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ABSTRACT

This paper asserts that any intellectually responsible program to instruct young children in math, science, and technology must overcome at least three seemingly insurmountable obstacles: (1) adults' inability to discover, either by reflection or analysis, the means by which children acquire science and technology concepts; (2) the fact that young children think differently from adults and do not organize their world along the same lines as do older children and adults; and (3) the fact that young children have their own curriculum priorities and construct their own math, science, and technology concepts which while age appropriate, may appear wrong from an adult perspective. After considering each of these obstacles, the paper offers suggestions as to how they can be best overcome: (1) the importance of observing young children's learning in order to make instructional decisions that truly reflect children's learning needs and processes; (2) the need to recognize the limits of instruction--for example, young children think transductively, and this limits the possibility of teaching abstract concepts; and (3) the value of employing capacity-linked and socially derived motivation, engaging the spontaneous learning motivation children experience as their cognitive capacity increases. Instilling social motivation by involving parents in ways that encourage their modeling of reading, question asking, and knowledge gathering are also crucial. (EV)

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EDUCATING YOUNG CHILDREN IN MATH, SCIENCE, AND TECHNOLOGY

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EDUCATING YOUNG CHILDREN IN MATH, SCIENCE, AND TECHNOLOGY

David Elkind

Any intellectually responsible program to instruct young children in math, science and technology must overcome at least three seemingly insurmountable obstacles. One of these is our adult inability to discover, either by reflection or analysis, the means by which children acquire science and technology concepts. Another obstacle is that young children think differently than we do and do not organize their world along the same lines as do older children and adults. Finally, young children have their own curriculum priorities and construct their own math, science and technology concepts. These concepts, while age appropriate, may appear wrong from an adult perspective. We need to consider each of these obstacles before turning to a few suggestions as to how they can be best overcome.

OBSTACLES TO EFFECTIVE EARLY CHILDHOOD EDUCATION

Deconstructing Math, Science, and Technology Concepts

Math, science, and technology are abstract mental constructions far removed from the immediate, here-and-now world of the young child. As adults, we cannot retrace the steps we took in attaining these concepts inasmuch as they are part of our intellectual unconscious and unavailable to retrospective analysis. A simple thought experiment illustrates the point.

Imagine you are teaching a young child of four or five to ride a small, two-wheeled bicycle. What is the most important thing the child has to learn to succeed at this skill? If the reader is like most adults, he or she will answer "Balance. The child has to learn to keep his or her weight centered on the seat."

In fact, if you actually attempt to teach a child to ride a two-wheeled bicycle, the problem turns out to be quite different. What you observe is that the young child focuses either upon pumping and forgets to steer, or focuses upon steering and forgets to pump. In fact, balance is attained when children coordinate pumping with steering. Once we have attained that balance, however, we are no longer aware of how we accomplished it. Although this is a simple illustration, it makes a very powerful point. If we want to teach young children math, science, and technology, we cannot start from some reflective analysis of the task, but rather we must actually observe children attempting to learn the task. This was one of Jean Piaget's (1950) most important insights, and one that must not be forgotten.

To make this insight concrete, consider Piaget's 1942 investigations of the child's conception of number. In that book, he nicely demonstrated the parallel between the child's spontaneous construction of number and the three types of scales used in psychological measurement. In psychological research, we distinguish between nominal, ordinal, and interval scales of measurement. We speak of *nominal* number when we use number as a name, say the number on a football or basketball jersey. Nominal numbers have no numerical value or meaning. Secondly, we speak of *ordinal* number when we use

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number to designate a rank. The numbers used to describe a figure skater's performance are ranks. That is to say, a rating of 5.6 given one skater is better than a rating of 5.4 given to a second, but there is no exact measure of how much better the one skater is than the other. There are no units of skating skill or of artistic presentation.

