

The Role of Dynamic Interactive Technological Tools in Preschoolers' Mathematical Patterning

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This paper presents case study data from an exploratory study investigating six preschoolers' patterning skills using three learning modes: concrete materials, screen-based technological tools, and combined modes. Children using *dynamic interactive software* and *virtual manipulatives* to solve pattern-eliciting tasks engaged in more "experimental" representations and created more patterns and transformations than children using concrete materials. However, there were no qualitative differences observed between children's understanding of simple repetition. This research highlights new ways of mathematics learning that can be enhanced through explicit techniques afforded by technology.

The importance of early patterning and pre-algebraic skills have been articulated in several recent research projects (Dougherty & Slovin, 2004; English, 2004; Fox, 2005; Mulligan, Prescott, Papic, & Mitchelmore, 2006; Papic & Mulligan, 2005). These studies have highlighted children's potential to develop simple repetition, growing patterns and functional thinking (Blanton & Kaput, 2004; Warren, 2005). Patterning skills have also been found critical to the development of other mathematical processes, such as analogical reasoning and transformation (Lehrer, Jenkins, & Osana, 1998).

In preschool settings, patterning is readily observed in children's play (Ginsburg, Lin, Ness, & Seo, 2003) however few teachers harness, or mathematise, these moments (Clements & Sarama, 2007; Fox, 2005). Patterning forms an integral part of the school mathematics curriculum and young children are required to engage in simple through to complex patterning (Board of Studies NSW, 2002). Generally these patterning experiences involve the use of concrete materials and representations of patterns through drawing and traditional media. Young children, particularly preschoolers, are rarely given the opportunity to create a range of patterns on-screen, yet they are capable of producing powerful mathematical ideas (Perry, Dockett, Harley, & Hentschke, 2006).

New technologies, such as *virtual manipulatives* and *dynamic interactive software* may allow young children to create mathematical representations that have increased potential mathematically (Clements & Sarama, 2007). For example, the development of simple repetition, and transformation skills such as reflection, rotation and scaling are enhanced through on-screen manipulations. Virtual *Pattern Blocks* and dynamic interactive software can provide representations of concrete manipulatives that allow children to experiment with a broader range of patterns with ease and flexibility.

Background to the Research

A number of researchers have highlighted the importance of linking concrete mathematical experiences with symbolic representations, a transition that may be assisted by using computer-based manipulatives (Clements, 1999; Clements & Sarama, 2007; Kaput, 1992; Moyer, Niezgoda, & Stanley, 2005). Virtual manipulatives are particular forms of mathematical software that can be defined as "interactive, Web-based visual representation of a dynamic object" (Moyer, Bolyard, & Spikell, 2001, p. 373). For

example, Pattern Blocks (see Table 4, following) have considerable mathematical potential because they can be easily transformed and recorded, simulating the manipulations that children make with concrete materials. Other programs utilising dynamic drawing tools, such as *Kidpix* (Brøderbund, 2004) have the added advantage of changing properties of objects.

It appears that dynamic processes afforded by these tools can enable children's spatial visualisation skills and experimentation with size, shape, orientation and simple repetition. Although there is little research on the use of technological tools with preschool-aged children, some key research has been conducted with elementary students (Moyer, Bolyard, & Spikell, 2001). Clements (1999) and Moyer et al. (2001; 2005) highlight benefits of virtual manipulatives for classroom use. For example, virtual Pattern Blocks have colours that can be changed, they can be “snapped” into position, unlike concrete material and they “stay where they're put” (Clements, 1999, p. 51). Although virtual manipulatives may seem advantageous there is little research explicating how young children make connections between concrete and dynamic representations. Reimer and Moyer's work with third graders highlights some possible benefits of virtual manipulatives as a “dynamic visual model” (2005, p. 22) with potential for multiple representations of concepts.

