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What Is Constructivist about Constructivist Education?[1]

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My work over the past 30 years has been to take what seemed to me the best theory of human mental development –Piaget's—and try to draw its educational implications. Those implications have grown into a general educational paradigm that we now call constructivist education. Many curricula and programs purport to reflect Piaget's theory. However, most of these can be characterized by what I call "the wave of the hand" usage of the theory—that is, a general citation without addressing just how the theory connects with recommended practices. I have also referred to this as a global translation of theory into practice in which the theory is simplified into vague generalities that are only loosely connected to certain educational goals or practices (DeVries, 1987/1990).

Whether you agree with Piaget's theory or its educational implications or not, perhaps you will agree that it is useful for us to have taken on this task—that is, to see how far one can go with education inspired by Piaget's work. In this presentation, I want to describe a model of dynamic interactions among constructivist research, theory, and practice.

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A Model of Dynamic Interactions among Constructivist Research, Theory, and Practice

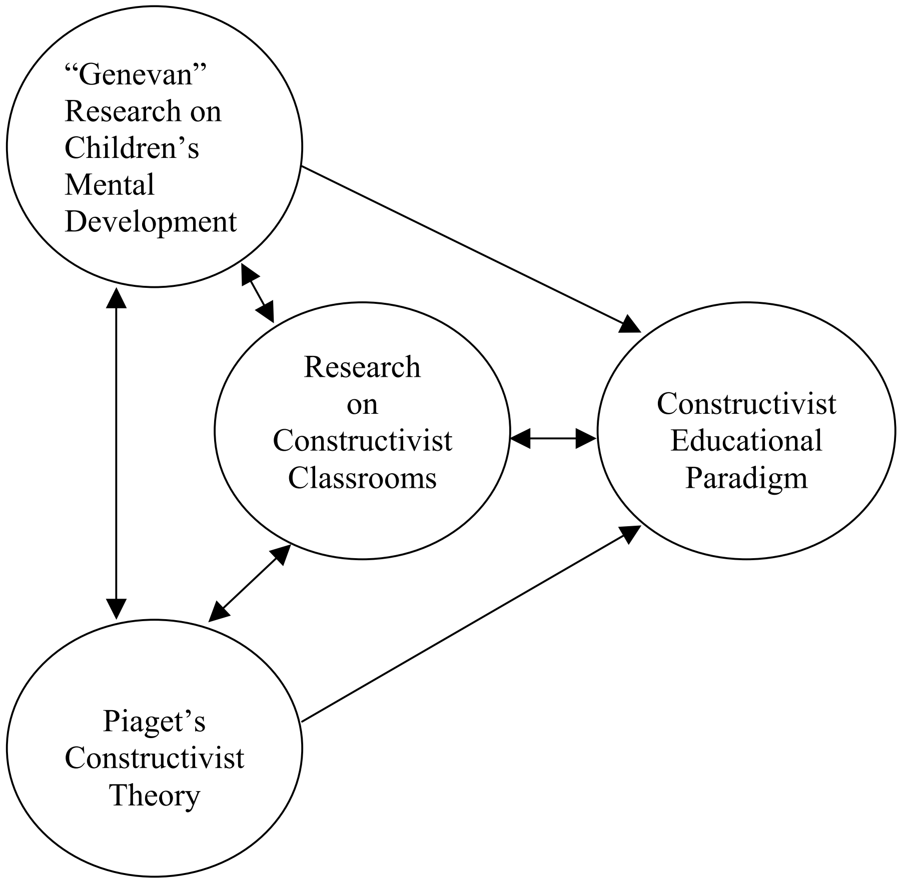

Figure 1. Model of Dynamic Interactions Among Constructivist Research, Theory, and Practice

Figure 1 shows the four main elements of my model: (1) Genevan or "Genevan-like" research on child mental development, (2) Piaget's constructivist theory, (3) the constructivist educational paradigm, and (4) research on constructivist classrooms. The arrows represent my conception of the directionality and interplay of influences among research, theory, and practice.

