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Technological Applications to Support Children's Development of Spatial Awareness

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This article presents methods and theory behind promoting children's spatial awareness through representing 3D reality in 2D cyberspace. Spatial awareness in children is an often neglected aspect in early education. However, applications such as GPS and 3D modeling programs can be used to offer children rich experiences that allow children to interact and experience 2D and 3D space in a way that promotes a sense of spatial awareness.

Understanding and representing 3 dimensional space requires the child to develop the ability to infer 3 dimensions by looking at a 2 dimensional representation. This ability is accomplished through having the children interact in a 3 dimensional environment and represent that action in 2 dimensions. This interplay between the 2D representation 3D world causes children some cognitive dissonance, what Piaget called disequilibrium (Piaget 1954, 1963; Piaget, Inhelder, & Szeminska, 1960). The child's mind must work hard to coordinate the seemingly disparate information. This conflict allows the child to develop a better understanding of spatiality (Kriesberg, Northrup, & Thorson, 1989).

Edward Tufte (1990) discussed the problem of how 3D information is portrayed and communicated in 2D.

> Even though we navigate daily through a perceptual world of three dimensions and reason occasionally about higher dimensional arenas with ease, the world portrayed on our information displays is caught up in the two-dimensionality of the endless flatland of paper and video screen (p. 12).

The problem of spatial perception does not end with the experience, but is continued in the ability to understand and communicate ideas of three-dimensional space in two dimensions. The use of digital technology in the classroom offers the opportunity to both develop spatial awareness and develop methods to communicate spatial concepts necessary for understanding the visual information within children's minds (Everett, 2000; Hermer-Vazques, Moffet, & Munkholm, 2001). The nature of the information created to communicate three-dimensional spatial ideas bridges science and art, physical space, and cyberspace.

Spatial awareness is important in the understanding and representation of real world physical conditions. Making maps, drawings, and models that represent actual conditions within our world are useful in scientific processes and developing spatial awareness. Concepts of spatial awareness are also linked to the development of imagination and the creation of original creative content. Design and the creation of new and original ideas must often be represented as maps, drawings, and models to communicate, and test ideas that are important in architecture, design, and art.

This article investigates a theoretical framework for using digital technology to enhance three-dimensional spatial awareness and three-dimensional creative expression in children. The framework is built on Jean Piaget's understanding of spatial awareness in children and enhanced by processes of learning spatial design issues using digital technology in architectural education. First Piaget's work on children's construction of change of position in space is discussed. Piaget studied children's map making ability and their ability to give directions and defined a theory of how children construct a representation of space in their minds that allows them to judge and explain their position in 2D space by coordinating landmarks using a mentally constructed coordinate system. Second how the computer and the interaction of 2D and 3D environments and computers help to develop spatial awareness is discussed. Finally, a way to use 3D modeling software and GPS to design curriculum and activities for children that stimulate them to construct complex ideas of spatiality is outlined.

The development of spatial awareness requires both an understanding of physical conditions, and the methods of two-dimensional representations that are used to communicate ideas of spatial ideas and content (Newcombe & Huttenlocher, 2000). The emergence of digital technology as a tool, media, and environment has allowed for new opportunities to understand and develop spatial awareness in children. Digital technology can be implemented in the curricula to enhance the understanding of the spatial relationships in the physical world and in the creation of creative content to express original ideas using digital technology.

PIAGET'S WORK ON CHANGE OF POSITION

The first chapter in Piaget, Inhelder, and Szeminska's book *The Child's Conception of Geometry* (1960) examined how children represent movement from one point to another. He asked children to make maps of how they move from one point to another in their neighborhood.

Piaget used an open interview method to examine change of position consisting of asking children about familiar surroundings. Piaget did his research in Geneva, Switzerland therefore the questions were about Geneva because it was important to use an area that the children were familiar. The experiment was divided into three parts. The first part consisted of the child making a map of the school buildings and surrounding features in the immediate vicinity using the wooden houses and the sand tray. The child was seated in front of a window and asked to point out familiar buildings and landmarks. Then the child was turned so his back was to the window and was presented with the sand tray. The examiner took the largest wooden house and placed it in the middle of the sand telling the child that it was the school. The child was then asked to use the other wooded houses to show everything around the school. The alternative for children who were too nervous to use the models was to have them draw everything in the sand.