In a study of Kindergarten children's patterning, Moyer et al. (2005) found that children's patterns were more creative, complex and prolific using virtual manipulatives compared with patterns formed with concrete materials. It is not known whether these findings would be supported in studies of preschoolers, who are likely to have less developed computer skills and limited mathematical patterning abilities. There is also scant research on young children's use of dynamic interactive software in early mathematical development. The work of Hong and Trepanier-Street (2004), although not specific to mathematics education, does show that young children's representations employing dynamic interactive software, such as *Kidpix* are more detailed than representations produced off-screen.

This raises a broad research question: In what ways can the use of dynamic interactive software and virtual manipulatives advantage the development of mathematical patterning skills in preschool children? This study focuses on the potential advantages of using such technologies in developing early patterning and transformation skills.

Method

This project took the form of a constructivist teaching experiment, integrating elements of a developmental design approach, using six collective case studies (three dyads) of preschool children, aged between four and five years (Hunting, Davis, & Pearn, 1996). This mixed-method approach allowed for teaching episodes to be constructed and scaffolded systematically, based on the continual reassessment of each child's progress.

Prior to commencing the teaching episodes each child was assessed for numeracy using *I can do maths* (Doig & de Lemos, 2000) and patterning skills using an *Early Patterning Assessment (EPA)*, (Papic & Mulligan, 2005). Three key tasks were administered in the EPA – “imagine and draw a pattern”, “make a pattern” with materials and “repeating pattern tasks” (tower tasks). Following the initial assessment children were paired into one of three dyads, balanced for gender. Each dyad then participated in six, 40-minute teaching episodes, conducted by the researcher over a 4-week period at a participating preschool. Each dyad was assigned to one of three learning modalities using:

1. concrete materials (such as blocks, counters, animal pictures, stamps, paint, pencils);
2. a combination of concrete materials, dynamic interactive software (*Kidpix*) and virtual manipulatives (virtual *Pattern Blocks*), and
3. dynamic interactive software (*Kidpix*) and virtual manipulatives (*Pattern Blocks*).

The aim of the teaching episodes was to engage the children in *pattern-eliciting* tasks, based, in part, on recent studies of mathematical modelling (English, 2006) and early patterning (Papic & Mulligan, 2005). Three pattern-eliciting tasks: making “wrapping paper”, creating “wall paper borders” and “threading beads” required the construction of simple repetition in different forms, with opportunity for multiple, alternate representations. Where possible the tasks directly related to the children’s context, such as creating a new wallpaper border to replace an existing border. These tasks allowed children to play with mathematical patterns but were structured sufficiently to promote mathematical thinking. Tasks were matched across each of the three modalities with concrete materials replicating on-screen resources and tools (and visa versa). Teaching procedures and the order of tasks remained consistent, although it was anticipated that the solution strategies used by each child would differ. The researcher encouraged multiple responses and encouraged children to create and discuss their own representations regardless of the learning mode. Following the six teaching episodes, the children were re-assessed, using the same assessment instruments. Multiple data sources (audio and digital media, work samples, and “researcher as participant observer” records) were compiled throughout the teaching experiment. All data were collated to enable a descriptive analysis for each child, and in turn, each dyad’s progress. Children’s responses to the tasks in each teaching episode were coded for the type and sophistication of patterning and transformational skills, supported by transcriptions of discourse between dyad and researcher.

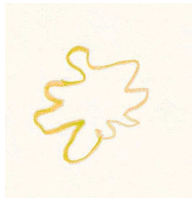
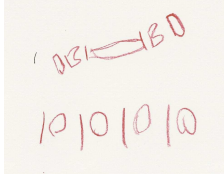
Results

Some initial findings are drawn from pre- and post-assessment data and the analysis of patterning strategies developed throughout the teaching episodes. The discussion provided here focuses primarily on differences between children's patterning and transformational processes afforded by the use of technological tools.