In the course of discussing the workings of this framework, I want to raise the question of what is constructivist about constructivist education. I remember that my mentor, Hermine Sinclair, was sometimes troubled when I referred to our educational paradigm as constructivist education. She pointed out that constructivism is a theory and wondered whether it was correct to say that education could be constructivist. I believe that it can be correct to use the word "constructivist" with reference to an educational paradigm, to classrooms, and to teachers, with certain qualifications that I will discuss. It does concern me that the word "constructivist" is often used rather indiscriminately, and I would like to clarify what for me is the essential element of constructivist education—a solid connection of the constructivist theory with practice.

Research on Children's Mental Development

Piaget, his collaborators, and many others have done laboratory research showing qualitative changes over time in children's mental development. With ingenious experiments, Piaget found that children's reasoning contains many ideas that were never taught. This fact allowed Piaget to propose the idea of sequential structural stages in the intellectual domain and levels in the sociomoral domain. The constructivist paradigm is especially informed by research on children's stages in mental development that bear on classroom activities. This is represented by the uni-directional arrow from Genevan research to the paradigm and the bi-directional arrows from Genevan research and paradigm to classroom research. Constructivist teachers of young children thus note in their action research preoperational reasoning in various content domains. For example, laboratory research on stages in play of marbles (Piaget, 1932/1965), Tic Tac Toe (DeVries & Fernie, 1990), and a Guessing Game (DeVries, 1970) enable practitioners to assess the developmental level of children's play.

It is important to note many Genevan experiments do not make good educational activities because the child cannot experiment and often does not experience disequilibrium. Many Genevan tasks involving the world of physical objects do not meet criteria for good physical-knowledge activities. That is, as Kamii and I

(1978/1993) pointed out, phenomena must be producible by a child's action, observable, variable, and immediate in reaction. For example, conservation of substance is not a good educational activity because there is no way for children to make the invariance conclusion through their own observations and physical actions on objects. Moreover, the interview materials usually do not lend themselves to experimentation, and children do not go on spontaneously with a task once the examiner has finished. In contrast, Piagetian experiments with sinking and floating and shadows do allow children to experiment and use feedback from objects to reason about various logico-mathematical relationships. We thus draw activities selectively from Genevan research.

Although Genevan and "Genevan-type" research can sometimes be a rich resource for educators about how children think, by itself it does not inform teachers about how children learn. Although the idea of qualitative discontinuity of stages describes mental development in broad strokes, it does not account for the continuous process of moving from one stage to the next. The importance of the description of stages for Piaget was to allow him to argue that knowledge is constructed. The question of how knowledge is constructed is the focus of Piaget's constructivist theory.

Piaget's Constructivist Theory

Piaget's research indicating that children have many ideas that are not taught to them led him to propose and elaborate over time a constructivist theory to describe and explain the functional continuity in intellectual, social, and moral development—that is, how children's reasoning changes through a process of equilibration (Piaget, 1975/1985). The two-way arrow between research on children's mental development and constructivist theory is meant to convey the bi-directional nature of the interplay between the research by Piaget and his collaborators and Piaget's constructivist theory. With some notable exceptions, most of his research focused on the intellectual domain and he wrote principally about the development of scientific knowledge. However, when he moved from writing about the development of *knowledge* to writing about the development of the *child*, his theory became more comprehensive. He indicated how affective, social, and moral aspects fit into his general theory—specifically topics such as self-esteem, moral feelings, personality, idealism, and schemes of social interaction (Piaget, 1954/1981, 1995). I wrote a 1997 article in the Educational Researcher addressing the myth that Piaget did not consider social factors to be important in his developmental theory. It is this more comprehensive theory from which we draw in conceptualizing our constructivist educational paradigm, represented by the one-way arrow from theory to the paradigm. Piaget's theory is not an educational theory and must be translated into educational practices. (See DeVries, 1978, 1984, and DeVries and Kohlberg, 1987/1990 for discussions of such translation efforts.)

The Constructivist Educational Paradigm

The constructivist educational paradigm is conceived as a kind of ideal prototype, an exemplar or model that provides a vision of what education inspired by Piaget's research and theory might be. We noted that the educational paradigm utilizes the results of research on children's thought and reasoning. For example, errors in child logic and reasoning are recognized as necessary for the construction of correct knowledge--the result of using the intelligence. Therefore, one principle of teaching is to "Figure out what the child is thinking and respond sparingly in his terms" (Kamii & DeVries, 1978/1993, p. 54).

