ELSEVIER
Early Childhood Research Quarterly 19 (2004) 150–158
Early Childhood Research Quarterly

Science learning pathways for young children

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Abstract

Preschool Pathways to Science (PrePS©) is a science and math program for pre-K children that has been developed by a team of developmental psychologists in full collaboration with preschool directors, teachers and other staff. The PrePS© approach is rooted in domain-specific theories of development, theories that assume that different areas of knowledge are organized into separate mental structures as opposed to domain-general ones like concrete operations. Features of this theoretical stance are outlined, and their implications for educational practice are illustrated using examples from classroom practice. Specific attention is paid to the importance of science process skills, the need to connect experiences using a central concept, and the roles of math, communication, and literacy in a science-based learning approach. Finally, the critical interdependence of basic research and classroom practice is discussed.

Keywords: Early cognition; Mental structures; Early science education

1. Introduction

The last several decades of developmental research have resulted in the recognition that preschool children have some potent cognitive competencies and related learning potentials. These include early arithmetic abilities and skills, implicit understanding of cause and effect sequences, pre-literacy ‘writing,’ and some science knowledge. These findings led us to accept an invitation from Gay Macdonald, the director of UCLA Early Care and Education, to collaborate on the development of a science and math program for young children. Our ongoing joint effort has resulted in a program entitled Preschool Pathways to Science (PrePS)©.[1] Aspects of the program have been introduced with relative ease to sites near the Rutgers-New Brunswick campus. Like other approaches featured in this volume, ours provides children

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[1] A guidebook, prepared by the members of our labs and the staff of the UCLA Center is in its final editing stage for release to potential publishers.

0885-2006/$ – see front matter © 2004 Published by Elsevier Inc.
doi:10.1016/j.ecresq.2004.01.009

with many opportunities to take an active role in the constructing and recording of their own knowledge in the context of hands-on experiences with sensitive adult guidance.[2] PrePS© combines these aspects with a teaching approach informed by a domain-specific perspective on cognitive development and learning that is consistent with the recent National Academy of Sciences publications, *Eager to Learn* (Bowman, Donovan, & Burns, 2001) and *How People Learn: Brain, Mind, Experience, and School* (Brown, Bransford, & Cocking, 2000).

2. Theory and implications for the development of PrePS©

Many developmental theories are domain-general. *Traditional learning theory* assumes that children form associations, piece by piece, about what is taught as a function of frequency of experience and contiguity between desired responses. The response is reinforced, either with social praise or a desirable item. The child's task is to master what is offered. The staff's task is to design and monitor a sequence of small learning experiences, often with ready-made checklists that are publicly available, that yield behavioral objectives.

Traditional developmental theories, like those of Piaget (1970) and Vygotsky (1962), are also domain-general. They assume, however, that cognitive development involves broad mental structures that facilitate mastery of a variety of tasks. Additionally, children are granted an active role in their own cognitive development. Existing mental structures seek and find inputs that can be assimilated to support cognitive growth. Whereas Piaget focused more on the child's own construction, Vygotsky emphasized the role of adult socializing agents who engage children in conversations and scaffolding activities. Nevertheless, both took the position that young children's cognition is perceptual and not abstract. Piaget, for example, believed preschoolers to be capable of only preoperational thought, which does not allow for the application of abstract classification and quantitative conservation schemes. Evidence that preschoolers attend to and use the relative lengths of the displays in a number conservation task or local similarities between objects in classification tasks rather than logical operations bolstered this characterization. Vygotsky similarly described young children's concepts as pre-concepts. These traditional views contribute to the assumption that many science and math experiences are not developmentally appropriate for preschoolers because they require the use of abstract thought.

Despite the differences between learning and traditional developmental theories, both assume that domain-general learning mechanisms serve concept acquisition across many areas of thought. They also hold that preschool children are perception-bound and unable to form abstract concepts. Demonstrations of non-verbal concepts in infants and toddlers and some rather abstract conceptual competencies in preschoolers have led to the emergence of a new class of developmental theories. These are variously referred to as *domain specific*, *core knowledge* or *rational-constructivist* theories.

