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ABSTRACT

This paper describes the characteristics of microworlds and discusses the basis of their use as educational tools. The power of a microworld as a learning tool is based in the philosophy of constructivism, the Piagetian principle of equilibrium, mental models, and intrinsic motivation. Research results of educational microworld studies appear to be divided into two major areas: research oriented and learner oriented. Research oriented studies employ computer microworlds as new tools to develop hypotheses, to predict performance, and to examine strategies and problem-solving. Learner oriented studies emphasize the learners' understanding of conceptual models and their use of debugging to correct errors and reconstruct their own mental models of how the real world functions. The paper defines a Microworld, its use as a learning tool, and two categories of research: research designed for the benefit of the researcher, and that which is oriented towards the learner. Microworld research indicates that although researchers disagree somewhat on definitions, boundaries, and criteria, there seems to be a consensus that well-designed microworlds provide the potential for engaging and rewarding learning. The paper discusses research-oriented studies; learner-oriented studies; general concepts and problem-solving; the procedural programming language, LOGO; and integrated concepts. (Contains 14 references.) (Author/AEF)

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Computer Microworlds in Education: Catching up with Danny Dunn

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Abstract

This paper describes the characteristics of microworlds and discusses the basis of their use as educational tools. Research results of educational microworld studies appear to be divided into two major areas: research oriented and learner oriented. Research oriented studies employ computer microworlds as new tools to develop hypotheses, predict performance, and to examine strategies and problem-solving. Learner oriented studies emphasize the learners' understanding of conceptual models and their use of debugging to correct errors and reconstruct their own mental models of how the real world functions.

One of my favorite books when I was a child was Danny Dunn and the Homework Machine. Danny was a middle-school-age boy who had an intense curiosity and the ability to find adventure, as well as trouble, as evidenced by the other books based on this character (Williams, 1958).

In this story, written in 1958, Danny lives with Professor Bullfinch, who introduces the boy to a computer named Miniac. Professor Bullfinch has refined his computer so that punched cards are not necessary to input instructions, but instead communication takes place with a keyboard and monitor. Danny finds the computer so compelling, that he and two friends (one of whom is a girl!) use it to complete homework assignments. Of course, they haven't told anyone that this is how they are doing their schoolwork, and eventually they are discovered in this charade.

To their surprise, their teacher gives them all an "A" in spite of the deception because she realizes they had to understand the underlying concepts to program the computer to do their work.

Although this book was written in 1958, it was amazing in its attitude toward, and predictions for, computers in education. After reading Mindstorms (Papert, 1980), which describes LOGO, an interactive programming language developed to teach children mathematical and logical concepts, I was struck by the similarity between Papert's views on education and Danny Dunn's adventure.

In his efforts to avoid doing homework, Danny had unknowingly encountered constructivism, the Piagetian principle of equilibrium, mental models, and intrinsic motivation, which are the foundations for cognitive tools referred to two decades later as computer microworlds.

Defining a Microworld

Microworlds are interactive learning environments that are defined somewhat differently by different researchers (see tables 1-3). Basically, a microworld is a conceptual model of some aspect of the real world. It is usually an idealized and simplified environment, based in a computer or other medium, in which learners (usually children) explore or manipulate the logic, rules, or relationships of the modeled concept, as determined by the designer. A microworld is a cognitive tool.

The idea of exploring aspects of the real, or physical world, through direct manipulation is not new. Nearly 400 years ago, Francis Bacon described in his unfinished work 'The New Atlantis' the idea of exploration in a form of a science center (Driver, 1989). However, learners in Bacon's proposed exploratorium would be forced to work with real world laws of nature. Experience in the real world is highly complex, and observations from real experience often lead to misconceptions and the induction of incorrect laws.

With the advent of the microcomputer, tools such as microworlds have become more popular as a means to simplify and design models of the real world. Computers make it easier to allow students to manipulate and observe constraints and variables individually, altering and experimenting with them to see how they interact.

Current research into microworlds usually involves computer-based simulations or games. However, simulations and games are not necessarily synonymous with microworlds, though in some cases there is considerable overlap. (Figure 1 illustrates a possible model for this relationship.) Generally, simulations which do not offer any significant difference from real-life experience, such as flight training simulators, are considered entirely distinct from microworlds.