In the second part of the experiment the child was asked to create a reconstruction of the route from school to a well known landmark. For this part of the experiment the examiner asked the child "to draw a plan in the sand or on a piece of paper, showing how he would go home from school or how he would go to a place which they all know." The place Piaget chose was the Place Neuve which is a large square in Geneva on which the theater, museum, and reformation monument are located.

The third part involved changes in the location of features when the school building was turned 180 degrees. The examiner turned the wooden block or house representing the school 180 degrees and asked: "Now if I turn the school round like this, must we move everything else about as well or can we have it just as it is? (p. 5)" The child is then asked to make the changes himself. With older children the experiment can be done with pencil and paper rather that in the sand table. (p. 5)

The examiner watched for evidence of the presence of a three dimensional coordinate system. The examiner noted how the child used reference points and how these reference points were coordinated. According to Piaget, the child gradually constructs two dimensional space in terms of horizontal and vertical axes which enable him to coordinate landmarks. He gradually structures space into a system in which he can put one landmark or reference point into relationship with all others in one well structured whole. In addition to a stage one in which the children were too young to make any sort of map, Piaget conceptualized four stages. In the first stage, children were to young to even understand the question and hence were unable to construct any type of map. Children 18 months to four years old were too young to make maps. Early spatial relations were observed by noting spontaneous remarks made by the children as they were taken for a walk. This is an example of egocentric thinking. An example of this is a child that believed his house was always going to be behind him, no mater what direction he/she was facing.

Stage two children attempted to make spatial relationships but showed no coordination of landmarks or use of a coordinate system. At this stage the children's descriptions of his/her route does not correspond with external reality. The child thinks mainly about his/her walking and turning which is what he/she remembers when he/she draws his/her map. His/her map is not based on landmarks but on the actions the child made in getting somewhere. Stage two children occasionally put two landmarks into relationships. These pairs are not indicative of a coordinate system, however. These relationships are not necessarily spatial in nature. Often landmarks that do not belong together are put together because the child makes repeated journeys between them. Children also pair landmarks because they have certain affection for the landmarks. For example children would regularly put the toy store next to the school.

Stage three is subdivided into two substages. Stage III-A Piaget called the coordination of landmarks into sub-systems. At his stage children are able to use landmarks to structure their journeys. The landmarks, however are not linked into a coordinated whole. They are instead coordinated into sub-systems. A sub-system is a group of landmarks or reference points that are correctly coordinated within themselves The landmarks within these sub-systems are coordinated but not linked into a coordinated whole by a coordinate system. These sub-systems are based on the child's vantage point and not on a two dimensional coordinate system. Each individual sub-systems cannot be coordinated with any other sub-systems and therefore the landmarks cannot be coordinated into a correctly referenced whole.

Children were able, for example, to reconstruct a route from their school to a central place in their town with great accuracy and detail because they had coordinated the landmarks on that journey into a sub-system. However each different journey creates a different sub-system that is based on the vantage point of the child.

Unlike stage II children, Stage III-A children use landmarks as references. A stage II child was content with representing change of position simply with a description of movement. One stage II child said "*I turn, I turn, I turn, I turn,. That's the Place Neuve*." The stage III-A child however recalled many details of the route. He mentioned reference points that he used to construct his route to the Place Neuve.

Children at stage III-A are able to coordinate changes of position and represent small sub-systems. Each journey created a different subsystem that was based on the vantage point of the child. However, when the children are asked to make a map of the area as a whole they fail because they cannot link all the landmarks in a single network.

In stage III-B which Piaget called coordination of all landmarks into a whole, children are able to coordinate landmarks using a two dimensional coordinate system. Their coordination of landmarks is planned from the beginning as a single whole. Changes of position are described in terms of a single comprehensive system of references rather than independent sub-groupings.

These children have no difficulty representing a general detailed map of the surrounding area. All landmarks were coordinated with each other in one reference system. They are even able to show alternative routes.