Pre- and Post-Assessment Responses

Pre- and post-assessment data from the EPA indicated that all six children’s responses progressed from idiosyncratic to more formalised representations containing a *unit of repeat*. This development appeared independent of the learning mode employed in each dyad. Using the descriptors developed by Papic (Papic & Mulligan, 2005), the children’s images of pattern (“imagine and draw a pattern”, and “make a pattern with blocks”) were initially analysed and coded. Table 1 provides an example of a typical pre- and post-assessment response for the task, “imagine and draw a pattern” using this coding.

Table 1
Sample Pre- and Post-Assessment for “Imagine and Draw a Pattern”

Child ID	Pre-assessment – imagine and draw	Pre-assessment Category and Image Description	Post-assessment – imagine and draw	Post-assessment Category and Image Description
Nicholas		Code 1: Inanimate objects and things. An image of a yellow star. No pattern is evident		Code 3: Informal notations showing evidence of symmetry. Code 4: Icons/ Symbols, A simple AB repetition using shape.

The most important finding that emerged at this stage of the analysis was that no child represented pattern depicting a unit of repeat at the pre-assessment. Although some diagrams showed evidence of symmetry and regularity, the children were seemingly unaware of any pattern features. The pre-assessment representations contrast with the post-assessment data where children depicted pattern as simple repetitions using a unit of repeat. Although it is clear that significant changes were made between assessments, it is not possible to infer whether the children’s initial idiosyncratic images of pattern remained or whether they had been reconstructed through new representational processes. Moreover it is feasible that the children learned, through the teaching episodes, to present simple linear repetitions in the way the researcher had scaffolded the learning.

Responses to pre- and post-assessment for the “make a pattern with blocks” task showed similar patterns of response to the first task. Examples of two typical pre- and post-assessment responses are provided in Table 2.

Table 2
Pre- and Post- Assessment Responses for “Make a Pattern with Blocks”

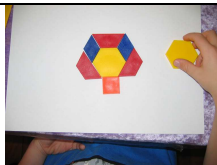
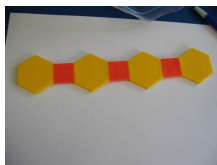
Child ID	Pre-assessment	Pre-assessment Category and Image Description	Post-assessment	Post-assessment Category and Image Description
Joshua		Code 5: Spatial structure. This image of “shapes” shows both tessellation and symmetry, using multiple shapes.		Code 3: Simple single variable repetition This is an example of a complete ABAB pattern.
Isabelle		Code 1: Random arrangement. This is a picture, of “butterflies and flowers”, and does not show repetition or regularity.		Code 3: Simple single variable repetition. This is an example of an incomplete ABAB pattern.

Table 2 provides a pre-assessment response by Joshua depicting a pattern with transformation symmetry. Similar pre-assessment responses were produced by two other children. Although some structure is evident in Joshua’s work, no child produced a pattern with a unit of repeat central to its design, such as ABCABC. This was in sharp contrast with post-assessment responses, where the children made patterns containing a unit of

repeat or an incomplete unit of repeat. Table 2 also provides an example of pre- and post-assessment responses for Isabelle, where an incomplete unit of repeat is shown at post-assessment. However, it was not possible to determine whether these children were aware of using symmetry or a unit of repeat in their designs.

In four repeating patterns tasks (tower tasks), the children used multilink cubes to extend, make and draw simple and complex repetitions, identify hidden elements, break the tower into elements, and record from memory (six modes of response). Table 3 indicates the number correct responses (six responses are possible) for the four tasks at pre- and post-assessment. At pre-assessment all children could continue simple AB repetitions but found most other tasks difficult. Matthew was an exception to this, as he was able to respond correctly to most tasks except for the “breaking into elements” strategy.