The unidirectional arrow between the constructivist theory and the constructivist classroom paradigm conveys the idea that we mine the theory for its relevance to practical educational efforts. The paradigm is never complete but is continually evolving. It strives to link the specifics of research and theory to specific classroom practices. To this end, it never refers to a theoretical conception without practical examples from classroom research that illustrate these links (arrow from classroom research to paradigm). The paradigm includes principles of teaching and practical illustrations derived from classroom research. It is not limited to Piaget's theory as many non-Piagetian elements are harmonious with it. It is more of an approach than a model in the sense that it does not detail every aspect of categories of life in the classroom, and teachers and children are empowered to create their own unique embodiment of the paradigm. The paradigm does, however, specify certain necessary elements (described below).

Many have pointed out that Piaget's theory is an epistemological, not an educational, theory. This means that some aspects of Piaget's theory are more relevant to education than others. Let me briefly summarize some of the practical implications my colleagues and I have drawn from relevant aspects of Piaget's research and theory and comment on the need for research to elaborate the paradigm.

Practical Implications

Active schooling. Piaget (1948/1973) advocated active schooling with the aim of education toward "full development of the human personality" (p. 87). He asserted "the right to find in these schools all that is necessary to the building of a questioning mind and a dynamic moral conscience" (p. 92). Constructivist educators design activities in constructivist classrooms to appeal to children's interests, engage them in experimentation, and involve cooperation with others (DeVries & Kohlberg, 1987/1990). However, saying that a school is active does not necessarily mean that it is constructivist. One has to specify the nature of constructive activity, especially the specifics of mental activity.

Play. Perhaps the most common educational implication drawn from Piaget's work is that play, especially pretend play, is important for children's development. Piaget (1945/1962) pointed out the role of play in the formation of symbolic thought and discussed certain socioemotional benefits of play. Stambak and Sinclair (1990/1993) extended Piaget's work and showed how shared meanings and negotiations reflect the construction or foreshadowing of cognitive operations. However, Piaget (1948/1973) did criticize "an excess of unsupervised liberty which ended in generalized play without much educational benefit" (pp. 6-7). Thus, it is possible to have a play-oriented classroom that is not constructivist.

In a recent book, my colleagues and I point out the political problem stemming from a tendency of critics of developmentally appropriate practice to devalue play as aimless and of little importance (DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002). One solution to this public relations problem may be to acknowledge that much of what is labeled "play" in constructivist early education is actually "work." Another solution is to go beyond a global justification to clearer analyses—microanalyses—of precisely what is the value of activities in which we engage children. Examples of such analyses are our recent efforts to specify the logico-mathematical relationships constructed by children in activities involving shadows, cooking, making musical instruments, draining and movement of water in tubes, and pattern blocks (DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002).

Work. Piaget (1969/1970) commented that "the play of small children is gradually transformed into adapted constructions requiring an ever increasing amount of what is in effect work, to such an extent that in the infant classes of an active school every kind of spontaneous transition may be observed between play and work." (p. 157). My colleagues and I believe it is important to recognize that some of what is called "play" might be considered "work" in that it is not always pleasurable and may require intense effort and involve initial failure (see DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002). In the constructivist paradigm, the most desirable work occurs when children are pursuing their own purposes in figuring out how to do something. Csikszentmihalyi's (1990) notion of "flow" could be applied to much of children's work and play in constructivist classrooms. Although children often work in constructivist classrooms, it is clear that many "work-oriented" classrooms are not constructivist.

A cooperative sociomoral atmosphere. Perhaps the most important implication drawn from Piaget's work is that teachers must establish egalitarian, cooperative relationships with children and avoid being unnecessarily coercive in order to promote child autonomy. Betty Zan and I wrote that the first principle of constructivist education is to establish a cooperative sociomoral atmosphere in which mutual respect is continually practiced (DeVries & Zan, 1994). Constructivist teachers regularly involve children in making classroom rules and decisions about classroom events and procedures, and engage them in conflict resolution and social and moral discussions. Teachers sometimes hear the sociomoral principle as a recommendation to be permissive, despite the fact that we have stated that it is sometimes necessary to externally control children (DeVries & Kohlberg, 1987/1990, p. 312). We are continuing to work on this issue, to clarify what we mean specifically in the life of the classroom. Certainly a classroom does not deserve the label "constructivist" if it does not have a cooperative sociomoral atmosphere. Yet, a cooperative sociomoral atmosphere may exist without adequate attention to the intellectual aspects necessary to a constructivist classroom.

