfully when students are engaged in constructing personally meaningful products - products they truly care about. But one person cannot dictate what is to be personally meaningful for another person. This is where *choice* enters the picture. The greater choice a student has of what to construct or create, the greater the likelihood of personal engagement and investment in the task. And the more a student can *relate to* or *connect with* the task at hand, the greater the chances are that the new knowledge will connect with a student's pre-existing knowledge - this is what Piaget meant by the phrase "assimilation of knowledge". Moreover, these impor-



tant elements of personal connection and care will serve to make the learning experience deep, meaningful, and long lasting.

Diversity is important to a learning environment in at least two senses: diversity of skill and diversity of style. A rich learning environment includes people of various skill levels, ranging from novice to expert. Sometimes this means combining different age groups in one classroom space.

When students are all at the same level, they sometimes reach a plateau and are at a loss for ideas and directions in which to advance their work. In a more diverse setting, people with less experience can learn much from freely associating with others who display a level of skill slightly above their own. People with more experience refine their skill and knowledge through helping and explaining things to others. And the diversity of artifacts created fuels everyone's creative imaginations. Ideas are borrowed and embellished in an exciting, vibrant cross-fertilization of knowledge.

Diversity of style means that, when it comes to creation of meaningful products, there is no one right way to do it. For example, some people like to plan out carefully what they want to do in advance. When they have thought through their plan, they get to work, perhaps revising their plan a bit along the way. This is often a very efficient way of working, but it is not the only way. Other people prefer to work without a preformed plan and instead engage in a sort of "dialogue" with their construction. They do something, and then they stand back, look at what they have done, and decide what to do next. People who prefer the first way of working are sometimes called "planners" and people who prefer the second way, "tinkerers". Both styles are equally valid and must be accepted and respected. Many boys tend to be planners and many girls tend to be tinkerers, though this is by no means always true. Historically, schools have tended to place a higher value on the more formal abstract style of the planner, than on the informal, concrete, dialogic style of the tinkerer. But fortunately many teachers are working to resist this bias. A few generations ago, schools forced left-handed people to write with their right hand. Forcing a tinkerer to act like a planner (or vice-versa) is equally harmful.

Finally, a good learning environment should be a *congenial* one. It should be friendly, welcoming, and inviting to the learner. Above all, it should be as free as possible from pressures of time. Creativity cannot be dictated by the clock. There must be time to muse, to talk, to daydream, to walk

around and investigate what the other people are doing. There must be time for false starts, time for getting stuck (and unstuck) - even time for (what looks like) doing nothing. Moreover, a good learning environment provides learners with time and space not only to do certain types of constructive work, but also to meet and form relationships with other people who are similarly interested in doing such work. This way, the joys and even occasional frustrations that are a part of constructionist learning can be shared with others in our midsts - others who, quite possibly, we come to regard as our closest friends: people who love what we love.

Aaron Falbel

Aaron Falbel worked as a research assistant with the Epistemology and Learning Group under the direction of Prof. Seymour Papert at M.I.T. For the past nine years, the principal focus of his research has been the social context of learning.

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