Finally, we speak of *interval number* when the numbers we use reflect equal units or intervals. It is only interval numbers that justify the operations of arithmetic and higher mathematics. This fact is often neglected, however. Many psychological measurements—such as the IQ, which is a rank—are treated as if they were interval measures. The distinction between nominal, ordinal, and interval scales dates from the early days of psychology as a science and its attempts to employ quantitative methods. Interestingly enough, as Piaget has shown, children employ first nominal, then ordinal, and finally interval scales in their spontaneous attainment of measurement concepts.

Inasmuch as nominal number is essentially a label, young children can use nominal numbers as soon as they are able to use names, usually by age two or three. Then, by the age of three or four, young children are able to order blocks (or other size-graded materials) as to size, and thus demonstrate the ability to construct ordinal scales and employ numbers in an ordinal sense. It is, however, only when children attain what Piaget termed concrete operations, at ages five to seven, that children can construct units and employ interval scales.

The way in which a child constructs a unit illustrates how different this process is than what one might conclude on the basis of an introspective or logical analysis of the task. Piaget (1942) demonstrated that to construct the concept of a unit the child must coordinate the ideas of sameness and difference. That is to say, to understand a unit the child must grasp the idea that, say, the number 3 is both like every other number (its cardinal meaning) but also different from every other number (its ordinal meaning), being the only number that comes after two and before four. It is only at this stage that the child can perform true arithmetic operations. In short, the only way to understand how children learn a concept is to observe them in the process of acquiring it.

Understanding Young Children's Transductive Thinking

Young children think differently than do older children and adults. It was Barbel Inhelder and Jean Piaget (1971) who gave us our most important insights into the thinking of young children. What Piaget and Inhelder discovered, among other things, was that young children think *transductively*, from object to object and from event to event, rather than inductively or deductively. All concepts and ideas are at the same level. For example, a child who asks, "If I eat spaghetti will I become Italian?" is thinking transductively, joining concepts at two very different levels of abstraction. Transductive thinking, it has to be emphasized, is age appropriate and is not something to be overcome or extinguished.

Transductive thinking helps to account for a number of characteristics of the thought of preschool children. Young children often exhibit *animism*, and ascribe life to any object that moves. Again, this arises from the joining of concrete and abstract conceptions as if they were on the same level. Young children also give evidence of *purposivism*, the idea that every event and object has a purpose or goal. Finally, young children also give evidence of *phenomenalistic causality*, the idea that when two things occur together, one causes the other.

In many ways, Inhelder and Piaget have done for child thought what Kuhn said historians of science have begun doing for science:

> "Rather than seeking the permanent contributions of an older science to our present vantage, they attempted to display the historical integrity of that science in its own time...Furthermore, they insist upon studying the opinions of that group and similar ones from the viewpoint—very different from that of modern science—that gives those opinions the maximum internal coherence and the closest possible fit to nature." (Kuhn, 1962/1970, pg. 3)

In the same way, young children's thinking has to be understood in its own terms and context, not from the perspective of adult thought.

The Fundamental Curriculum

The third obstacle to the effective math, science, and technology education of young children is that preschoolers have their own curriculum goals. As adults we tend to assume that young children are born with all of the concepts that most children display when they enter first grade. This results from the fact that as adults we have few memories of the first few years of our lives. Recall memory requires a space time framework that young children have yet to achieve. It is not until the age of seven or eight that children have a good sense of clock time. And a true understanding of calendar time

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comes even later than that. In the same way, young children only acquire a sense of map and geographical space when they are in the later elementary grades. Without a space/time conception there is no framework within which to order and store memories. When we try as adults to remember what we learned as preschoolers, we start where we should be ending.

What we do learn as young children, despite not remembering it, is what might be called the *fundamental curriculum* (Elkind, 1987): our knowledge of things, their sensory properties, their spatial relations, and their temporal sequencing. Put more concretely, to operate successfully in the world, young children must learn *light* and *heavy*, *behind*, *inside* and *on top*, *night* and *day*, *before* and *after*, and much, much more. None of these ideas is inborn; they all must be constructed using a great deal of time and effort. Young children have their own curriculum priorities. Perhaps Friedrich Froebel (1904), the inventor of the kindergarten, put it best when he wrote that young children need to "learn the language of forms before they learn the language of words." Even without explicit instruction, young children are acquiring elementary and adaptive knowledge and skills in math, science, and technology.