The sociomoral aspect of the constructivist paradigm also calls for teachers to concern themselves with interpersonal understanding among children. Constructivist teachers use Selman's (Selman & Schultz, 1990) notion of perspective-taking (based on Piaget, Mead, and Kohlberg) and levels of interpersonal understanding to evaluate children's progress in the context of socially active experiences. Teachers engage children in conflict resolution, and they promote children's shared experiences, reciprocal reasoning, and feelings about relations with others. However, it could be possible to promote child-child relations without other aspects of the constructivist paradigm.

The three kinds of knowledge. Piaget's (e.g., 1969/1970, 1970) distinction between physical and logico-mathematical knowledge proves to have practical utility to teachers. With Sinclair's additional conception of arbitrary conventional knowledge, teachers can use these distinctions to decide how to teach. When what is to be taught is arbitrary conventional knowledge, constructivist teachers give children information. When what is to be taught is physical knowledge, constructivist teachers encourage children to experiment with objects. When what is to be taught is logico-mathematical knowledge, constructivist teachers encourage the construction of relationships.

Physical-knowledge activities. Piaget's distinction among the three kinds of knowledge led Kamii and me to advocate physical-knowledge activities (DeVries & Kohlberg, 1987/1990; DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002; Kamii & DeVries, 1978/1993). We recommended these activities not only because children learn about properties of objects and phenomena of the physical world, but also because in the course of physical-knowledge activities, children construct logico-mathematical relationships and thereby increase their intellectual power. However, it is possible to include physical-knowledge activities in a program without other aspects of constructivist education.

Group games. Piaget's (1932/1965) research on children's play of marbles resulted in a description of stages that can be generalized to play of all games with rules. Group games provide a particularly good context for social and moral development, especially for the construction of reciprocal and reversible relationships. Kamii and I (1980) show how individual games can be analyzed in terms of cognitive challenges. For example, board games and card games can contribute to children's construction of number and arithmetic relationships. We also show how observation of children's play reveals their reasoning and how teachers can intervene to promote reasoning.

Arithmetic activities. Kamii (1982, 1989, 1994, 2000) has developed the mathematics component of the constructivist paradigm, including mental math, story problems, and situations in daily living, in addition to group games.

These are the unique aspects of the constructivist paradigm that also includes literacy and subject-matter content whose aims are little different from non-Piagetian programs. Methods of teaching similar content, however, may be different in constructivist classrooms.

Need for Research to Elaborate the Paradigm

The constructivist educational paradigm would be enriched by more research on stages or levels of development in the content of activities in constructivist classrooms. When teachers have information on stages in children's conceptions of specific content, they can anticipate some of children's errors and plan how to provide materials and interventions that may enable children to experience disequilibrations and construct more adequate understandings. In addition to Genevan work, examples of existing studies of stages that inform the paradigm include research on stages in children's conceptions of shadow phenomena (DeVries, 1987), play of Guess Which Hand the Penny Is In (DeVries, 1970), play of Tic Tac Toe (DeVries & Fernie, 1990), and levels of interpersonal understanding (Selman, 1980, Selman & Schultz, 1990).

Research on Constructivist Classrooms

Many of the educational implications of constructivist theory are not obvious, and practitioners and researchers must work in special ways to derive what is important for education from Piaget's body of work. Piaget (1932/1965) addressed this issue in the last paragraph of his book The Moral Judgment of the Child.

> But pedagogy is very far from being a mere application of psychological knowledge. Apart from the question of the aims of education, it is obvious that even with regard to technical methods it is for experiment alone and not deduction to show us whether methods such as that of work in groups and of self-government are of any real value. For, after all, it is one thing to prove that cooperation in the play and spontaneous social life of children brings about certain moral effects, and another to establish the fact that this cooperation can be universally applied as a method of education. This last point is one which only experimental education can settle. Educational experiment, on condition that it be scientifically controlled, is certainly more instructive for psychology than any amount of laboratory experiments, and because of this experimental pedagogy might perhaps be incorporated into the body of the psycho-sociological disciplines. But the type of experiment which such research would require can only be conducted by teachers or by the combined efforts of practical workers and educational psychologists. And it is not in our power to deduce the results to which this would lead. (p. 406)

It is important to note that Piaget envisioned a great deal of work in experimental pedagogy to be necessary in order to test his own educational ideas. Perhaps he even implies that pedagogical research can enlighten and test his theory, leading to its correction and elaboration.

