Interpreting and Constructing Models in Computer Environments: Lego™ Blocks and Spatial Reasoning

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This paper examines the problem-solving approaches employed by eight Year 6 students (aged 11 or 12) as they completed a task that involved the construction of a model using computer software. The participants were required to interpret two pictorial elevations of a pre-designed model and then construct the model using the simulation software. The students who were able to effectively use the perspective and orientation functions from the software package were more likely to accurately complete the task.

Computers make it possible to represent visual and spatial mathematics with an amount of flexibility not offered by other media. Construction-based programs, for example, allow the user to represent and manipulate images accurately as either two- or three-dimensional (2D -3D) representations. These images can then be transformed or rotated with precision. With appropriate software the computer can become a powerful tool that enables students to manipulate spatial arrangements and construct visual images that would usually be limited by their own drawing capabilities. Construction-based software allows the user to develop new mental tools (Clements and Battista, 1992) and establish more sophisticated spatial reasoning skills (Amory, Naicker, Vincent, & Adams, 1999; Nemirovosky and Noble, 1997). The interactive nature of such software ensures "computer screen representations of visual objects and even visualised relationships can be acted upon directly and we can observe the ensuing changes in the represented relationships" (Noss, Healy & Hoyles, 1997, p. 210).

In studies away from computer environments, strong links between construction play and the development of visual and spatial skills have been established. Brosnan (1998), for example, found that children with high spatial ability were more likely to be able to construct a specific 3D model using Lego blocks than children who did not possess these high spatial skills. Other studies (including Lowrie, 2000) have found that differences in student's ability to solve spatial tasks have been attributed to the extent to which they play with construction toys and building blocks. Similarly, other studies have found that representations of the physical world (Trawick-Smith, 1998) and play in naturalistic settings (Clements & Sarama, 2000) are also influential in spatial development.

As our society becomes increasingly reliant on visual stimulus, new technologies will push the boundaries between "real life" environments and 2D representations of 3D space. Links between foundation spatial skills (including depth perception) and engagement in simulated environments will almost become transparent (Lowrie, in press). The impact these inevitable changes will have on the children's spatial development is uncertain. Computer simulation programs, despite their obvious advances, do not always make 2D-3D representations easy to interpret or understand. Children often find it difficult to transform their understanding of real-life experiences to the representations created on the screen (Lowrie, 1998). This is particularly the case when children have not yet established

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foundation spatial and visual concepts through lived experiences in a 3D world (Lowrie, 2000).

The Purpose of the Study

The central concern of this study was to investigate the extent to which the participants were able to construct a model using a software program from a pictorial (2D) representation of the object. The following research questions were posed:

- Were the participants able to make connections between pictorial and screen-based images?
- What spatial skills did the students employ to complete the task?
- To what extent could the children highlight possible difficulties that may arise when completing the task?

Method

The Participants

The investigation took place in a primary school in a large rural city in New South Wales. Eight Year 6 children (aged 11 or 12) were involved in the study. All of the participants were competent technology users in the sense that they used computers for a variety of purposes in both home and school contexts. Moreover, each student regularly played entertainment games in technology-rich environments at home. Importantly, all of the children had played with traditional Lego constructions in the past, although some of the children had not played with these blocks for some time. The students selected for the investigation had varying mathematical abilities.

The Activity

Each participant completed an activity involving the Lego™ (2000) construction program titled *The Knight's Kingdom.* The program allows the user to move building blocks onto a background and construct designs of their choice. There are a number of design facilities available in the program including buttons that could rotate blocks, change the orientation constructions, change perspective, move between close-up and wide-angle views, and change the colour of blocks (see Figure 1).

Figure 1. A representation of the screen image encountered at the beginning of the problem-solving activity.

The activity was conducted in an hour-long session on a one-to-one basis with the author. The session included: 1) a 30 minute instructional program that scaffolded the students' understanding of the program; 2) an explanation of the problem; and 3) adequate time for the students to complete the problem-solving activity. The students were asked whether or not they had played this game or similar construction games with a Lego theme in the past—with all participants indicating that this was the first time they had seen such a program. An instructional tutorial was developed in order to provide the students with opportunities to use key functions of the game. The instructional component of the session was interactive in the sense that the students were encouraged to ask questions about the program's features and build their own models using the construction facilities of the program. This is in line with Lesh's (1999) notion of *representational fluency* which encourages the user to develop increasingly powerful conceptual understandings by adapting (refining, revising, extending, integrating and differentiating) existing ideas and schemes. All of the students became familiar with the design elements of the program including the perspective and orientation features before being given the problem to solve.