Table 3

Children’s Performance of Tower Tasks at Pre- and Post-Assessment

		Pre-assessment				Post-assessment			
		AB	ABC	AAB	ABBCC	AB	ABCABC	AABAAB	ABBCCC
Dyad 1	Tina	1	0	0	0	4	4	0	0
Materials	Joshua	3	2	0	0	6	5	0	0
Dyad 2	Nicholas	3	0	0	0	6	4	0	0
Combined	Yvette	2	0	0	0	4	0	0	0
Dyad 3	Isabelle	4	0	0	0	6	4	0	0
Technology	Matthew	5	5	5	3	5	5	5	4

Table 3 indicates that all of the children progressed in their understanding of simple repetition (ABAB) with four of these children also constructing complex repetitions (ABCABC). By the post-assessment all children had progressed significantly in both complexity and awareness of pattern.

The overall progress shown for individuals between pre- and post-assessments across all three EPA tasks was evident but the differences in responses between dyads was too small, or not consistent, to be noteworthy. Further reporting of the individual patterns of response is required to describe individual progress within learning modalities.

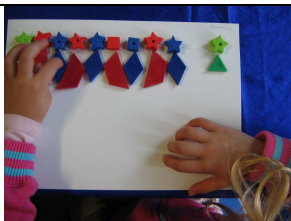
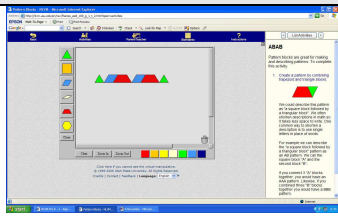
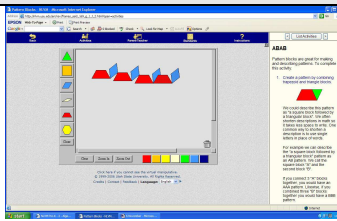
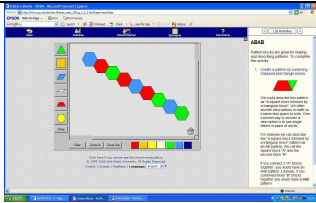
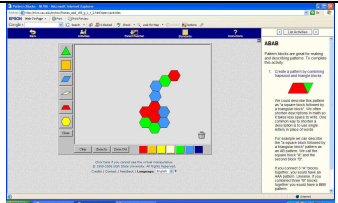
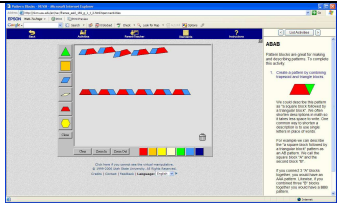
Teaching Episodes

Increased representations using technology. Technological tools allowed ease of representation, with children in dyads 2 and 3 consistently engaged in increased experimental patterning. Children working on-screen produced a broader range of patterns, and edited or deleted them before completion. In part, this could be attributed to the “delete tools” that held “novelty value”, with the children enjoying “rubbing out” and “chucking” things in the “bin”. The figures provided in Table 4 provide examples from each dyad, of children’s experimentations from the third teaching episode, where they re-visited a “beading” task, seeking alternate patterns. In this teaching episode, as in all teaching episodes, the more permanent nature of the concrete materials meant that children using traditional representational tools were less likely to experiment with their representations. In contrast, children using technological tools were motivated to experiment with, and

produce more patterns. For example, in dyads 2 and 3, Yvette and Isabelle cloned pattern elements following demonstration by the researcher.

Table 4

Three Children's Work Samples for Beading Task "Mum's Beads"

	Teaching Episode 3: Sample 1	Teaching Episode 3: Sample 2	Teaching Episode 3: Sample 3
Dyad 1: Materials		Neither child in this dyad would produce further patterns.	
	Joshua created a complex repetition (ABC) compared with previous pattern.		
Dyad 2: Combined			
	Yvette reconstructed previous pattern (AB) with shapes.	Yvette constructed an ABC repetition created with assistance using 'cloning' technique.	Yvette produced an AB repetition created independently using cloning technique.
Dyad 3: technology			
	Isabelle produced a sequence of hexagons, carefully aligned, using three colours without use of unit of repeat.	Isabelle produced a 'pendant' using a different arrangement of hexagons, without use of unit of repeat or cloning.	Isabelle constructed two AB patterns including a unit of repeat using a cloning procedure.