Research on constructivist classrooms occupies the central place in this dynamic framework, represented by bi-directional arrows connected to all three of the other parts. It is not possible to develop the paradigm without constructivist classrooms or at least classrooms that are becoming constructivist. Classroom research is the stuff out of which the paradigm evolves. Three purposes of research on constructivist classrooms are discussed below.

1. <u>Research to develop the educational paradigm.</u> Basically, what we have done is help teachers study constructivist theory, discuss with them our ideas on educational implications, and then study what teachers do. Two methodologies are notable.
   a. <u>Systematic videotaping of constructivist teachers.</u> Unfocused systematic videotaping of constructivist teachers inspires us to identify significant events, expand our thinking, and conceptualize types of activities and principles of teaching that are saturated with the realities of life in classrooms. In preparing to write *Moral Classrooms,* Betty Zan and I simply studied stacks of videotapes and transcribed significant events related to the sociomoral atmosphere—for example, children's conflicts and teachers' interventions (DeVries & Zan, 1994).
   b. <u>Videotaping of specific activities.</u> Focused videotaping of activities we have planned with teachers allows us to collaborate in experimenting with certain materials and activities. Constance Kamii and I proposed specific physical-knowledge activities and group games to teachers, and we discussed together what materials to use, what challenges children might encounter, how to introduce activities, and possible interventions (Kamii & DeVries, 1978/1990, 1980). Betty Zan and I also used this methodology in developing certain chapters in our book on the sociomoral atmosphere. Children's spontaneous actions, teachers' own inspired interventions, and teachers' reflections after activities provided the raw material out of which we fashioned principles of teaching and other practical suggestions that are part of the constructivist educational paradigm. Analyses of children's actions were central in our evaluation of the educational possibilities of activities and in our connection of specific aspects of the theory with these actions. Other examples in our new book on constructivist curriculum include activities exploring the art and science of musical sounds, cooking transformations, experimenting with draining and movement of water in tubes, developing

geometric reasoning using pattern blocks, and using group games to teach mathematics (DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002). Longitudinal research can be short term or long term. One example of longer term research is Zan's study of development in the practice of rules in checkers of two boys over a semester (Zan, 2002).

Some of this type of videotaping takes place in classrooms, and some takes place outside the classroom. In the latter case, children are engaged in an activity that could take place in the classroom but occurs in a quieter, protected location in order to better observe what children and teachers do and say.

Focused study of specific activities is especially fruitful when basic constructivist research provides a related description of stages in children's conceptions about the content of the activity. For example, I (DeVries, 1986) identified stages in children's conceptions of shadow phenomena. This study belongs in the circle representing research on children's mental development. However, the interview used was an active one in which children could do some experimenting. It thus met criteria for good physical-knowledge activities. Moreover, it led to pedagogical experimentation in the classroom as we sought to create situations in which children might experience disequilibrium and construct new relationships (see DeVries & Kohlberg, 1987/1990; DeVries, Zan, Edmiaston, & Wohlwend, 2002). This brought characteristics of the paradigm into the basic research and thus illustrates how such basic research on child thought can connect with classroom research and the constructivist paradigm. We need more research on stages in the content of constructivist activities.

2. <u>Research to develop understanding of children's mental development.</u> It is easy to see how research on children's mental development informs work in classrooms, represented by the arrow from theory to classrooms. It may not be so apparent, however, how research in constructivist classrooms contributes

to research on children's mental development, as suggested by the arrow in the figure. The fact is that published research on children's thought only reveals this thought in part.
a. Documentation of spontaneous remarks by children in classrooms. Constructivist teachers are often able to observe child logic that no researcher has ever written about. For example, when one 4-year-old observed that her shadow "moved" from front to back when she turned, the teacher "became Piaget" for a moment and said, "How did that happen?" The child answered, "The wind blew it there!"