Domain-specific theorists share with other developmental, constructivist theorists the assumption that, from the start, the mind is actively engaged in seeking and assimilating nurturing inputs. They differ by virtue of their commitment to the notion of domain-specific, as opposed to domain-general, learning and development structures. Evidence for some early high-level conceptual competence in various domains leads these theorists to posit the existence of innate, domain-specific mental structures that underpin and

[2] These include ones created by or based on the approaches of: Barbara Bowman, Reggio-Emilia, David Feldman, Howard Gardner, Lillian Katz, Anne Lewin, Jeannette Stone, and so on.

guide rapid learning in certain knowledge areas. Like general structures, domain-specific ones are used to actively search environments to find and assimilate relevant information, literally "food for thought"; however, different learning structures seek different inputs. To illustrate the notion of *domain-relevant inputs*, consider the acquisition of knowledge about numbers as opposed to physical objects. For the principles of addition and subtraction, the domain-relevant entities are quantities, not physical attributes. When counting to obtain a discrete number, one need not consider the size, shape, material, or weight of the items. When it comes to causal reasoning, however, these variables become particularly relevant.

Another key notion for domain-specific theorists (as well as Piaget and Vygotsky) is that concepts in a domain do not stand alone. What we know about dogs, for example, is linked to what we know about other animate creatures. This allows the learner to make inferences or generalize from known cases to novel cases. For example, if we are told that the unfamiliar item *umquat* is an animal, we know that *umquats* breathe, eat, reproduce, and move by themselves (Gelman & Lucariello, 2002). Concepts do not stand alone; nor, does vocabulary within a domain. The language about concepts in a domain is connected to those concepts just as the concepts are to each other. Put differently, one should think of the language and knowledge about scientific concepts as the two sides of a coin. In a recent study completed in our lab, adults and children agreed that various animate objects (people, dogs, and elephants) could move (Subrahmanyam, Gelman, & Lafosse, 2002). Many adults (and a few children) agreed that plants move, too, but it was clear from adults' explanations that this "move" was of a very different sort than that of animals. Plants move in response to external agents such as the wind and light, not in response to any desire to move. It is as if the same term, *move*, is a homonym with its possible meanings depending on whether it refers to a plant, an animal, or an inanimate object (Keil, 1979; Subrahmanyam et al., 2002).

A domain-specific, constructivist description of mental structure (and learning) has implications for the development of educational experiences about scientific material. The connectedness of concepts in the head and in the world implies that learning experiences should be conceptually linked as well. The importance of the language within a domain suggests that one should not "cheat" on vocabulary; terms such as respiration, nutrients, and the concepts to which they apply belong in the preschool classroom, both because children learn words at an astonishing rate during these years and because proper vocabulary is part and parcel of conceptual growth. Children can begin to learn the actual terms that refer to the concepts they explore. Commitment to the active learner who is also capable of abstract thought means that introduction to, and use of, aspects of the scientific method also can be undertaken. Our approach parallels current educational standards and best practices (as outlined by the National Academy of Sciences) that hold that inquiry learning in the arena of science should be related to the concepts, language, and processes of science. This is because they are all interconnected and mutually supporting.

3. Implications for preschool education

We begin with an example. The following describes a method we have used to introduce PrePS© into some classrooms. Although it is a very simple example of a PrePS© experience,[3] it illustrates some key features of the program that relate to our theoretical approach to cognitive development.

[3] The choice of example is a difficult one for us. As one long-time PrePS© teacher puts it, "We have gone way beyond seeds and planting." Still, this example is useful for illustrating key points of the program.

Very early in the school year, a teacher used circle time to introduce the vocabulary and methods of *observe*, *predict*, and *check*. She began with the already familiar five senses, asking what the senses are and which body parts are associated with each. After children listed these, the teacher showed the children an apple and introduced the term *observe* saying that one could observe the apple using all five senses. She explained that each child would have the opportunity to make an observation about the apple and that these would be written down "because scientists record their observations." Children offered observations about color, surface texture and parts, temperature, lack of sound, and so on which were recorded on a simple chart and displayed on the wall. During the next circle time, *predict* was introduced. Children were told that scientists predict when they cannot observe something. They use the knowledge they have to make a prediction, which is something like a guess. Next, each child predicted what was on the inside of the apple (e.g., wet stuff, white, seeds, etc.) and then how many seeds were inside. An adult recorded these predictions. The apple was cut open and checking about the insides and the number of seeds began, with children taking turns *observing to check their predictions*. The main goal of this activity was to introduce children to some scientific vocabulary and the processes to which the terms apply. These words and processes are practiced again and again as children investigate the natural world, regardless of the particular concept being explored.