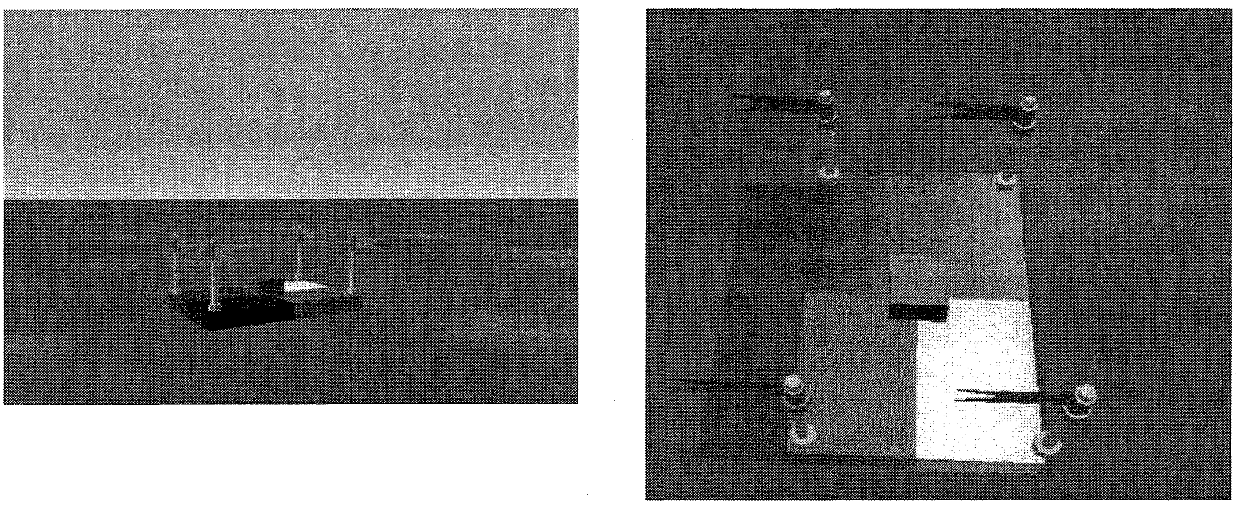

Figure 2. The front-view and bird's-eye view elevations of the pictorial representations.

The students were given two elevation views of a model (in pictorial form) which the author had constructed using *The Knight's Kingdom* and were asked to replicate the model using the program. The two colour prints of the elevations are presented in Figure 2. Consequently, the students were challenged to construct an exact replica of the model using the information presented from the elevation views. The students were informed that the two representations were of the same model and were asked to explain how this was possible. This allowed the author to ascertain whether or not the students understood what the task involved. Once any misconceptions were addressed, the students were encouraged to construct the model.

Results

The time taken to complete the construction activity ranged from seven to thirty minutes. Three of the eight students who engaged in the activity were able to complete the task accurately. The other five participants made one or more errors associated with the correct position or orientation of the blocks, the selection of the appropriate sized block or the correct block colour. Not surprisingly, the students who were prepared to use the orientation and perspective facilities from the computer program were more likely to complete the activity in an accurate manner. Nevertheless, the eight participants used a variety of approaches and techniques to construct the model on the screen (see Table 1 for a summary of these approaches).

Table 1
Different Elements of Orientation and Perspective used by Participants in both 2D and Screen-based Contexts

Student	Orientation and Perspective Techniques Used
Alex	Predominantly worked from above (bird's eye view)
Found task difficult	Never worked from a different orientation (remained in front-view)
Simone	Screen orientation limited to front view but changed perspective to
Found task difficult	a bird's eye view on occasions
Ebonee	Only worked from front-view picture. Initially worked from this
Initially, only correct from front view	view but began to change the screen orientation as confidence grew
Laura	Only consulted the bird's-eye picture. Wanted to work from this
Unable to complete task successfully	perspective on screen but became frustrated when the orientations were not identical.
Carli	Constantly moved between different perspectives (above, wide
Completed task	view and close up)
with incorrect blocks	Frequently changed orientation using shadow techniques for accuracy
Bailey	Used both pictures as reference for design. Tended to limit screen
Accurately completed task	orientation to a front view but moved between close-up and far-away perspectives
Joe	Predominantly worked from front-view picture. Worked from a
Accurately completed task	range of perspectives and orientations.
Percy	Used a range of orientations and perspectives to complete task
Accurately completed task	Made explicit reference to one picture or the other depending on the orientation of the screen object

Three of the five students who were unable to accurately construct the model viewed the screen from only one perspective—either a bird's eye or front view. By contrast, all of the students who accurately constructed the model moved between these perspectives, with one of the students using close-up and far-away perspectives in addition to the bird's eye or front views. The students who were able to replicate the model on the screen were also more inclined to alter the orientation of their model in order to make sure that the blocks and flags were positioned correctly. On occasions these students would rotate their model through 360^0 as they made connections between the pictures and their screen-based model.