Another example I heard last week from an Iowa teacher of 4-year-olds involved a child's work with ramps. The teacher had arranged on the playground two gutters side by side. One had a low slope, and the other a steep slope. The child shoveled pea gravel on the low slope and saw it rest there in a pile. Then she saw the teacher shovel gravel into the steeper slope which made the gravel rattle and slide down the gutter. The child turned to the teacher and said, "I want your shovel." So the teacher gave it to her and took a third shovel to use for herself. They both shoveled, with the same result as before. The child turned to the teacher and said, "I want your shovel." Thus we often observe children's reasoning about causal variables.
I would like to point out that these observations were made possible by the constructivist teachers' "way of being with" children. Non-constructivist teachers are much less likely to be privy to children's preoperational logic when they keep children focused on following the teachers' dictates.

I believe that teachers' classroom observations such as the shadow and shovel comments can be published by teachers and/or research colleagues who reflect on constructivist classroom practices. Certainly the observation of children's preoperational remarks shows teachers how children are constructing knowledge. The results of such classroom research inform us all about children's mental development as it is revealed in classroom activities. We need a list serve to collect and share classroom observations.

b. Cross-sectional and longitudinal studies of children's conceptions of content related to constructivist schooling. Here I refer to research such as that of Ferreiro (Ferreiro, 1978, 1984, 1985a, 1985b; Ferreiro & Teberosky, 1979/1982) on reading and writing; Fosnot (1989) on writing; Constance Kamii (Kamii & Randazzo, 1985) on social interaction and invented spelling; Mieko Kamii (1980, 1981) on children's ideas about place value and written numerals; Furth's (1980) on children's understanding of money, societal roles, government, and community; Fosnot, Forman, Edwards, and Goldhaber (1988) on balance; and Selman's (Selman, 1980; Selman & Schultz, 1990) work on the development of children's interpersonal understanding. This is obviously not an exhaustive list. Maybe we in ACT need to collect and organize these studies that contribute to a justification of constructivist education and aid teachers in assessing children's development.

3. Research to test the constructivist educational paradigm. Research to test the constructivist educational paradigm must be done with classrooms that meet criteria for the prototype as described above.
   a. Study of implementation of constructivist education. Any research to test the constructivist paradigm must begin with a study of implementation of constructivist practices in the classrooms in the study. Pfannenstiel and Schattgen (1997; Pfannenstiel, 1997) developed a questionnaire on teacher beliefs as an initial screening to identify constructivist and traditional teachers. They also developed a 144-item Classroom Observation Learning Environment Scale designed to assess comprehensively characteristics of constructivist education. My colleagues and I have developed the Constructivist Early Childhood Classroom Evaluation (CECCE) (DeVries, Edmiaston, Fitzgerald, & Zan, 2001), a self-study instrument for teachers who are in the process of becoming constructivist in their teaching. We also have

derived from the CECCE a research version that can be used by observers to assess constructivist implementation. It is expected that degree of implementation will be associated with positive child outcomes.

b. Comparative study of constructivist and other paradigms. Scientific research on the effectiveness of constructivist education depends on comparative studies of different educational paradigms. Thomas Kuhn's (1970) conception of scientific paradigms in the natural sciences has been extended by Tuthill and Ashton (1983) to education. They point out that almost all classrooms are "conglomerates of contradictory elements" and that teachers "eclectically apply teaching strategies derived from conflicting scientific paradigms, using a little behaviorism here and a little humanism there, for example" (p. 10). Tuthill and Ashton argue that "such eclecticism significantly reduces the likelihood that researchers will be able to make sense of research results obtained in such classrooms" (p. 10). They call for conscious development and study of "pure prototypes" that avoid the usual eclecticism, in order to evaluate the practical effects of educational paradigms. Research on constructivist education indicating its effectiveness has been discussed elsewhere (DeVries, 2002). We must do comparative studies of classrooms in which good implementation can be demonstrated.

4. Research to develop constructivist theory. Research in constructivist classrooms may be expected to illuminate constructivist theory as indicated by the arrow from classroom to theory. As teachers and researchers study the constructive process in classrooms that make special efforts to foster that process, I expect us to learn more of the specifics about what equilibration looks like in life. One example is my research on children's conceptions of shadow phenomena (DeVries, 1986). I was able to describe certain coordinations among spatial relations and the nature of light that elaborated Piaget's early work on this topic.

So What Is Constructivist about Constructivist Education?