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IMPLICATIONS FOR MATH, SCIENCE, AND TECHNOLOGICAL EDUCATION

The foregoing obstacles to the math, science, and technological education have a number of practical implications for educating children in these domains. Only a few of these can be described here. These are: the importance of observing young children learning, the need to recognize the limits of instruction, and the value of employing capacity-linked and socially derived motivation.

Observing Young Children Learning

In a nursery school recently, I observed a group of children gathered around a computer that one child was operating. They were working together and making suggestions to the child at the keyboard, who seemed to appreciate their help. The teacher, however, intervened and suggested that they needed to take turns and to let the child at the keyboard have his turn without the other children bothering him. This is good example of how a well-intentioned teacher nonetheless ignored the necessity of observing children before making an instructional decision. The children were working cooperatively, not fighting or competing to be at the keyboard. This may be the way young children approach technology—they may find it less intimidating when approached as a group project. That at least is a possibility that should be investigated.

The world of technology, particularly computers, is a new one. But the obstacle to the most effective instruction using this technology is the same. We need to observe how children themselves deal with the technology. To be sure, some initial instruction is required and certain limits need to be set, but we also need to be careful observers of the choices that children themselves make. To give a second illustration, in another nursery school, I observed a child at a computer who was enjoying an animated reading program that she chose. The teacher, however, encouraged her to use a more advanced, strictly word-oriented program. In such situations, I believe, we need to respect children's choices. We really don't know what types of programs are most effective with young children without careful observation and study.

Recognizing the Limits of Young Children's Learning

Transductive thinking is concrete and unilevel. Math, science, and technology, on the other hand, have concepts at many different levels of abstraction. For some disciplines, even the lowest levels of abstraction are beyond the abilities of young children. The failure to recognize and accept this fact was the fundamental error in Jerome Bruner's (1962) assertion that, "you can teach any child any subject at any age in an intellectually responsible way." There is simply no way to teach a preschool child algebra without so concretizing the concepts as to beg the question as to whether or not they are algebraic. Algebra requires the learner to have acquired what Inhelder and Piaget(1958) call formal operations, operations that enable the young person to deal with

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second symbol systems. In algebra, a letter stands for another symbol, a number. Young children are unable to deal with second symbol systems.

A more concrete example may help amplify the point and provide a practical guideline. Early childhood is a question asking period, but how one answers has to reflect the child's level of thinking. If a child asks, say, "Why does the sun shine?" he or she will be lost if you begin to explain the relation between heat and light. What the young child is asking, is not for a scientific explanation, but for a purposive one. If we say, "To keep us warm and make the grass grow," we respond to the true intent of the child's question. Such answers are not really "wrong," and they accomplish the important goal of encouraging further questioning and a wonderful sense of being understood.

Alternatively, one can always turn the question around and ask what the child thinks. Many of the young child's questions are partly rhetorical in the sense that he or she has thought about them and may well have come up with his or her own answers. The child is most happy to share these with us. If we accept these answers without challenging them, we get insight into the child's thinking and communicate that we are interested in his or her ideas, not in right or wrong answers. In so doing we are not reinforcing wrong answers so much as promoting the child's sense of self-confidence and security in expressing his or her ideas.

There *are* limits to what one can effectively teach young children in the fields of math, science, and technology. But there are no limits to the young child's curiosity and imagination if we support and encourage their own ways of thinking.

