How Young Children Learn Spatial Concepts

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Paper

Most of the current research into the development of young children's mathematics has centred on the acquisition of numerical or measurement concepts. There have been few contemporary research projects on the development of spatial concepts and these have mostly concentrated on primary or secondary aged children.

This research project has examined the development of spatial concepts in preschool aged children.

Before the research could proceed, it was necessary to answer the question:-

What is space?

Philosophers and psychologists have argued about the nature of space for centuries. It was difficult to separate the term "space" from "spatial relations". A child needs to explore spatial relations in the process of developing spatial orientation and awareness.

The Macquarie Dictionary (1981) defines space in fourteen different ways. The most acceptable, for this research, is:-"...an expanse extending in all directions (or having three dimensions) in which, or occupying portions of which all material objects are located" (p. 1 620).

This defines space in broad global terms and supports the inclusion of topology in the exploration of spatial concepts. Yakimanskaya (1980) looked at "space" in its broadest sense and included the idea of one's position in space. Piaget and Inhelder (1948) adopted the concept of the place of topology in the child's understanding of space. Topology is defined in the Macquarie Dictionary, (1981) as:- "the study of those properties of geometric forms that remain invariant under certain transformations, as bending, stretching, etc." (p.1 789). This reflects the accepted mathematical perceptions. Holloway (1967) describes topology as:- "very early modes of perception from which the small child can form his elementary spatial representations" (p. 3). This is the concept of topology adopted for this research as it is descriptive and pragmatic. pragmatic.

In contrast, other authors such as the van Hieles (1986) and Rosser (1988), have viewed space in a narrow sense. They saw space in terms of Euclidean and projective geometry.

Spatial relations appears to encompass many global concepts and so it has wider parameters the traditional subject of geometry. This research project has taken the concept of space and spatial development in its broadest sense. This included the formal aspects of position, two and three dimensional geometry as well as the more global aspects of topology.

Literature

It was impossible to discuss the nature of spatial relations without first examining the work of Piaget. His theory expounded a sequence in the children's cognitive development. This was dependent on age and only the first two of the four Piagetian levels relate to children of preschool age.

According to Clements and Battista in Grouwns (1992), there are two main themes in the work of Piaget and Inhelder. The first aspect is constructivist and asserts that children build up spatial notions through previous interactions and manipulation of their environment. The second aspect is a that spatial understandings follow a definite logical order beginning with topology and later moving to projective and Euclidean geometry. "This has been termed the

topological primacy thesis" (p. 422). This is supported by haptic perception as the child interacts with objects and evidence shown in children's drawings, though this has been disputed by some researchers, including Clements & Battista in Grouwns (1992). One criticism is that the topological terms used by Piaget and Inhelder, including separation and proximity were not mathematically accurate. Other criticisms centred on problems of classifying the topological figures.

In the first Piagetian stage, the sensorimotor stage, spatial concepts begin to develop as the infant becomes aware of topological notions including proximity, separation, order, and enclosure. (Piaget, in Holloway, 1967). In the second half of this stage, the child begins to coordinate vision and movement so that the exploration of space becomes more purposeful. The child also begins to internalise thoughts and to create and store simple mental images for later use (Piaget & Inhelder, 1948).

The preoperational stage bridges the topologically based first stage and the third stage, the concrete operations stage, when, according to Piaget, the child is ready for the formal projective and Euclidean forms of space. During the first half of this stage, the child is guided by immediate perceptions and so tends to rely on haptic perception during spatial explorations. In the second half of the preoperational stage, the child can perceive basic geometric forms such as straight lines, curves and circles (Piaget, 1960). The child interacts with toys and other objects to explore the world around and acquire images through visual and tactile activities.