It is clear that constructivist education inspired by Piaget's theory is an approach to education that is still evolving. The model of the interrelations among constructivist theory, research, and practice is dynamic and has the potential to develop indefinitely.

More specifically, constructivist education for me necessarily involves the microanalysis of children's actions. For example, Piaget (1941/1995, 1945/1995, 1950/1995) described the way in which social co-operations function. In one article, I showed how children's pretend play begun with a proposal, "I'll be the mommy" and a response, "I'll be the daddy," necessitates conservation of an agreement, conservation of one's own and others' ideas, non-contradiction, feelings of obligation, equality in virtual actions, correspondences, reciprocity, reversibility in the coordination of past and present ideas, and grouping of coordination of actions (DeVries, 1997). In children's pretend play we can thus find foreshadowings of later operations. Further, Piaget argued that intellectual operations are identical with social co-operations. These kinds of specific links between theory and classroom activity make stronger our educational rationale for the value of pretend play and children's social interaction.

Piaget's discussion of logico-mathematical experience and its role in development has inspired my colleagues and me to analyze children's construction of specific logico-mathematical relations in classroom activities. For example, Hyang Lim Kwak and I looked at a 5-year-old's actions in eleven sessions taking place over the course of a semester in a study of draining and the movement of water in tubes. Plastic cups having holes varying in size and location were provided (See Figures 2 and 3). The 4-year-old children in Christina Sales's rural Iowa preschool experimented with these cups. At the beginning of Session 1, the teacher shows Tom the holes in the cups and asks what he thinks will happen. His answer: "Water will come out." This is the first scheme. He picks up individual cups from the water table and holds them at eye level to observe them drain. This is essentially reproductive assimilation as he simply repeats the same action on different objects. Different reactions of cups lead Tom to begin to differentiate his "water will come out" scheme. Then the teacher gives Tom a new cup with holes on both side and bottom. She calls his attention to the side hole and asks what he thinks will happen. Again, he says, "Water will come out of it." Tom dips the cup in the water table, lifts it up, and exclaims in surprise, "Eeee!" as water from the side hole spurts on his arm. This results in cognitive and affective disequilibrium, but the perturbation is quickly accommodated as Tom compensates by turning the cup so the water does not hit his arm. Subsequently, he consistently holds side-hole cups above and to the side of recipients and bottom-hole cups directly above their recipients, indicating that the "water will come out" scheme has been differentiated. One can also say that Tom has constructed regularities concerning the nature of draining from bottom and side holes. He has also constructed the regularity that bottom-hole cups empty completely but side-hole cups do not (unless tipped). This implies the regularity that water must be over a hole to produce a flow. Tom expresses this regularity when asked why water is flowing from only one place in a cup with two side holes: "'Cause it's past that hole." Tom conserves these regularities throughout the semester, indicating their consolidation.

Reciprocal assimilation can be identified when Tom works with a vertical system of three cups in Session 1. He sets one cup on the bottom of the water table and holds two cups above, making the middle cup simultaneously a drainer and catcher. The two schemes of catching and draining are thus applied to the same object and combined by reciprocal assimilation into a more differentiated structure than previous combinations of pairs of cups. We can also see the construction of similarities and differences and coordination of relationships in Tom's actions. Over the first four sessions, he repeatedly holds up pairs of cups side by side at eye level and compares the streams. Seriated correspondences are based on constructions of such comparisons of similarities and differences among pairs of objects. During the latter part of Session 1, after Tom has carefully observed the holes and compared pairs of cups, the teacher shows Tom three cups with small, medium, and big bottom holes. She asks, "If I fill all of the cups full with water, which one is going to get empty the fastest?" Tom immediately points to the cup with the big bottom hole and says, "And then that one (medium bottom) will get empty, and that one (small bottom) will." Tom chooses the big-bottom-hole cup to use in a race to test his hypothesis. When the teacher asks why, he responds, "'Cause that's the biggest, that's a middle size, and that's a little size." Tom clearly has constructed a seriated correspondence between three sizes of holes and order of emptying. He has constructed the series big hole > medium hole>small hole, and the series big stream>medium stream>small stream. When he connects the two series, he has constructed a seriated correspondence based on a function. Thus we see how progress at the practical level leads to progress at the conceptual level.