The growth of spatial relations is not a mere matter of accumulation. It is true that children collect a lot of information about their surroundings through their journeys. However, the coordination of space is much more complex than a simple additive relation.

> ...[objective coordinations] are not themselves the outcome of a simple additive process. They do not arise from the summation of relations, each of which is valid in itself and can therefore be added to the others. They are the result of a structuring of the whole which leads to a complete reversal of the type of linkages that children make (Piaget, Inhelder, & Szeminska, 1960, p. 23).

Children gradually construct a coordinate system with which they structure their space. As this coordinate system gradually develops so does the child's ability to represent changes of position. And to construct 2 dimensional and 3 dimensional awareness. Educators and parents can promote this construction by the use of technology including global positioning systems, virtual worlds, three dimensional modeling software, and mapping software. However, it is important that technology is integrated with real world experiences. This type of interaction between the child, the real world, perception, and a computer virtual environment is vital for the child's development of spatial awareness.

Using this understanding of how children construct mental understanding of spatial relationships, one can begin to think about the interplay of the real world, the mental representation, the 2D representation, and the cyberspace representation of a 3D world (often referred to as 2½ dimensional representation). Piaget did some work on children's construction of 3D space from the angle of how children understand that objects in their environment exist in 3 dimensions, however he did not discuss the interaction and mental activity involved in representing 3D environments in 2D. For this a cue from architectural design is taken. If how design professionals develop understanding of spatial awareness is examined, one can better understand how spatial awareness in children can best be promoted.

WHY COMPUTER-AIDED METHODS FOR DEVELOPING SPATIAL AWARENESS

Methods and processes in spatial awareness need to explore issues of two, and three dimensional relationships in the construction of environments much like architecture and design students do at a college level. Digital technology is implemented in the educational process to enhance the development of spatial awareness and in the creation of drawings, images, and animations to communicate original ideas of space and form. Matthews and Temple (2000) have developed a model of integration that links digital and physical processes of design that assist in the development and communication of spatial awareness (Plumert & Hawkins, 2001) (Figure 1).

The model can be used as a framework to critically implement the computer as a tool, media and environment in educational settings for young children to enhance and communicate spatial conditions. The model is predicated on the ability for one to have an understanding of the physical spatial conditions to effectively use the computer as a tool to communicate spatial ideas and concepts. In turn, the use of digital technology enhances the understanding of spatial concepts in the physical world. The model describes the transformation that takes place as a student in design represents and constructs spatial concepts on the computer and then in a physical format. The similar concepts applied to the design student may be used to in early childhood education.