Transformation skills. Both dyads using technological tools engaged in more explicit transformative actions, such as reflections, translations and rotations, and shearing or scaling of images (see Figures 1 to 3). Although children using concrete materials did engage in transformations such as sliding, rotating and flipping of materials, these actions were not as defined as those actions performed with technology. As well, these children did not engage in shearing or scaling of images, as this was not easily performed off-screen. Children using technology also engaged in rich mathematical discussions about their transformations (see excerpt accompanying Figure 3). Discussion of mathematical actions was not forthcoming from dyad 1. The prevalence of transformative actions on-screen had not been anticipated by the researcher and subsequently this was explored further in response to the children's experimentation. Transformations, such as rotation and translation were identified in representations and discussions of the dyads working on-

screen across all teaching episodes. The transformations produced by the children working with traditional materials were not explicit, nor were these discussed spontaneously by the children. Transformative actions for off-screen dyads only occurred in one teaching episode, after the researcher modelled reflections and rotations.

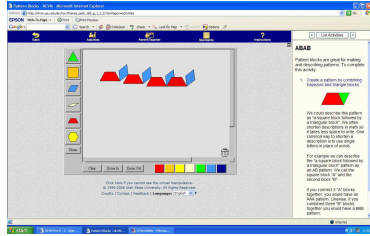


Figure 1. Yvette's repetition, with rotational transformation of parallelograms.

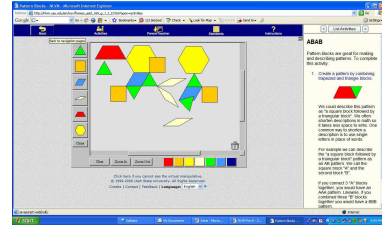


Figure 2. An image created by Isabelle, showing transformations of shapes.



Nicholas: Oh he's really big now. He's really, really big. Wee ... Oh ... Big ... Fat (*as he scaled the lion, enlarging it*)
 Yvette: Make him long (*pointing to the seals*).
 Nicholas: Flat (*after shearing the seal*).
 Yvette: They're both flat (*pointing to the seals*).

Figure 3. Screen shots of shearing and scaling lion and seal icons, with accompanying transcript.

Accuracy of representations afforded by technology. Both dyads using technological tools produced more mathematically accurate representations on-screen. Use of shape icons and stamps ensured that all representations using virtual Pattern Blocks contained geometrically accurate features, compared with those drawn by the children.

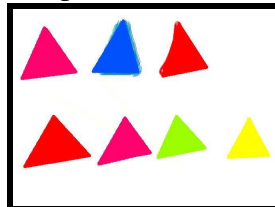


Figure 4. Isabelle's triangles, created using "sticky straight string".

Other tools, such as the "sticky straight string" (Figure 4) available in *Kidpix*, allowed children to present geometric shapes more accurately and with structure. This may not have been permitted with some children's limited fine motor skills.

Discussion

The findings of this study indicate some potential advantages and disadvantages of using technological tools in early patterning. Dyads working on-screen were enabled by the technological tools to pursue alternate learning trajectories. Children restricted to concrete materials still produced patterns using a unit of repeat. However, without the dynamic appeal of on-screen tools they were not motivated to investigate other mathematical processes such as cloning a unit of repeat, or transformations such as shearing and scaling.

Potential Advantages of Screen-Based Tools

The observation that technological tools motivated children to experiment more readily and practice patterning skills is an important insight gained from this study. An increase in on-screen patterns was also described by Moyer, Niezgoda, and Stanley (2005) in their study of Kindergarten children's patterning with virtual manipulatives.