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Motivation in Math, Science, and Technology Education

Young children, as noted earlier, have their own curriculum priorities. They also have their own motivations for assigning these priorities. All those who have worked with young children remark upon how eager children are to explore and learn about their world. The origins of this motivation, however, are a matter of dispute. Some argue that children are intrinsically motivated to learn and that it is rigid, constraining schooling that dulls the young child's avid striving to learn about his or her world. Piaget (1950), in contrast, suggests that the spontaneous motivation we observe is actually a by-product of developing mental abilities. When a child's abilities are maturing, he or she spontaneously seeks out stimuli to nourish those abilities. Young children will often ask adults to give them numbers to add or subtract once they are able to use these operations.

If we accept this relation of motivation to developing operations, it means that once the operations are fully acquired, the motivation will be lost. Indeed, this is what seems to happen during the early grades of school. It is not that the school deadens motivation, but rather, that the spontaneous motivation associated with developing mental structures has dissipated. What takes the place of that spontaneous motivation is social motivation. Parents are curious—who read newspapers, magazines, and books and who talk about the events of the world—encourage their children to be curious. Children, in turn, believe that by following the parental example they will please their parents and warrant their continued love and protection. In early childhood education, as in later education, parental modeling is all-important. Involving parents is an important part of effective early education.

Before leaving the subject of motivation, it is important to distinguish between capacity and learning. This is particularly true today when there is a growing body of knowledge about brain growth and a number of facile extrapolations to early childhood education. As John T. Bruer (1997) has recently made very clear, such extrapolations are quite premature and reflect a failure to appreciate the complexities and intricacies of brain growth. Even if the young brain is growing rapidly, that does not tell us what type and how much stimulation is most conducive to productive learning. As Jane Healy wrote:

> "Unproven technologies...may offer lively visions, but they can also be detrimental to the development of the young plastic brain. The cerebral cortex is a wondrously well buffered mechanism that can withstand a good bit of well intentioned bungling. Yet there is a point at which fundamental neural substrates for reasoning may be jeopardized for children who lack proper physical, intellectual and emotional nurturance. Childhood--and the brain--have their own imperatives. In development missed opportunities may be difficult to recapture." (Healy, 1990)

In addition to inappropriateness, there is also the issue of the relation of motivation to capacity. A case in point is the young child's great facility for learning foreign languages. It is generally accepted that the early years are the time to acquire a second language. Children who learn a second language early often speak without accent and with the rhythm and intonation of a native speaker. This unquestioned capacity of young children to learn a second language has prompted some parents and schools to provide second-language learning in kindergarten and first grade. Around the country, young children are being instructed in languages from French to Japanese. Much of this instruction is wasted time and effort.

Learning a foreign language requires more than capacity, it requires motivation. If a child has parents or grandparents who speak a foreign language, the child has plenty of motivation to learn that language. But there is no such motivation if the child is just given lessons in the language. He or she does not need it for anything and cannot use if for anything. Even with the capacity to learn a foreign language, without the motivation, that capacity will not be realized. It is not unlike the natural athlete who lacks the competitive zeal to succeed in a sport. Another individual, with less native ability but more ambition, may succeed where the native athlete failed. It is when motivation and capacity work together that we find the most successful results.

CONCLUSION

In this paper I have suggested that there are three major obstacles to effective math, science, and technology instruction in early childhood. The first barrier is the futility of using reflective or logical analysis as a means of arriving at how young children learn. The second obstacle is the transductive nature of young children's thinking. A final barrier resides in the fact that young children have their own curriculum priorities and their own motivations, which may be different than our own. These obstacles are not insurmountable but must be addressed to engage in meaningful and effective early childhood education in math, science, and technology.

A few strategies for overcoming these roadblocks were suggested. To overcome the barrier of learning how children learn we have to observe children learning. To surmount the barrier of the limits of the child's transductive thinking we need to encourage their unlimited imagination and curiosity. Finally we need to engage children's spontaneous motivation. But we also need to help instill social motivation by involving parents in ways that encourage their modeling of reading, question asking, and knowledge gathering.

Early childhood is a most important period for math, science and technology education but only if we adapt such instruction to the unique needs, interests, and abilities of young children.

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