Case Study Analysis

Some of the students were able to make strong connections between the 2D images (see Figure 2) and their screen-based designs whereas others found it difficult to interpret the different representations. Those students who were unable to make these connections either a) found it difficult to appreciate that the pictorial representations were in fact the same object and/or b) did not understand how the computer program represented images in a 3D-like form. This was the case even though the students had been assured the elevation views were of the same object before attempting to complete the task.

Alex. It was evident that Alex used computers on a regular basis. Some of the software she used included paint and drawing programs. She quickly learnt how to use a range of functions and was quite prepared to explore the environment in an exploratory manner. Alex was able to explain why some objects looked smaller than others despite the fact that they were the same size and appeared to have a good understanding of perspective and diminishing line. She had trouble placing the flags in the correct position—fundamentally because she was reluctant to rotate her design. As she commented, "it's confusing to change the angle because it makes it look like a different shape…mak[ing] the blocks look larger than they are." Here reluctance to move from a font view of her model resulted in a considerable amount of frustration. "Getting the flags with the right angle is the hardest part."

Simone. Simone did not have as sound an understanding of perspective as Alex did. Although she was able to navigate her way around the program quite well, it was evident that she had not been exposed to many 3D-like programs in the past. Without support, she was unable to make sense of the pictorial representations—for example, felt that the blocks at the back of the design were a different shape to those at the front. Consequently, she had considerable difficult selecting the appropriate blocks to make the design. On occasions it seemed that the combinations of blocks grouped in colour were puzzling her because her block selection matched the size and shape of colours rather than individual pieces. For example, Simone used two 8 x 4 block rather than a number of 8 x 2 blocks. Although she commented that she played Lego with her brother it was evident that she was not making connections between real and simulated contexts.

Ebonee. Ebonee was able to navigate her way around the computer environment quite effectively. She indicated that she was familiar with a range of software programs which were used for both entertainment and homework purposes. Although she was quite willing to experiment with orientation and perspective functions in the tutorial mode of the session, she did not use the rotation functions when constructing her model. Her completed design was accurate from the front view but incorrect from all other orientations. The block on the top of her design was not positioned in the centre of the model—it was too far forward (as could be interpreted in the front-view design).

Laura. Although Laura played entertainment games at home (eg. Playstation) she did not use the computer on a regular basis for any purposes except wordprocessing. She struggled to come to terms with many of the programs functions and had considerable difficulty in using the mouse in a coordinated manner. Instead of building her design from the base up, as all other participants did, she constructed her model from the top down. Laura used 4 x 2 blocks (and not the correct 8 x 2 blocks) for her design and continued to do so until she completed the base. It was only when she began to colour in the design that she recognised that she had used blocks that were too small. On her second attempt, Laura still persisted with a top-down approach. It could be the case that she was pre-occupied with making sure that the flags were positioned carefully. When asked to comment on which aspects of the problem she found difficult to complete she suggested "it was really hard to get all the angles right because they looked different on the paper than on the screen even though they were the same…the angles on the flags were the most difficult to work out." Laura found it difficult to make connections between the two pictorial representations, compounding difficulties faced in making the links to the simulated environment.

Carli. Carli played with traditional Lego blocks, with her brother, on a regular basis. She was quite adept at using all of the function keys demonstrated in the tutorial and was able to effectively use orientation and perspective functions to navigate around the screen. Carlie was able to make connections between the two pictorial representations and referred to each as she constructed her model. She had no difficulty moving between the two environments. As she commented, "You need to have two pictures so that you can build a 3D model. Without the top view you would not be able to tell how deep it was." Although Carlie completed the task in less than ten minutes, the model was not in the correct proportion. She had used blocks that were too large. Initially she insisted, "It looks too long because it looks more like a real thing on the screen than it does on paper." After showing Carlie that she had used the wrong size blocks she maintained, "When I play Lego I am able to count the little circles on top of a block to make sure it is the right size...but it was hard to tell here." Although she had completed the task quickly, a considerable amount of time was devoted to selecting the blocks. Laura had realised that her selections were inappropriate once she began to colour the blocks. Carli more than likely realised her mistake at this stage of the problem too, but reasoned that the screen representation was different to the 2D form.