3.1. Embedding the scientific method

As indicated, in PrePS© the science experiences that engage children are characterized by the use of relevant language and the scientific method. Because the language of a domain and its concepts go hand in hand, it follows that scientific terms and the processes to which they refer should be paired with concept learning material from the start. As children encounter examples of new words in relevant learning environments, they develop intuitions about both the meaning of the word and the contexts in which it is used. One of the great surprises for us is how readily children take up seemingly difficult new words. For example, several days after K.B. and Beth Lavin introduced the idea of observing during the circle time of a 4- and 5-year-old group, a child approached them with a Lego block stating, "It's green. It's a rectangle. I cannot *observate* anymore." We find that, over time and with repeated opportunities to use scientific vocabulary in meaningful contexts, children fall into using it in appropriate ways. When a child coins a new version of a term introduced in class we know he or she has some understanding of its use. Deep understanding will take some time (and experience) to achieve, but at least the child will bring a relevant knowledge base to new learning opportunities. It is unlikely this would be the case if the child were simply put through vocabulary memorization drills.

Vocabulary is just one tool for thinking, talking, and working scientifically. *Observe*, *predict*, and *check* are more than terms; they are skills that are introduced and used throughout the year and across a variety of settings. Likewise, the term *record* is used often and children's natural interest in and developing skill with drawing is applied in a new way to record observations, to note predictions, and to document findings. Observation (magnifying glasses, light tables) and measuring tools (rulers, measuring spoons, tape measures, balance scales) are introduced into the classroom slowly but once introduced remain available throughout the classroom and throughout the day, not just at a science table or during science time. This interplay between science process and science content allows learning to spiral as process skills are applied to familiar content allowing for the construction of new knowledge. As knowledge develops, the learner seeks new, but related, inputs upon which to apply developing thinking skills. The

PrePS© teacher provides these learning opportunities by planning activities that vary on the surface but share deep conceptual connections.

3.2. Conceptually-connected experiences

A scientific attitude towards exploration binds PrePS© experiences. So, too, do underlying central concepts. One educational implication of a domain-specific approach to development is that classroom experiences should encourage the construction of conceptually-connected knowledge by being connected themselves. Many preschool teachers have successful science activities that entertain and amaze children. The PrePS© approach goes further to encourage deeper understanding of one or two concepts through sets of related experiences that cohere around a central concept.

Returning to the apple example, one could imagine it being part of a larger exploration. For example, many preschool classes study seeds as a curriculum theme in the spring. PrePS© expands this traditional treatment. The apple activity might serve as a starting point for explorations of insides and outsides (How well can we predict the features of the inside of an object by observing its outside? What is the same about the insides of various fruits? animals? machines? How does the outside of a machine differ from the outside of an animal? How does the inside of a machine differ from the inside of an animal?) or of biological change and life cycles (Where do seeds come from? Are all seeds inside fruits or can some be outside? Do vegetables have seeds? Where are they? Do animals have seeds? How do we get new animals?).

To illustrate the kinds of experiences a PrePS© teacher might plan, imagine that he or she decides to focus on biological change and life cycles to explore the question, “How do living things grow and change?” The possible activities are nearly endless. The apple activity might be part of a focus on seeds and plants. Another activity might involve sorting various seeds based on size, color, or shape. Children could try to match three seeds to the plants they become using prediction skills. Checking could be as simple as looking inside seeds packets or planting to find out. Requirements for germination and growth could be explored. Children might discuss the possible requirements for seed growth by predicting and checking what happens when seeds are placed in soil, water, in the air, with or without sunshine. Exploration of this central concept, *biological change and life cycles*, does not end with plants, however. It is further illustrated with activities focused on, for example, human (and/or other animal) growth. Children bring in baby pictures. The class predicts which picture matches which child. The shoe sizes of a younger class and an older class could be measured, charted, and contrasted to illustrate growth. Discussions of requirements for human growth (oxygen, nutrients, water, sleep) would lead to health and hygiene issues (certainly a staple theme in preschool classrooms). The changes explored for living things could be discussed with respect to non-living things as well.