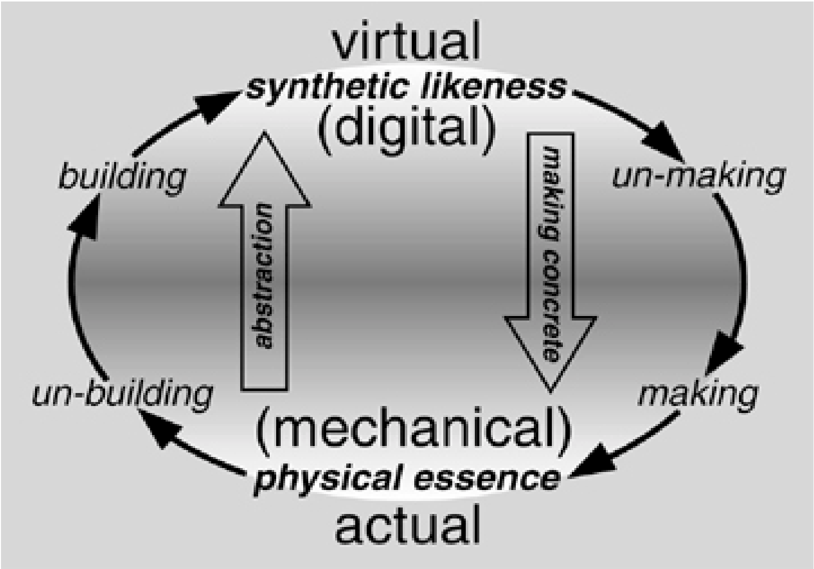

Figure1. Model of digital and physical integration

Starting at the bottom of the model an understanding of the physical world exists. This understanding of the physical (spatial) world is abstracted as the process moves from the physical to the digital in a clockwise direction. The first phase of the abstraction is the "unbuilding." The unbuilding is a systematic process of taking the world apart so it can be reconstructed in the computer. The system used to "unbuild" the world may vary. If a student needs to explore the idea of a brick wall on the computer one needs to understand the nature of brick construction. Blocks are typically of similar shape and size and are stacked in an orderly fashion. The understanding of "unbuilding" of the construction system allows for a more accurate construction on the computer. Young children should already have interactive experience and understanding of this from block play (Case, 1992). Block play allows them to work through the "building" and "unbuilding" process in an intuitive 3D environment. The next step is asking them to translate that experience into representation in 2D.

As one moves from the "unbuilding" phase into the "building" phase a new system of construction is used on the computers. The system of construction or building on the computer can be different, but related to the physical world. Typically, in computer modeling applications the central system of building is of polygon geometry using a Cartesian coordinate system.

As data is entered into the computer and spatial a cyberspace environment emerges, the designer can use the computer to envision ideas of space, form, and movement in abstract relation to the physical environment. The spatial experience on the computer can liberate the designer from the constraints from properties such as gravity, context, single point of view, and scale. The computer acts as a filter, allowing the designer to limit aspects of the spatial environment. The limitation should not be viewed as a negative, or something less than real, but as a way to reduce the amount of distracting information and enhance or emphasize certain aspects of space and form.

One of the most striking examples of how a computer can be used to enhance the understanding of spatial awareness is the capability to have simultaneous views when constructing space and form (Figure 2).

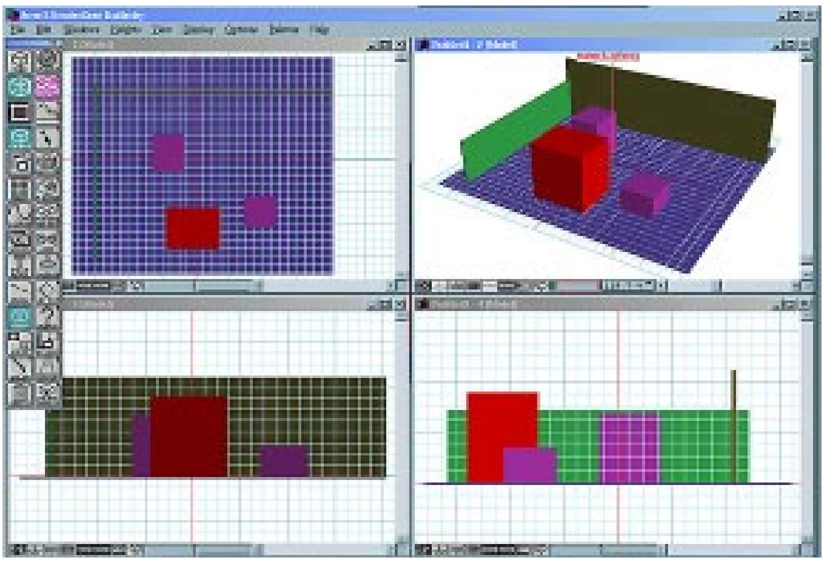

Figure 2. Form-z screen capture of four simultaneous views

Three-dimensional computer modeling applications are designed to allow the user to have more than one view of the model present at the same time. A user of the application can see the top, front, side, and perspective view on the screen at the same time. When an object is created, moved, rotated, or edited the change appears in real time in all four views. Human perception of the physical environment only allows for a single point of view. It is impossible to view the top, front, side, and perspective view at the same time in our physical environment. Because the computer allows for multiple views at the same time students are able to more quickly and accurately see the relationships of objects and space. The multiple views also emphasize the three-dimensional nature of space. Judgments of spatial relationships in the construction of cyberspace environments look at length, height, and width at the same time in multiple views. This process tends to aid in the ability to develop and construct spatial environments.