When two children collaborated to make a system of flow with four cups, each holding two, we decided they needed a pegboard on which they could arrange cups in holders to create more complex systems. In the course of his experimentation, Tom develops a preference for the cups with big bottom holes. Early in Session 4, Tom puts three cups in a vertical arrangement on the pegboard (Figure 4a). The top cup has a small bottom hole, the middle cup has a big bottom hole, and the bottom cup has a medium side hole. The top cup drains so slowly that the middle cup becomes empty. A first regulation is to put a finger over the bottom hole of the middle cup so that it can accumulate water (Figure a). A second regulation is to fill the middle cup directly with a pitcher (Figure 4b). The pitcher is placed on the bottom of the water table, added as a catcher of the curved stream from the bottom cup (Figure 4c). Finally, Tom exchanges the top small-bottom-hole cup with a big-bottom-hole cup (Figure 4d), and he succeeds in achieving a more coordinated system of flow relationships among three cups and the pitcher (Figure 4e). Later, he adds a holder above the top cup and puts a small-bottom-hole cup in it (Figure4f). Then he exchanges it for a big-bottom-hole cup (Figure 4g). The teacher asks if he is interested in catching the water from the bottom cup and offers him a holder. Decentering to take account of the side flow, he places a holder and cup at the bottom of the pegboard to complete his coordinated system of five cups that include both bottom and side holes (Figure 4g). He enjoys pouring water in the top over and over, observing the flow. Another child joins in to cooperate with Tom by pouring water in the top while Tom catches it at the bottom. Later in the session, the teacher calls his attention to some cups left by another child. She asks if he can fix it so one can pour into the top cup and make the water drain into the bottom cup in his arrangement. He managed to create the arrangement shown in Figure 5 by coordinating sequences of pairs of cups. It is doubtful whether Tom had in mind a conceptualization of the whole system before he began his series of adjustments. The practical result, nevertheless, is a coordination of spatial relationships involving both bottom and side positions of holes. After the completion of the array, he pours water many times into one side of the system (composed of cups with big bottom holes) while the teacher pours into the other side (composed of cups with medium holes). They observe the result—all the water ends in a central cup at the bottom. Once completed, it is likely that Tom grasps to some extent the set of interdependent relationships in the system, appreciating a differentiated and coordinated set of logico-mathematical relationships. However, he has not yet understood the fact that the side with big-bottom-hole cups must be filled more frequently to maintain flow. The teacher calls Tom’s attention to the fact that he has to fill his pitcher more often than she does. However, this problem is beyond his interest and possibly beyond his capacity at this time, and he does not reply.

An incorrect assimilation can be seen in Sessions 5, 7, and 9 when Tom takes the tube attached to reservoir and puts the free end into the top of the reservoir, trying to make the water recirculate (Figure 6a)! He seems to generalize the idea that water comes out of the tube, and he simply puts it where he wants water to come out. This may be a distorting assimilation to experiences with hoses where flow has pressure behind it. This contradiction to his expectation also does not lead to resolution as he continues over and over to try to make the water recirculate in the same way, looking expectantly as he lowers the free end into the reservoir. During Session 5, Tom presses down on the top part of the tube and sees the water seem to rise a little in the tube (Figure 6b). Taking the end out of the reservoir, he moves it downward (Figure 6c), and water gushes out. The teacher engages as a companion in these experiments, and Tom explains, "When it's this way, it's shorter (Bent downward) (he probably means "lower"), but when it's the other way (held over the reservoir, it's higher, and so it's hard for the water to get up high." With a partial regulation that is little more than a description of the water's action, Tom struggles to understand the contradiction to his expectation. He never resolves the contradiction of this practical negation and tries many times during Sessions 5-8 to achieve a recirculation.

Such analyses as these make the equilibration process visible and strengthen the case for the constructivist educational paradigm by showing directly how knowledge is constructed in classroom activities. The teacher who is able to notice actions such as these on the part of a child is going deeper into children's understanding than if he or she were simply looking to see if the child understands correctly.

In conclusion, the constructivist paradigm draws from research, theory, and experimental practice, all of which are in a dynamic interaction with one another. One way to summarize is to say that logico-mathematical relations and social co-operations bind all parts of the model together. These lie at the heart of Piaget's theory, the constructivist educational paradigm, and constructivist classrooms.

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