We know that achieving understanding takes a great deal of time and requires many different illustrative examples of the target concepts (Brown et al., 2000; Gelman & Lucariello, 2002). Varied and ubiquitous experiences that cohere around the same underlying concept provide multiple entry points to learning, and a child who is given only one or two opportunities to work with a given concept may miss the entry point and may not have enough opportunities to connect constructed knowledge to novel, but related, experiences. For these reasons, the same central concept guides curriculum planning not over a week or two, but for months or even the whole year. This allows for a deep exploration of a central concept by exposing children to many variations of it. Hurried exposure to many, disconnected science topics often fails to provide opportunities for the rich conceptual growth that comes from a coherent, measured approach (Winnett, Rockwell, Sherwood, & Williams, 1996). And, with young children it is not even likely that much will be assimilated. Although this approach may seem unusual to those who use a new theme to guide planning every week or two, we expect that readers can imagine how explorations of biological growth and change could encompass many traditional and important themes such as aspects of seasonal change, plant care, pet care, nutrition, personal hygiene, personal safety, among others.

3.3. Choosing central concepts

These activity ideas are just a start, and while you were reading, we know that you were generating your own ideas. The PrePS© approach relies on just this sort of creativity on the part of teachers. We know that children (and adults) do not learn best, and most happily, when presented with lists of facts to memorize, outside a relevant learning context. For related reasons, we do not believe that teachers must teach from a fixed set of curriculum units. The PrePS© program is not a prescribed list of topics (with related activities) that teachers should teach to children. Rather, it is an approach to classroom planning that allows teachers, staff, and children to explore a given concept through many, varied experiences, that nonetheless are connected by an underlying concept or question.

A key finding from cognitive psychology (and tenet of constructivist approaches) is that it is easier to learn more about what one already knows than to build concepts in a new domain about which one has little or no relevant knowledge. We base the conceptual content of PrePS© on research findings that suggest that children already have begun building relevant knowledge in a domain; that is, they are already on a *learning path*. Evidence that preschoolers are, and have been, on learning paths for a number of science topics include those related to the sciences of biology (e.g., the differences between animate and inanimate objects, Carey, 1985; Massey & Gelman, 1988), and physics (e.g., causality, Bullock, Gelman, & Baillargeon, 1982; physical properties of objects, Baillargeon, 1995; Spelke, 2000). The goal is to take advantage of that existing knowledge by providing experiences that will enable children to move further on the learning path for a particular concept. Taking our cues from early cognitive development research, as opposed to adapting a K-3 curriculum, also helped us avoid the tendency to create a pushdown curriculum, one that involves bits and pieces of the science curricula for middle and high school. For example, it made no sense to introduce mechanics or the science of light when it is known that many college students lack understanding of these.

The concepts that PrePS© teachers have worked with include change (biological, chemical, and/or physical), insides and outsides of a wide variety of objects, the differences between animate (living) and inanimate (artifacts and non-living things of nature) objects, form and function, and systems and interactions. Yes, these topics are abstract, but research tells us that children have relevant intuitions about them, intuitions that can serve as the basis for further learning. For example, although preschoolers do not have an advanced understanding of biomechanical and mechanical motion, they are able to judge whether photographed objects can move by themselves (are animate), even when these animals are unfamiliar. Further, preschoolers do not over-attribute animacy to statues that resemble animals or people (Massey & Gelman, 1988). Research findings of this sort suggest that children have relevant knowledge that can serve as a foundation for learning more about the *animate–inanimate distinction*. Similar evidence for early intuitions underpins our choice of other central concepts as well.

3.4. Connections to other curricular areas

PrePS© uses science concepts to organize preschool experiences. In so doing, the approach encompasses many topics that are already part of preschool curricula. Similarly, PrePS©, while a science program, encompasses other curricular topics such as literacy and mathematics. In fact, these skill areas are critical for doing science. To do science is to predict, test, measure, count, record, date one's work, collaborate and communicate. Science involves not just "doing" but thinking and talking about the work being done (see also Gallas, 1995) and recording activities and ideas (Katz, 1993).