As the person or child moves from the top of the model clockwise it is a process of concretization. The person or child is making physically tangible what was digital. The first step is one of "unmaking." The filters or inability of the computer to represent all of the complexities of the physical environment makes one aware of potential limitation of cyberspace. As data is printed from the computer it represents spatial relationships and measurements without expressing the materiality, texture, or possibly the scale of the environment. The designer must deconstruct or "unmake" cyberspace before it can be created in a physical form.

The "making" phase of the process demands that the designer find a construction system to create space and form that engages all of the complexities of the physical world including such items that may be missing from the cyberspace environment such as gravity, weight of material, scale, texture, and context. The model is to suggest that the development of design and spatial awareness is an integrated relationship between digital and physical experiences. Software such as *Form-z*, a three-dimensional modeling application, is designed to create spatial perception that is similar to the physical environment. But because the software is a digital, rather that physical (atoms rather than bits) the metaphysical nature of the experience shifts. Table 1 outlines some broad complementary differences between the digital and physical spatial environments.

DESIGN PROCESS AND DEVELOPMENT OF SPATIAL AWARENESS

The process of the model is not a singular activity to be completed one time, but a cyclical activity that is to be repeated, so discoveries can be made and complex development of spatial awareness can emerge. John Zeisel in *Inquiry by Design* emphasized the important nature of design as a cyclical activity that includes a process of imaging, presenting, and testing.

Table 1

Differences between Digital and Physical Spatial Environments

Qualities of Cyberspace Environments	Qualities of Physical Environments
Multiple viewpoints	Single viewpoint
Change is non-linear (jump between top view and side view instantly.)	Change of view is linear
Potentially less complex and inherently filtered (The computer does not express qualities of the physical environment.)	Complex and difficult to filter. (Spatial environments express all of the many different qualities at the same time. Color, texture, context, gravity, sound, movement are a few of the elements in the physical environment that may be filtered from the digital environment.)
Non-contextual (The computer is a blank slate.)	Contextual (Something is always beside something else.)
Easy to change and edit, not "wasting" physical resources.	Often more difficult to change. Waste physical resources.
Easy to save different ideas	Difficult to save different ideas

Imaging is the process of forming a "fuzzy" mental picture of an idea. Imaging includes the ability to think spatially. The presenting phase is the representation of the design idea in the form of a drawing, model, or other communication media. Testing includes the processes of personal and group insight, criticism, judgments, and evaluations of the design. Zeisel then further described the design process as a complex "spiral metaphor." Designers image, present, and test in consecutive cycles, often backtracking and repeating imaging, presenting, and testing (1986).

Although design includes many more issues than just spatial awareness and spatial representation, the processes used in design support the holistic processes needed to both develop understanding and the ability to represent spatial ideas. Design processes are nonlinear, and cycle between modes of working and thinking. Processes outlined in this article are presented as clear and even linear format. But in practice the processes of design move quickly between modes of operation and it is often too difficult to distinguish phases as outlined in this article. One may imagine a situation where during the review of the design in the testing phase that it is easy to start imaging new ideas and spatial relationships based on evaluative discussions.

PROMOTING SPATIAL AWARENESS IN CHILDREN

Objectives

Children's understanding of three dimensional space is constructed through interactions with their environment. In recent years, advancements in technology have given educators a number of tools to promote children's construction and understanding of spatiality. However, these tools have been underused because spatial awareness in preschool and kindergarten is not viewed as an important objective. In an attempt to offer teachers a way to begin thinking about how to promote this in their classrooms, a number of objectives and suggestions for uses of technology follow.