Microworlds have essential characteristics which distinguish them from simulations and games, but this can be an area of confusion, even for researchers defining microworlds (L. R. Rieber, personal communication, 1994). Basically, simulations start to become microworlds when they are designed to let a novice begin to understand the underlying conceptual model.

Though computer-based microworlds are most common in current research, the computer is not required as the medium. Cuisinaire rods are an example of a microworld which is neither computer-based nor a simulation. These cognitive tools, named after their originator, George Cuisinaire, are a set of colored rods of varying lengths. The rods act as a microworld for many mathematical concepts. Children may manipulate them to explore mathematical ideas that are fundamental to learning other, more sophisticated concepts. As another example, Papert (1980), one of the developers of the programming language LOGO, has described mechanical gears as the microworld he envisioned to understand mathematical ideas when he was a child.

Microworlds as Learning Tools

The power of a microworld as a learning tool is based in the philosophy of constructivism, the Piagetian principle of equilibrium, mental models, and intrinsic motivation (Bliss, 1989; Rieber, 1994; Papert, 1980; Edwards, 1992).

Constructivism is the name of a school of educational philosophy closely aligned with the theories of Jean Piaget. Although the discussion of constructivism could itself take the space of several chapters, essentially it consists of the idea that learning involves individual constructions of knowledge. Constructivists can range from those stressing an orientation

where learning occurs through open discovery to those who accept varying degrees of structured learning depending on the setting.

Piaget's theory proposes that learners, when confronted with discrepant information between the environment and their understanding of it, will perceive this as a conflict and attempt to adjust their conception in order to resolve it (Driver, 1989). This cognitive conflict is referred to as disequilibrium, and according to Piaget's theories, is required for learning to occur.

Microworlds rely on the tendency of most learners to seek equilibrium, and they succeed as learning environments when they foster learning conflicts. This occurs because learners are then required to restructure their own mental model of how a system works in order to achieve conflict resolution. Microworld designers must take care, however, to structure the environment so that conflict resolution is within the learner's grasp (Rieber, 1991).

Constructivism implies that learners are responsible for their own learning. Microworlds push this responsibility further by helping learners to determine the correctness of their own solutions, rather than reserving this responsibility for a teacher. This is referred to as debugging. One of the attributes of computer-based microworlds is that the feedback necessary for self-correction can be graphic and quick.

Another important aspect of microworld design as a cognitive tool is that a well designed microworld is engaging and intrinsically motivating. When a microworld succeeds in this, it is more likely to be successful as a learning tool. As Papert (1980) asserts, "Anything is easy if you can assimilate it to your collection of models. If you can't, anything can be painfully difficult."

Research into Microworlds

Research involving microworlds seems to split into two basic categories: that which is designed for the benefit of the researcher, and that which is oriented toward learners.

As noted previously, microworlds are defined by many, and there seems to be some confusion between microworlds, simulations and games. Some studies may not actually involve the use of microworlds, though it is so described in their published research. Stricter definitions emphasize the interaction of learners with the simulated environment and the learners' grasp of the inherent conceptual model. This may exclude some of the research oriented studies from the realm of microworld research, placing them instead with the categories of simulations or games.

According to Rieber (1994, p. 229), "Simulations start to become microworlds when they are designed to let a novice begin to understand the underlying model." If this is the "true" definition of a microworld, then the case might be made that a microworld design may also help a researcher understand an underlying model. Researchers are, after all, learners themselves. The microworld they are trying to understand in this context consists of a simulation within a simulation; a microworld modeling how subjects interact with an environment.

Research Oriented Studies

Brehmer and Dörner (1993): Psychology Simulations

Brehmer and Dörner's research is an example of work oriented for the benefit of the researcher. They discuss using microworlds in psychological studies as new tools capable of handling complex experiments for the purpose of studying how subjects interact with simulations.

In their experiments, they design a microworld with suitable characteristics and then observe the subjects' interactions with the microworld. Focus is on the general strategies and tactics used to solve problems, as well as the problems the subjects create for themselves. Often this means inferring strategies from patterns of behavior.

Brehmer and Dörner discuss three approaches to using microworlds in psychology research. The individual differences approach is used to characterize differences among individuals, as a means of predicting performance, and to understand the differences between those doing well at a task and those who do not perform well.

A case study approach is used to generate hypotheses and to develop theories of how people cope with uncertainty and complexity.

A system characteristic approach is used to study groups of subjects under different conditions, in a manner similar to traditional psychology experiments.