This was in direct contrast with the purely constructivist theory put forward by Dina and Pierre van Hiele. They believed that there are five levels in the child's development of spatial concepts beginning with projective and Euclidean geometry. Topology appeared in the fifth or highest level, when the geometric concepts became global and included atomic and universal or abstract concepts (van Hiele, 1986). The hieratical and sequential structure of the van Hiele levels removed the concept of age based development. The van Hieles placed a great emphasis on instruction and the active role of the teacher and the increasing sophistication of the mathematical language used at each level. Criticism of the van Hiele levels included the fact that the levels do not form a continuous learning curve and that there were gaps between the levels. Other authors have suggested the need for a new level "O" or pre-recognition level before level one. This would cater for younger children who needed visual or tactile stimuli and who were unable to name geometric shapes (Clements & Battista, in Grouwns, 1992).

In 1991 the National Council of Teachers of Mathematics (NCTM) in the United States of America published a set of mathematics education books that were translated from a series previously published in Russia. These reported on school mathematics education in the former Soviet Union and provided us with some useful information. Until now we had heard from few Soviet researchers apart from Vygotski and Luria who are well known for their work on language and how children think.

Leushina (1974) believed that the physical and sensory development of the young child follow a similar order to that proposed by Piaget (1948). The term topology was not used specifically but implied. Yakimanskaya (1980) was the only one of the researchers from the former Soviet Union to specifically acknowledge topology. He stated that the child first learns the notions of proximity, order, enclosure and continuity. Note that this list is incomplete when compared to the topological list of Piaget. Leushina (1974) stated that children begin to develop a system of spatial reference. At first, children orient themselves in space

on the basis of a personal reference system. This closely resembles the Piagetian stages of development. The first orientation is towards oneself and later the child is able to shift the point of reference to other objects or persons.

The researchers from the former Soviet Union, including Luria and Vygotski (1978) in Yakamanskaya (1980), valued the place of language in the development of spatial concepts. The role of the teacher was also seen as being very important. Adult input was very structured and was at the core of their teaching philosophy. This was supported by the van Hiele theory of the place of instruction. It was in direct contrast to Piaget (in Wyne and O'Connor, 1979) who stressed that adults can only usefully provide information when children are ready for it. Thorndyke (in Leushina, 1974) claimed that instruction and development were identical. This would seem to support the Soviet case. Piaget, however, claimed that the two processes were separate and that educational instruction does not always coincide with the developmental process (Wyne and O'Connor, 1979).

Perhaps the most fundamental difference between the western and the researchers from the former Soviet Union was the order in which children learn about space. According to Piaget (1948), the development of the child's understanding of space proceeded from topological notions to projective (3D) representations and finally to metric (2D or Euclidean) representations. However, the sequence proposed by the van Hieles and some of the former Soviet Union authors such as Metlina (1977) and Leushina (1974) omitted the first stage of topology. They placed Euclidean (or 2D) geometry first, followed by projective geometry. Topology then appeared as the final or global stage.

Who was right? There was some support that the notion of spatial concepts began with topology in the very early years. On the other hand, there was also support for the proposal that topology was the final or global applications stage. The place of topology was one of the questions that was included in this research.

The Research Project

This research examined a series of questions which included:-

What aspects of space do preschool children explore? What is the place of topology?

What behaviours do mainstream and special needs preschool children engage in as they explore spatial concepts? How do these compare?

It was relatively easy to find out what spatial knowledge young children possess. However, it was a much more difficult task to find out "how" young children develop spatial knowledge. This research attempted to find out what was happening as the children were engaged in spatial explorations. A number of aspects were examined.

What interactions were taking place and with whom?

What were the roles of peers, adults, language and concrete materials

This research project was conducted in three early childhood centres situated in different socio-economical areas. These centres had early intervention programs in operation so children with special needs were included in the research. This meant that this research project included children at different stages on the learning continuum and provided a basis for comparison. The special needs children had been formally assessed or determined to be developmentally delayed.

Each centre was visited on one morning per week over a period of eight months. Once accepted by the children, the researcher was able to make anecdotal records while the children were engaged in the normal activities as set out by the teachers. The researcher took on the role of an assistant when not actively gathering information. In this way, the

researcher was able to ask questions to clarify some situations that otherwise might have remained unclear.

The preschool teachers and early intervention personnel were available for discussion during each visit. Information gained was shared with the relevant staff. This served as feedback for each centre as well as checking on the accuracy of the material gathered. The preschool teachers were keen to learn more about early childhood mathematics and spatial concepts. So the researcher's visit provided some informal inservice.