Objectives for a Curriculum of Spatial Development and Ideation

1. *Cycle between physical and digital understandings and representations of space.*
   Children should be provided a holistic experience that builds on both cyberspace and physical spatial concepts. The experiences should have a relationship with each other so children can build links between what happen when using a computer and physical experiences.
2. *Emphasize disequilibrium in processes of abstraction and making concrete.*
   Changes will arise from moving between cyberspace and physical space. The change can create feeling of discontinuity and uncertainty within the children. These feelings become the engine for discovery and learning. Resolving the differences may exposes greater spatial awareness.
3. *Allow nonlinear development of imaging, presenting, and testing.*
   Design is not a linear process that every child will experience the same way. Design is a very dynamic process that combines both factual knowledge and creative expression. Allow for different development of imaging, presenting, and testing in the classroom between the children. Often children will need to repeat processes, and move both forward and backward in design explorations. The most important factor is that shifts in investigations are made and repeated.
4. *Emphasize the differences in cyberspace and physical space.*
   Activities should make apparent inherent qualities being used to explore spatial relationships. Do not think of cyberspace and a representation of a physical condition that is burdened with limitations, but a new way to experience spatial relationships.

5. *Create activities of actual conditions of the physical world and original ideas of space authored by children.*
   The development of spatial awareness should combine activities of real world conditions combined with activities that engage the imagination of space and form as original content created by children. Technology should be used as a creative instrument to describe what the world might be. Children should be encouraged to interact in various representational material such as paint, chalk, clay, and computer drawing and animation software to develop these concepts.

Activities

The technological advancement over the last few years has produced cheap computers that have the ability to handle graphic intensive 3D modeling applications. These 3D modeling applications such as *Form Z* by autodessys, *Roboworks* by Newtonium, *Infini-D* by MetaCreations Corporation, *ModelMagic 3D* by ImageWare development, *Merlin VR* by digital immersion, and many other packages allow children to build 3 dimensional shapes on the computer and manipulate them in a simulated 3 dimensional space. The software allows the user to view their digital creation from four view points; top, side, front, and back forcing the user to coordinate the different views of the object to understand its full dimensionality.

The advent of Global Positioning Systems (GPS) that are cheap and accurate also offer a new tool to use in spatial awareness. Units from *Magellan* and *Etrex* can be accurate up to 10 feet and are excellent at helping the user think about their present location and the relationship of other landmarks and points of interest. Many of these GPS units also have mapping capability which can also be used to develop a spatial sense.

Phase I of helping children construct and develop spatial awareness is helping the child to develop a representation of the physical worlds and a coordinate system that allows them to put landmarks into a mental relationship. This is the developmental pattern that Piaget studied in depth and that was reported earlier in this article. The goals in this phase are for children do have the opportunity to put themselves and their present position into a relationship with other landmarks. The GPS unit can allow the child the ability to check their position regularly.

For example, a class takes a walk in the woods and there are many twists and turns in the path. Without the GPS the students would soon lose their bearings (and many adults also) because they have lost track, visually and mentally, of the landmarks that allow them to judge direction, distance, and position. If the children have a GPS unit, the teacher could regularly have the students refer to it. It can give the students information on how far they are from their starting point, in what direction their starting point is, and what direction their destination is. However, unlike a compass, this information is relative to the position the children are moving and constantly adjusts for any changes in direction and speed. It can also calculate and depict how far off course the user is to a specific destination, allowing the children to think about actual path and "as the crow flies."