Results of these studies indicate that it is not possible to find strong correlations between subjects' performance with microworlds and their performance on traditional psychological tests, i.e. intelligence or personality tests. The authors speculate that microworlds (and the real world they simulate) may make demands that differ from those traditionally considered important in psychological analyses of tasks.

If this is true, then microworld research may improve the accuracy and validity of psychological measures, provided the microworlds used are indeed good models of the real world situations they are designed to represent.

Horak (1990): Nimbot. This study is an example of a psychology experiment which described the use of a microworld in its design, but which failed to convince me that this was indeed the case. The study employed a

computer game, Nimbot, to study problem-solving heuristics by junior high school students.

Nimbot is presented as a computer microworld based on the ancient game of Nim. On the screen are three rows of robots, with 5, 4, and 3 robots in a single row. The objective of the game is to force one's opponent (in this case, the computer) to take the last remaining robot on the screen.

The study concluded that the junior high school students were capable of using a variety of problem-solving heuristics to play the game. They also appeared to demonstrate thoughtful planning and evaluation in the process of searching for a winning strategy.

One of the characteristics of a microworld is that it promotes problem-solving and self-correction of errors (debugging) during the exploration process. This does seem to be true of the Nimbot study, and as suggested by the author may lead to development of computer software that encourages and assists students in monitoring their own cognitive processes.

However, other criteria for microworld design seem to be missing. Nimbot does not appear to allow novices to understand the underlying model, nor to provide a doorway for exploration by students of varying abilities and inclinations. This seems to be an example of a computer game which offers some similarities to a microworld, and which may offer some insights into the heuristics of problem-solving, but is in fact, still within the realm of gaming.

Learner Oriented Studies

Studies with emphasis on the learner's objectives fit into three major types: (a) specific concepts, (b) general concepts and problem-solving, and (c) integrated concepts.

Specific Concepts

Microworlds in which the major emphasis is to explore a small, but complete subset of a domain are models of specific concepts. These usually explore some aspect of the physical sciences, or a concept in mathematics or geometry. Most of the definitions put forth to describe microworlds refer to this category of research.

Rieber (1991): Space Shuttle Commander. This software package is aimed at elementary and middle school students to help with a wide range of learning goals related to Newton's laws of motion. Tutorials and a combination of gaming and simulations are employed to introduce learners to the laws of motion in nonmathematical ways. Students are given flight lessons (the tutorials) and allowed practice in maneuvering the space shuttle on missions (the gaming/simulation) in the process of learning and exploring Newton's laws of motion. Space Shuttle Commander is designed to combine a hierarchical instructional framework (the tutorials) with constructivist exploration (the simulation).

Carefully designed microworlds should encourage incidental learning. However, results of this study indicated that students who learn in incidental ways apply the information in a variety of contexts: some of which may be correctly applied to a larger set of learning goals; some of which may actually promote misconceptions.

Results of this study emphasize the importance of some instructional guidance by a teacher or other expert. Although microworlds are designed to

encourage constructivism and "discovery learning," teachers are still needed to direct or redirect incidental learning to prevent it from becoming counterproductive.

Edwards (1992): Green Globs and TGEO. Edwards' studies tested the hypothesis that there exists common patterns of learning and interaction, and that students would make use of the debugging quality of microworlds to refine and correct their mathematical understandings while playing the games.

Edwards' first study examined learner interaction with graphing equation software designed by Dugdale and Kibbey (1981), call Green Globs. This game links symbolic representation of an algebraic equation with its graph. The program displays a set of large dots scattered over a coordinate grid. Students type in an equation and the corresponding graph is drawn on the grid. The goal is to formulate an equation which will pass through as many dots as possible. Students in the study were able to use the visual feedback from the game to refine and correct their understanding of the algebraic functions.

The second study used a LOGO-based microworld for transformational geometry, called TGEO. Students type in the specifications for a set of geometric transformations such as rotations, reflections, and translations, and see the effect of the transformation displayed on the computer screen. This microworld included a game, called The Match Game, in which the goal was to superimpose two congruent shapes by applying a sequence of transformations to one of the shapes.

Both the Green Globs and TGEO microworlds were designed to support children's debugging of their own solutions, and to reconstruct their own mental models of the mathematical concepts presented in the environment. Results of the studies did suggest that the microworlds were effective in

assisting students to gain a working knowledge of the mathematical models. Qualitative results indicated changes in the students' thinking as well as changes in strategies for solving problems.