Even in the simple apple activity, literacy and mathematics played key roles. Children watched as their verbal observations and predictions were transformed into written words by adults. Children were interested in the reverse transformation as well, asking teachers to read what they had said long after the activity ended. Additionally, children used a whole apple and a cut apple as models to record, by drawing in their own science journals, what they observed before and after the apple was cut. If they wanted, an adult wrote down what the child said they had recorded. Mathematics skills were used when children estimated the number of seeds in the apple and counted the number actually found. As an extension of the apple activity, one PrePS© teacher used her lunch to encourage estimating and predicting. Each day she asked students to predict the number of seeds in the apple she brought that day. Early in the week, estimates were rather wild, but as evidence mounted over the course of several experiences, they became more accurate. As a related activity, one could practice addition skills by stating that Monday's apple had 5 seeds and Tuesday's had 6, and asking children to predict how many seeds altogether. Predictions could be checked.

The possibilities for incorporating math and literacy into a science curriculum are endless. Our point is that science should be considered content for mathematics and literacy experiences (which is not to say that these do not have meaning without scientific content!) and not as a separate activity that takes time from these core content areas.

In sum, the PrePS© approach is rooted in domain-specific theories of development. We are deeply committed to the idea that children actively participate in their own learning from the earliest ages. Our goal is to harness existing, but emerging, knowledge and to provide opportunities for children to move along learning paths for science and mathematics concepts. We believe that embedding concepts throughout the school year in a variety of relevant contexts encourages movement along these paths. The idea that experiences must be conceptually connected so that concepts are available to be worked with and considered over long periods is what sets PrePS© apart from once-and-done science activities. It turns out that the development of PrePS© was occurring as national standards for K-12 science education were being outlined. We are gratified that many of the key principles of PrePS© map onto these standards. Of special import are an emphasis on teaching fewer concepts in a deeper way and the re-definition of science as a process of knowledge acquisition, doing and recording, not just a body of facts.

4. Partnerships in research and education

Too often developmental theory and educational practice are separated, but PrePS© is an example of current efforts to merge the two. The development of PrePS© was, and continues to be, a collaboration between basic researchers and educators. Research in preschool cognitive development provided a starting place for content. Domain-specific accounts of learning paired with the latest approaches to preschool education resulted in an educational approach that supports the constructivist learner. PrePS© creates an environment of conceptually connected learning experiences that supports a curious intellectual attitude and movement along relevant learning paths. The interdependence between research and practice continues as we use the surprising competencies revealed in PrePS© classrooms to generate new research paradigms. For example, the ease with which children catch onto the ideas of predicting and checking has given us a way to gather evidence about early arithmetic abilities that can be used to address theoretical issues (see Zur & Gelman, this volume). Similarly, an activity in which children gathered survey data about their classmates' favorite foods and then worked with the teacher to graph results has inspired new research into individual children's understanding of graphs both before and after a short educational intervention. A related effort will investigate whether children who are involved with designing and implementing data collection will show more advanced graphing skills than children who are not involved in this way. Findings from this research can then be used to develop truly appropriate classroom experiences that both take advantage of children's abilities and support further growth of these skills.

Another direction for future research concerns collaborations between researchers and practitioners. A number of teachers who have participated in PrePS© have found renewed interest in teaching as they take on more responsibility for the development of curriculum—and find that they really can do science. The researchers involved are likewise inspired by working with teachers to translate basic findings into experiences that help children learn. We suspect that those who participate in such collaborations emerge with changed attitudes about their work, their professional goals, and the potentials of research and practice to improve the other. In other words, we adults have moved further along a learning path when given the opportunity to engage in goal-directed activities in a collaborative, nurturing environment. Empirical exploration of these anecdotal findings should be undertaken. A related direction for future work is documentation of a variety of collaborative efforts between researchers and practitioners so that the potential problems and solutions are highlighted and benefits are celebrated (see Barnett & Frede, 2001). Our experience with PrePS© indicates that teachers, researchers, and, most importantly, children benefit from these connections.

Acknowledgements

The development of PrePS© has been funded by grant support from NASA, NSF, UCLA, and Rutgers-New Brunswick. We have also benefited from budget support for staff at both UCLA and Rutgers. Many thanks to teams of gifted professionals at UCLA Early Care and Education and in the Cognitive Development and Learning Lab who have worked on the program throughout the years. We are grateful to the staff of the Douglass Child Study Center at Rutgers for allowing us the opportunity to introduce the program to their school.

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