Parents were rostered to assist at each centre. They were interested in the research and asked questions about the development of mathematical concepts. At times the parents provided background information that was useful for the study.

The data was written up in a format that was convenient and easy to read. Then the data was then typed and coded so that the original questions could be addressed.

The first set of codings identified the type of spatial activity that the children were engaging in. These included position (P), topology (T), 3D space (G3) and 2D space (G2) that were previously mentioned in the literature base.

The second set of codings identified the interactions that had taken place. It examined who or what the special needs children (S) and the mainstream children (C) were interacting with. These included materials (M), peers (C) and adults (A). The instigator of the interaction was shown first, so CA meant that the child had approached the adult.

The final set of codings looked at the purpose of language that was being used during these interactions. Thus included attention seeking (A), describing (D), reinforcing (R) and intent (I).

A table was created to assist in answering the original questions. Each observed behaviour was included in the table. It should be noted that the special needs children and the mainstream children were recorded as separate groups in the first instance. These figures were then totalled at the end of the study so that the groups could be compared

Table 1: Summary of Observations

Special Needs	P	T	G3	G2	CC	CM	CA	AC	ACM	A	D	R	I
Centre A	32	2	7	3	16	43	20	16	2	13	18	8	
Centre B	14	10	5	4	-	22	11	14	3	3	2	4	1
Centre C	34	7	3	4	6	31	18	14	4	6	15	7	3
Total	80	19	15	11	22	96	49	44	9	22	37	19	4
Main-stream													
Centre A	22	-	8	7	20	41	5	8	-	6	21	9	15
Centre B	-	1	1	-	-	1	-	-	1	-	-	-	-
Centre C	11	3	11	8	17	16	1	-	-	7	10	2	6
Total	33	4	20	15	37	58	6	8	1	13	31	11	21
All Children													
Centre A	54	2	15	10	36	84	25	24	2	18	39	17	15
Centre B	14	11	6	4	-	23	11	14	14	3	2	4	1
Centre C	45	10	14	12	23	47	19	14	4	13	25	9	9
Total	103	23	35	26	59	154	55	52	10	34	66	30	25

Discussion

Spatial Activities.

Several trends emerged from the data.

All of the children engaged in spatial exploration as they played. There appeared to be a hierarchy in the developmental levels of the different types of spatial activity.

The very young special needs children or those with multiple handicaps (in Centre B) engaged in many topological activities when they painted, constructed

with blocks and played with farm sets. The special needs children, tended to be involved in more frequent explorations of topology as they explored boundaries, nearness and separation. They were aware of the proximity of peers as well as adults. In contrast, the mainstream children did not explore many topological notions. They were able to use topology as a basis for the exploration of two and three dimensional space to support their play activities.

The special needs children had a decided preference for spatial activities that involved position. They were involved in exploring position through using their own bodies and in manipulating blocks, lego and toys. The mainstream children's play only accounted for 33 of the 103 recorded positional interactions. They seemed to use position as a tool to solve problems or reach a goal, rather than an end in itself. All of the children engaged in positional play. The difference was that the special needs children saw position as the product of their play whereas the mainstream children used the notion of position as a process in achieving the final product.

The older special needs children explored two dimensional shape in sorting objects and solving jigsaws. Three dimensional space was examined when playing in the sand pit and when playing with blocks and lego. The more formal notions of two dimensional and three dimensional geometry were explored by both groups of children. The observations produced a similar result as for positional space. The special needs children were often able to name and sort shapes and objects according to geometric principles. The mainstream children could do this too but they could also use the same geometrical characteristics of the same shapes to solve their problems. They were able to build higher towers and more exact roads and assemble three dimensional puzzles. The mainstream children were able to utilise their spatial knowledge to solve such problems as constructing a block city. They were more willing to take a risk and use trial and error techniques in problem solving. Their excellent command of language meant that they were able to discuss failure and then determine a new method of tackling the problem.