Martin, Shirley, and McGinnis (1987): Island Survivors. This study, aimed at upper elementary school students, examined their experience with an ecosystem microworld to speculate on the relationship of such learning environments to regular instruction.

Software used for the experimental group was Island Survivors (Rhineholt and Winston, 1985). The aim of the game is to help 3 shipwrecked humans live on an island for a year without disturbing the ecological balance of the island's plant and animal species. The control group used other software which did not cover the concepts presented in the Island Survivors game. Both groups received classroom instruction and participated in field trips related to principles of ecosystems.

Results showed some transfer of microworld concepts to other settings, as well as application of some teacher-taught material among students who had experience with the model ecological system. The conceptual gains were most clear when children worked in small-group settings, as they had when they interacted around the microworld. The teacher described gains to her own instruction from the microworld, because the children's talk about the game provided conceptual bridges to the material she had introduced.

General Concepts and Problem-Solving

Microworlds which concentrate on improving general problem solving skills are also limited to small domains, but are somewhat more nebulous in their design. Most microworlds have the potential for development of

problem-solving skills, but in this category, a greater emphasis is placed on these skills as well as general cognitive abilities.

Papert (1980): LOGO. LOGO is one of the first and perhaps one of the best known computer languages applied to constructivism and microworlds. Many people contributed to the development of LOGO, but Seymour Papert is usually credited as its chief developer (Rieber, 1994).

LOGO is a procedural programming language used to build microworlds. Turtle geometry is an example of a LOGO microworld which allows learners access to principles of geometry through interactive graphics. The graphical tools are turtles, manipulated by LOGO statements, used to draw lines, circles, and other geometric objects on the computer screen. A mechanical turtle, the movements of which are controlled by LOGO statements, has also been used with young children.

One of the most important aspects of turtle graphics is that it aids debugging. As discussed previously with Edwards' (1991, 1992) TGEO study, LOGO microworlds provide graphical feedback to the learner which is almost instantaneous, thus increasing the usefulness of errors, and encouraging risk taking and hypothesis testing.

The reason I am classifying LOGO in a more general area of research is that although a number of studies have been made into the effectiveness of LOGO programming as an educational tool, results from most studies have been inconclusive (Rieber, 1991). Papert (1987) contends that this is because the programming language was meant to be part of a cultural influence on learning, and consideration of its effects on learning in isolation is not defensible. Indeed, other defenders of LOGO, such as Lawler (1986), insist that learning in LOGO environments improve general problem-solving skills and encourage positive attitudes toward self as well as learning.

Papert (1986) also suggests that results from LOGO remain unremarkable since LOGO and turtle graphics may be taught in a wide continuum of approaches from constructivist explorations to rigidly directed instructivism, which confuses the results. Papert would prefer to see LOGO used as a tool for exploration in "an open, child-centered way," but many schools use it very differently:

> I've been in some classrooms where LOGO is taught "by rote" in a very mechanical way, where everyone has to draw a square, then a triangle, put them together and make a house. When I see that I sometimes wish I had never drawn that house (referring to a house he drew for his book Mindstorms). (Papert, 1986, p. 36)

Integrated Concepts

Microworlds which integrate concepts reflect a broad constructivist approach to integration of an entire curriculum.

Ritchie and Dodge (1992): Cabrillo. In the fall of 1990, the O'Farrell Community School attempted a unique educational experiment. This middle school, located in southeast San Diego, opened its doors to a collaborative effort between the school faculty, San Diego State University, and Apple Computer Corporation. The project was one of 32 similar partnerships established throughout the United States by Apple as part of their Christopher Columbus Consortium. Apple's goal for the program was to form partnerships between universities and public schools to apply microcomputer solutions and educational technology strategies to help solve classroom problems. The focus of the San Diego project was to provide a tool which

would allow students the ability to easily develop computerized instructional programs.

Cabrillo, a Hypercard-based authoring tool, was developed by Bernard Dodge at San Diego State for the purpose of creating a microworld curriculum at O'Farrell. (The research paper fails to identify the other author, Donn Ritchie.) Students used Cabrillo to design an interdisciplinary program incorporating a wide range of educational topics, including language arts, social studies, science, mathematics, computers, art, music, and physical education.