Bailey. Bailey accurately completed the entire task in just over five minutes. She continually made reference to both pictorial representations when selecting and positioning blocks. Although she predominantly viewed her model from a front perspective, she continually moved between close-up and wide-angle views as she constructed her model. She suggested "moving between close-up and far-away angles lets you see your work in different ways and makes it easier to understand if you have the depth right." The "depth" she referred to was associated with the 3D-like nature of the object.

Joe. Joe was a very capable young mathematician who frequently used computers for a variety of purposes. He moved between different orientations and perspectives very quickly, with both precision and confidence. He was quite accustomed to efficiently navigating around computer environments and was able to quickly apply this knowledge to the problem-solving context. His initial interpretations of the pictorial representations (Figure 2) revealed that he was aware of the elements of the problem that would be most difficult to interpret. "You cannot tell what shape and colour all the blocks are unless you look at the information in both pictures...even then you need to predict what some of the blocks might be and then make sure it matches both pictures." Although Joe predominantly worked from the front-view picture he made reference to the bird's-eye perspective at critical times during this construction phase. What he did do more than most other participants was move between different orientations (through 360^0) in order to check that his model accurately matched the pictorial representations. Joe completed the activity in less than ten minutes.

Percy. Percy was another capable student who had extensive experience in using entertainment and educational programs on the computer. He was able to "click and drag" icons easily and played with Lego constructions far more than any of the other participants. In fact, he had an extensive collection of Star Wars Lego and other Technics Lego blocks. He ordered blocks from magazines and always asked his grandparents to purchase Lego for him at Christmas and on his birthday. Although he had not used this software before, he navigated his away around the environment intuitively—using tools that had not been demonstrated in the tutorial session. For example, he used the Control key to orientate his object through rotations of five degrees. He recognised that the base "was a Lego mat [and was] still a square even though it looks narrower and longer than a square." Interestingly, he made more connections between the game's theme and the actual activity than the other students. "This could be one part of a castle." Moreover, he was more inclined to respond to questions with a particular context. For example he commented, "the flags are at 45^0 angles because the wind is blowing from the East." He also indicated that the software program was more challenging that used the traditional block constructions. "This is more difficult than normal Lego because you have to make sure that you have planned it out in your mind first, otherwise it might look funny...even with directions it would be hard because you need to see that it looks right from 360^0 because some images are still flat." The notion that "flat" screen images require careful planning was, in part, overcome by his ability to use the perspective and orientation functions so well. Nevertheless, Percy was aware of the relationships between 2D and simulated 3D space.

Conclusion and Implications

Generally, the participants were able to make strong connections between the elevation representations and their screen-based constructions. Although only three of the eight students were able to accurately complete the task, all participants were able to make some links between the 2D and simulated 3D environment. In most instances, the students were able to appreciate that the screen-based images were representative of both the pictorial representations and actual Lego blocks. Moreover, the students were able to develop increasingly powerful conceptual understandings by modifying their computer-based constructions and relating these new experiences to existing ideas. The successful participants were able to develop powerful ideas about links between the 2D, the simulated 3D computer environment and the traditional concrete manipulatives.

Although a range of spatial skills were required to complete the task—including concepts associated with position, location, arrangement and diminishing line—conceptual understandings of perspective and orientation were essential. The students who were able to interpret dimension and manipulate objects in both front-view and bird's-eye perspectives were more likely to successfully complete the task than those individuals who worked only from one perspective. Similarly, those students who continually rotated their construction in order to view it from different angles found the task easier to complete. The students who had most difficulty completing the task tended to keep their construction in a front-on view. This became problematic if an individual was not able to rotate the model "in the mind's-eye."

Most of the students were able to recognise that it was worthwhile to have front- and bird's-eye elevations of the model. This was particularly the case when they were attempting to place the flags in the correct position. The activity certainly provided opportunities for the students to develop increasingly powerful spatial understandings (Amory et al., 1999) and more sophisticated mental tools (Clements & Battista, 1992).

Several implications for teachers emerged from the study:

- Investigative tasks that challenge students to simultaneously interpret information from different perspectives and orientations provide opportunities for more sophisticated spatial development.

- These students were able to efficiently navigate their way through a novel technology-rich environment because they were able to contextualise the problem by relating it to a familiar context.
- Children are exposed to a range of technology rich activities outside school settings that are more spatially rich than activities typically presented in the classroom.

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