Dynamic interactive software and virtual manipulatives provide tools whereby the children can easily link units and clone or copy units of repeat which can promote mathematical processes such as unitising and multiplicative reasoning. Some of these technological functions have been partially investigated with older children (Clements, 1999; Moyer et al., 2005). In this small-scale study there were few spontaneous examples of cloning units of repeat observed but with teacher guidance and further experience the children may have been able to develop this process independently.

Transformative actions exhibited by the children working on-screen provided a powerful example of the potential of technological tools to enhance geometric concepts and related mathematical processes. The use of technology also exposed children to novel techniques for exploring concepts such as scaling and shearing, fundamental to the development of proportional reasoning.

Representational Detail and Accuracy

The children's on-screen representations elicited more detailed and more mathematically accurate images. Similar results were presented by Moyer, Niezgoda, and Stanley (2005) and Clements (1999), who found that virtual manipulatives offer opportunities for explicit representations that were previously unavailable to young children. Although the children's use of pre-formed, readily available images on-screen allow representations to be more detailed, there is also a risk that exclusive use of these images may limit the development of off-screen representations. It was not possible in this study to ascertain whether a child who exclusively used pre-drawn shapes on-screen had developed the drawing skills to produce these shapes off-screen. On the other hand, it is possible that some drawing tools, such as the "sticky straight string", allowed representations to be scaffolded until the child's fine motor skills were sufficiently developed to enable similar representations off-screen.

Potential Disadvantages of Technological Tools

Despite the advantages, there were two main features of virtual manipulatives and dynamic interactive software that may impede children's patterning skills. The first of these relates to the computer skills that children need to use these tools. In this study, the children initially found the mouse control and the skills needed to manipulate objects on-screen challenging. The importance of modelling and demonstration of processes in early childhood settings is described by Plowman and Stephen as "guided interaction" (2005, p. 152). Without teacher support, scaffolding and practice this impediment could limit learning. Limited mouse control also leads to unexpected actions, such as accidentally spinning shapes with virtual Pattern Blocks.

The second feature that may impede children's learning while using these tools is the distracting nature of some features. This was particularly evident with *Kidpix*, where the tools had the potential to distract children's attention from the learning, and limit dialogue. Again, guided interaction and adequate experience would allow the children to become

familiar with these features, thus reducing a novelty effect. Teacher scaffolding of learning also enables children to re-focus attention on mathematical concepts and skills.

Limitations of Study

Pattern-eliciting tasks were designed to encourage repetitions and transformation skills. To some extent the children may have perceived the tasks as somewhat contrived. Thus, the patterns they produced may not have represented their intuitive and emergent patterning concepts that were reflected in the pre-assessment phase. This was further constrained by the limited number of teaching episodes, and the time frame for each episode that may have inhibited further experimentation. The learning may have also been constrained because the children had no access to the materials or a computer in the preschool until the researcher's next visit. Further, it was not possible to ascertain the explicit connections that children made between representations of their patterning and other learning experiences.

Implications and Conclusions

This exploratory study highlights the need for further research investigating the complex representational processes that children engage in when learning mathematical concepts with dynamic technological tools. The preschoolers in this project engaged in mathematical processes usually placed in the K-6 school curriculum. However, it was observed that these children were capable of constructing and representing complex patterns in a variety of ways. It was apparent from discussions with preschool staff that this potential learning had not been harnessed. Staff were intrigued by the dyads' use of technological tools but were apprehensive about continuing such activities because of their lack of pedagogical knowledge and technological skills. Professional development programs in both preschool and formal schooling may assist in promoting the appropriate use of technology in early learning.

This study supports current research advocating that virtual manipulatives and dynamic interactive software have the potential, when used with appropriate teacher support, to be powerful mathematical tools (Moyer et al., 2005). A longitudinal study would provide the opportunity to investigate whether the child's ability to manipulate virtual materials has a significant influence on their conceptual development of patterning and transformation skills. New research might also draw attention to the need for integrated, multidisciplinary approaches to investigating the role of technological tools in the early development of mathematical concepts.

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