The project design required cooperative learning in teams of students from various cultural backgrounds and was to reflect interactive game scenarios which were historically accurate and culturally relevant to the student population.

At the end of the 12 week project, the student population showed improvement in cooperative learning and research skills, and demonstrated higher level thinking skills. Teachers were impressed with students' acquisition of facts and concepts of the cultures under study, but they also expressed some concern for the tradeoff of time from a traditional curriculum in exchange for the microworld development. Students expressed increased motivation and excitement as they worked with the microworld curriculum.

This study is an exciting approach to education, and although at first glance it appears possible in this setting only due to funding from Apple, the authors state that massive technology is not required for the efforts involved in this project. However, the study does describe extensive workshop time necessary for teachers to become familiar with the hardware and software used for the project. It is encouraging to note that the faculty voted to incorporate the microworld concept again the following year.

Conclusions

Microworld research indicates that although researchers disagree somewhat on definitions, boundaries and criteria, there does seem to be a consensus that well designed microworlds provide the potential for engaging and rewarding learning.

Microworld design faces several challenges. Since the microworld is to be a simplified, yet accurate subset of a real system, the designer must understand the system well enough to provide the accuracy required by the novice. An inaccurate model can lead to serious misconceptions and inappropriate mental models for the learner. This is especially important to the research oriented studies which assume their simulations are based on a true picture of a real world system.

Results from computer-based microworlds which are used to form hypotheses and predict performance do not correlate well with established psychological testing. Although the microworld is thought to be representative of a real world system, further evaluation is needed before forming any conclusions regarding their usefulness as psychological predictors.

In learner oriented studies, the main emphasis is on the value of microworlds to help learners understand the underlying conceptual model, and to reconstruct their own mental models of how the real world functions. Misconceptions can still occur by learners even when the model is well designed. As some studies indicated, instructional guidance is still necessary to prevent learners from misapplying the concepts learned while interacting with the microworld.

In addition, evaluation of the conceptual model, as well as the results, may be difficult (i.e. LOGO and turtle geometry). Perhaps it is true that LOGO does not improve problem-solving skills or general cognitive abilities. Perhaps cognitive gains from learning LOGO do not transfer to other settings. I am not convinced that this is true, but faith is not redeemable in the area of research. Perhaps some advanced measure will be developed that can prove some differences in these areas.

Another important challenge in designing a microworld is to make it engaging for the learner. The studies which showed positive results almost unanimously reported that students enjoyed them and would have liked to continue playing them given the chance. This is not a trivial point. When students feel an ownership of a problem, they are more likely to pursue a better understanding of it and want to succeed. And when microworlds, as well as games and simulations, are designed well, students will also abstract the essential properties of the concepts embedded within them.

> Danny's teacher said nothing for perhaps a minute. Then she said, slowly, "Danny, I won't force you to stop using the computer. But I'm asking you for your own good not to use it. Children learn through practice. You'll have to take my word for it that it would be better to do your homework the old-fashioned way." (Williams, 1958, p. 72)

Danny Dunn would be about 50 now. I wonder what he's up to....

Microworld Definitions

Table 1: Characteristics of a Microworld

• Small but complete subset of a domain
• Simplest model of a domain that is recognizable by an expert of the domain
• Provides immediate "doorway" for novices to gain immediate access to a domain through experiential learning
• Provides general, useful, and syntonic* learning experiences (Papert)
• Provides learners with "objects to think with"
• Promotes problem solving through "debugging"
• Shares characteristics of an interactive "conceptual model"

*Syntonic learning means, "it goes together with." It suggests that learning is made up of connections, such as connecting new ideas to old. (Rieber, 1994)

Table 2: Guidelines for Mathematics Microworlds

• The environment should consist of a "working model" of the concepts to be learned, in which the math is intrinsic. Students should be able to explore and manipulate the working model.
• Direct, meaningful feedback should be provided which the learners themselves can interpret in order to diagnose and correct their own errors.
• The environment should include a set of inherently interesting problems which can be explored by students of varying abilities and inclinations.

(Edwards, 1992)

Table 3: Microworld Characteristics

complex	Learner must consider goals, choice of different actions, and the repercussions of those choices.
dynamic	The current state of the simulation is dependent upon the interaction of the subject with the system, and the simulation changes as a result of the subject's actions as well as independently.
opaque	Some aspects of the system have to be inferred, forcing the subjects to form hypotheses and test them as part of the activity.