Interactions

There was a noticeable trend, in the special needs children, towards being dependent on adults. The older special needs children tended to seek reassurance from adults. These children were often unwilling to risk or to proceed to a new aspect of the activity without adult reinforcement. When confronted with a problem, the special needs children would quickly become frustrated. Then they would give up and walk away or ask for adult assistance. Centre B had a large number of adult helpers who assisted the multiply handicapped and non mobile children. The more able children at this centre were encouraged to be independent and to make their own decisions but this was sometimes impeded by willing adults.

Sometimes the special needs children would engage in parallel play while keeping a close watch on their peers. At times they copied the same activity or game at a later stage. The special needs children who had received early intervention were noticeably more field dependent and often asked for adult assistance. Both groups of children were able to summon adult assistance when it was required but the special needs children did this more often.

Mainstream children were independent and seemed to have high self esteem. They explored the different concrete materials that were available. When they were in a group, they declared their intentions to reach a certain goal and then proceeded towards reaching that goal. They interacted freely with peers and would persist with a task or play activity. Trial and error techniques or discussion were used to solve

problems. If any assistance was needed, they would readily go and ask for help rather than sit and wait. The type of assistance that these children requested was sometimes to ask for the adult to enhance the play. This was seen when the girls asked the teacher to read a story; something that they were unable to do for themselves. At other times teachers were asked to come and see a finished product.

The special needs children who had not received any formal early intervention did not function like the mainstream children. This group displayed some of the characteristics of both groups. They did not play alone or request as much help as much as the group that had early intervention and they did have some interactions with their peers. Perhaps this shows that it is part of a continuum rather than a simple solution at either end of the scale.

As a group the special needs children interacted with concrete materials rather than peers during play. Interactions with their peers tended to describe what was happening and to reinforce their activities rather than to predict or make a contribution towards a common goal.

Special needs children saw play as work and it was a product rather than the process. In comparison, the mainstream children usually played in groups and co-operated or worked as a team to solve problems. Play was a way to meet the goal that the group or individual had set.

Communication

The communication skills of the special needs children tended to be very limited. In the majority of cases members of this group tended to work alone or in parallel play and only interacted with adults. Language was used as a tool to summon adult help or to reinforce actions. In contrast, the mainstream children appeared to be fluent in communication skills as they interacted in a group situation. Most of the group conversations were complex and quick. They predicted, made suggestions and discussed how they would solve problems as they played with the concrete materials. They sometimes described and reinforced their activities with accompanying language but this was not as frequent as in the special needs group. Language was used as a vehicle to solve problems as well as being a communication between peers. The only times that the mainstream children were non verbal were when they were completely engrossed in a task.

Many of the children indicated what they intended to do (25 occurrences). However, the mainstream children not only used this strategy more often (19 times) but they immediately began to proceed towards the set goal. Sometimes these were difficult goals to reach as was clearly seen when the children wanted to set up an aqualab. In contrast, the special needs children, set goals less frequently and the goals they set were more immediate and more easy to reach.

All of the children used descriptive language. The special needs children used description as a commentary to monitor or reinforce their play. The mainstream children frequently used descriptive language as a means to an end; to say how long or which block to move.

All of the children engaged in spatial exploration during play activities. Differences were apparent in the type of spatial activity and how the children played. It was the nature of the interactions and the people involved that separated the two groups.

Conclusion

The children in this study represented the learning continuum for preschool children. The study showed that young children initially explored the spatial concept of topology. This was followed by the concepts of position and then the three dimensional and two dimensional formal or Euclidean geometry. These findings seemed to support Piaget's theory and question the ideas of the van Hieles and the researchers from the former Soviet Union on the place of topology.

The question of "how" young children learn spatial concepts also needed to be addressed. The young children developed spatial concepts by interacting with their environment. In preschool settings, they were constantly exploring spatial concepts during their hands on play. Children learn well in a social situation. Communication with peers and adults was an integral part of the process of developing spatial concepts.

The development of spatial concepts is a complex process. There is a delicate balance between the child and the interactions with concrete materials, peers, adults and communication skills.

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