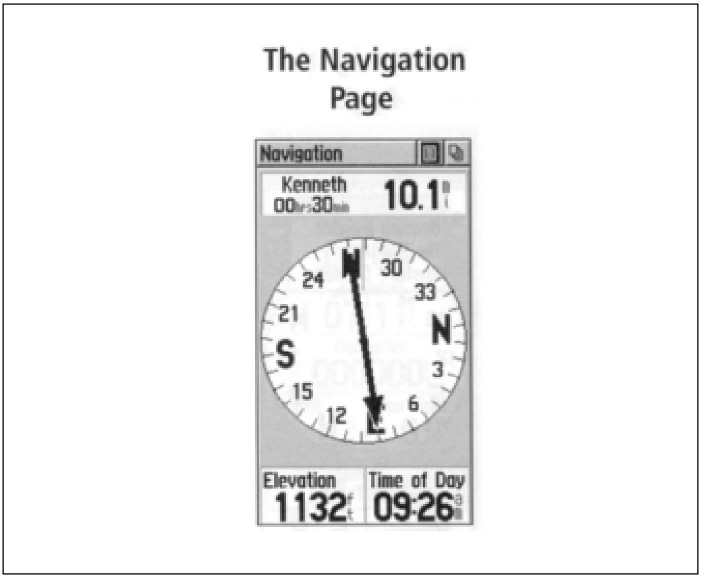

Figure 3. The navigation page

A great activity for the GPS to allow students to experience all these challenging and constructive situations is a treasure hunt using the GPS system also known as Geocaching. These treasure hunts could be designed by the teacher or could be located using the Internet. If the teacher designs the experience, he or she would need to hide an object and record its location using the GPS unit. Then the students would input the numerical location into a GPS system and follow the information about bearing, and distance, to the hidden object. These contain trinkets and a logbook. If the teacher decides to use the Internet, there is a site at www.geocaching.com that has a number of hidden treasure troves called geocaches that are hidden across the country and around the world. All the teacher needs to do is enter a zip code and the site will display geocaches that are close to the area. The site also gives information on terrain and difficulty that can help the teacher determine if a geocaches is feasible for their students. Most geocaches ask you to sign the log and write a bit about yourself. Then you may take an item, but you must replace it with another item.

Another use for the GPS unit is to have students use it to create maps of unfamiliar territory. Phase II of the sequence of promoting children's spatial awareness is describing the parts of the material world (unbuilding). This requires the students to think about space in a more abstract way and to represent that abstract idea using measurement and drawing. They must coordinate their earth bound perception with a mentally constructed "birds-eye" view. They can use the data accumulated from the GPS to record their direction, distance, and even altitude and then translate that data into a 2D representation of their journey and the space around them. The GPS allows them to construct their own mental landmarks. Mental landmarks would be points in space defined by the child and recorded by the GPS unit but without any physically real landmark. This allows the children one more level of abstraction in their understanding and construction of spatial relationships.

Phase III involves constructing objects and space in a 3D cyberspace environment (building). This is where computer 3D modeling environments can be used to help students build and experience representations of objects in 3 dimensions even though in reality it is projected on a 2D computer screen. The relationship was made earlier to the building and unbuilding phases as being related to children's block play. It helps to think about working with the 3D modeling program as block play in a cyberspace environment.

Children can create blocks in the 3D modeling program and place and manipulate them in that environment. Creating spheres, boxes, cones, and other interesting objects is not difficult in this type of program. What causes the disequilibrium is the act of moving those objects in 3 dimensions while looking at a 2 dimensional representation. Children are presented with many different views of their objects as they build and position them. Each different view requires the child to change their visual and mental orientation to the object or objects and can be disorienting.

Many of these programs (such as *Form-Z*) will also allow the children to then explore their environment from a first person perspective. They can fly through their creation and move in 3 dimensions within the setting. This is definitely something that children cannot do in normal block play. Children can also post their environments online for other students to experience by flying through.

There are also other cyber worlds where children can experience 3D worlds on the Internet and even interact with other people while in that environment. One is called cybertown (www.cybertown.com). This is a child safe 3D interactive environment where children can move in 3 dimensions and interact with others. Users can also build and decorate their own personal 3D space. Cybertown also allows users to import items built in other 3D programs such as *Form-Z* and use them in their environment it also lets them sell or trade them.

Using Cybertown or another similar site a class could create their own classroom space online. They could discuss the design and lay out of their cyber classroom. This type of imaginative exercise and design in 3D cyberspace is exactly what design professionals do everyday. This cyber classroom becomes a very plastic and changeable environment for children to create and plan using spatial reasoning.

CONCLUSION

These simple activities that integrate digital and physical spatial activities can help children develop a strong sense of spatial awareness. This awareness not only helps the child develop cognitively, but creatively. Design professionals spend a lot of time trying to instill spatial concepts in their college students and have a difficult time because many of them have not had a basis as young children. It is known that children need to be stimulated musically, artistically, and cognitively to excel in these areas. Children also need to be stimulated to think about spatiality. This spatial awareness will impact their creativity, their ability to mentally represent space, their mathematical ability, and many other cognitive, social, emotional, and physical abilities.

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