(Brehmer and Dörner, 1993)

Figure 1. Possible model of interrelationship between microworlds, simulations, and games.

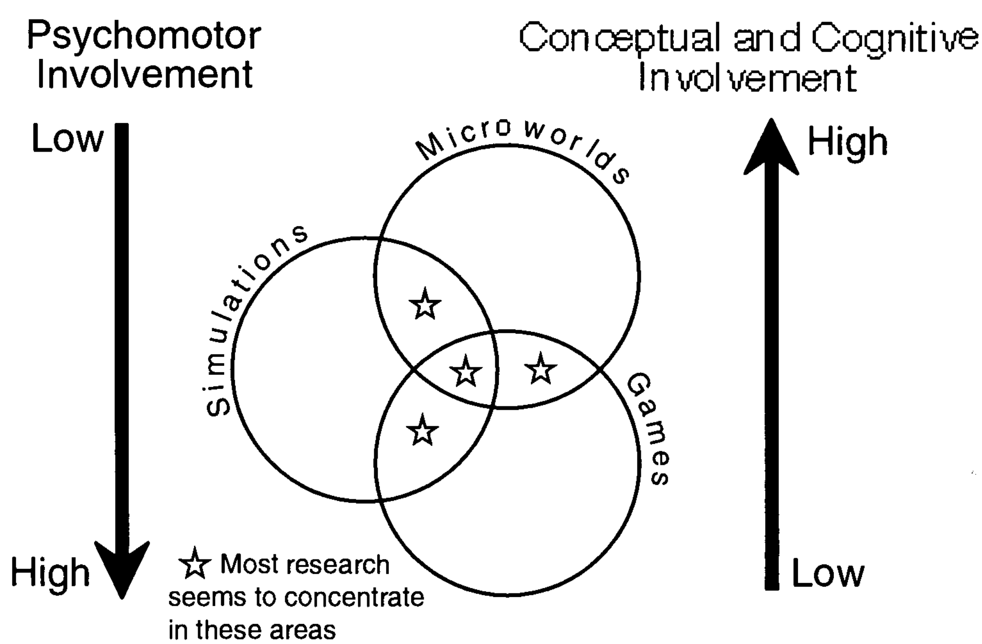
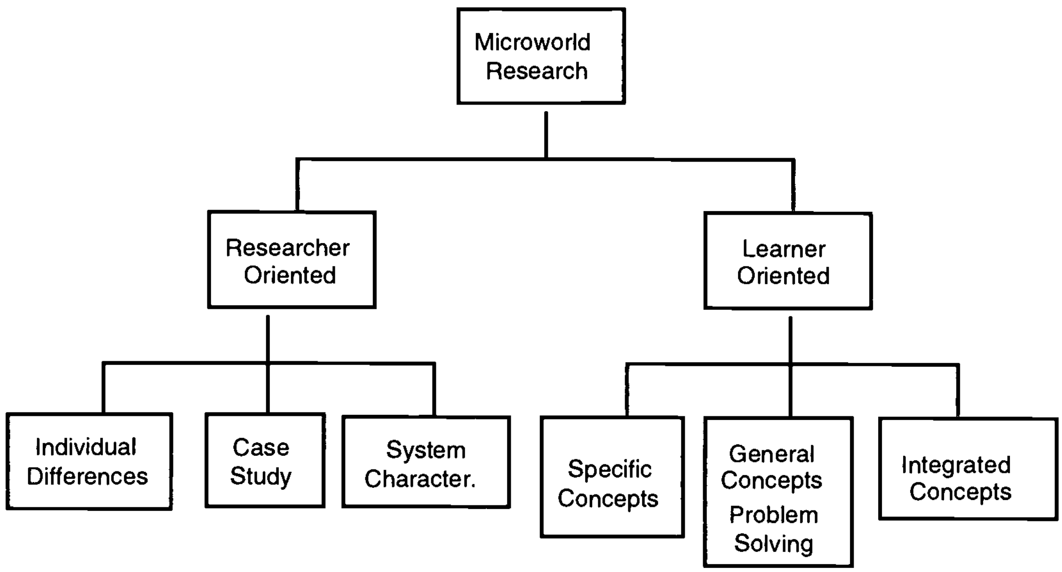


Figure 2: Microworld research



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