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Rethinking scaffolding in the information age

Nicola Yelland [a,*], Jennifer Masters [b]

[a] *Victoria University, Australia*

[b] *Queensland University of Technology, Australia*

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Abstract

This paper addresses the use of scaffolding in learning contexts that incorporate technologically based novel problems. We suggest that in computer contexts extended conceptualisations of scaffolding are needed in order to gain greater insights into teaching and learning processes. Our work has revealed that traditional forms of scaffolding, based on the "expert's" view of how the problem *should* be solved, need to be modified in order to accommodate the child's perspective and that three different types of scaffolding which we refer to as *cognitive*, *technical* and *affective* can be conceptualized. This paper discusses the ways in which the performance of pairs of children is enhanced in such scaffolding contexts, to include more examples of meta-strategic processes and strategies for problem-solving, than when the pairs are left to spontaneously solve the problems. This study provides additional support that cognitive, affective and technical scaffolding are beneficial for learning and that children are able to support each others learning via sharing strategies and articulating the reasons behind them to each other.

Keywords: Scaffolding; Learning; Computers; Thinking skills

* Corresponding author. Present address: Victoria University, School of Education, Footscray Park Campus, Ballarat and Geelong Roads, Footscray, Victoria, Australia. Tel.: +61 4 3834 4139.

E-mail addresses: nicola.yelland@vu.edu.au (N. Yelland), j.masters@qut.edu.au (J. Masters).

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1. Introduction

The influence of Vygotskian theory (Vygotsky, 1978) on educational practice has been one the most striking features of the past decade. Although a constructivist approach, grounded in the work of Piaget, had previously dominated pedagogy in schools, its lack of consideration of group learning processes, the social contexts of learning and the influences of cultural diversity, together with problems associated with the invariant notion of stages of development that are universal, has lead to its demise as the primary means for explaining and providing contexts for learning and development.

One of the main tenets of Vygotskian theory is the notion of a *zone of proximal development*, which was conceptualized as:

> The distance between the actual development al level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers (p. 86).

Vygotsky (1978) believed that guided interactions, with an adult, or a more skilled peer, could facilitate a higher level of thinking within the zone and his ideas have been the subject of much research over the years (e.g. Newman, Griffin, & Cole, 1989; Rogoff, 1990).

There have been a number of ways of describing and representing the ways in which adults or more experiences others may assist novice learners within their ZPD. These have included guided participation (Rogoff, 1990), "means of assisting" (Tharp & Gallimore, 1991), reciprocal teaching (e.g. Brown, 1978; Palincsar & Brown, 1984), the integrated approach of collaboration in conceptual change (Rochelle, 1992) and the cognitive apprenticeship model of Collins, Brown, and Newman (1989). For example, Rogoff (1990) used the term guided participation to denote "that both guidance and participation in culturally valued activities are essential to children's apprenticeship in thinking" (Rogoff, 1990, p. 8). Rogoff contended that the guidance could be tacit or explicit and that guided participation involved children and caregivers in a collaborative process which could link the learner's current level of understanding to a new level via activity which involved differential rates of participation and responsibility as the process proceeded. One of the key elements of Rogoff's guided participation was the notion of *intersubjectivity*, which involved a shared focus and purpose between children and their tutor. As Rogoff noted, "From guided participation involving shared understanding and problem-solving, children appropriate an increasingly advanced understanding of and skill in managing the intellectual problems of their community." (p. 8) This notion is critical for the work reported here since the forms of scaffolding that we used were derived not only from our knowledge about effective ways of learning and knowing but also from observing children's spontaneous problem-solving in novel contexts and identifying aspects which were problematic for them in relation to solving a given task.

Yet probably the most common way of describing the provision of assistance to learners has been related to the use of the building metaphor, scaffolding. The term "scaffolding" is generally attributed to Wood, Bruner, and Ross (1978) who described it as a:

> …process that enables a child or a novice to solve a problem, carry out a task, or achieve a goal which would be beyond his unassisted efforts (p. 90).

It was thought that if learning was mediated, or scaffolded, by adults children could not only accomplish the task at a higher level but also would be able to internalize their thinking, strategies or mechanisms used to be able to approach other similar tasks (Rogoff & Gardener, 1984). So, gradually the nature and extent of the scaffolding would be diminished and it would be finally removed. The metaphor of the ZPD as a construction zone promulgated by Newman et al. (1989) is an apt one, since scaffolding is used in the building profession during constructions, renovations and extensions, and removed once the building is complete. They also used Leont'ev's notion of 'appropriation' to describe learning in the ZPD whereby children are guided to reach solutions to problems via the acquisition of skill in using tools, strategies and concepts. In this context learning is aligned with 'relocation' to a different zone.

In the original article published over 25 years ago, Wood et al. (1978) referred to the scaffolding process as "… the usual type of tutoring situation in which one member 'knows the answer' and the other does not…" (Wood et al., 1978, p. 89). They viewed scaffolding as being mainly concerned with "… the adult controlling those elements of the task that are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence. The task thus proceeds to a successful conclusion (p. 90).

Wood et al. (1978) stipulated that in order for learning to occur there had to be a comprehension of the solution even though the learner did not necessarily realise how to achieve it without assistance. The authors contended that comprehension must precede production in order for the learner to obtain feedback about strategies deployed, in order to determine their effectiveness, while admitting that in some instances serendipitous event or unexpected discoveries could also lead to successful task completion.

Our previous research had shown (e.g. Masters & Yelland, 1996, 1997; Yelland, 1999; Yelland & Masters, 1994, 1995b) that since scaffolding is a concept that needs to be modified to suit the circumstances of implementation (i.e. the scope of the task and the learner's own zone of development), the nature of the scaffolding process is dynamic. However, several key characteristics of scaffolding can be identified (Beed, Hawkins, & Roller, 1991; Wood & Wood, 1996). First, the interaction must be *collaborative*, with the learner's own intentions being the aim of the process. Second, the scaffolding must operate *within* the learner's zone of proximal development. Rather than simply ensuring the task is completed, the "scaffolder" must access the learner's level of comprehension and then work at a slightly beyond that level, drawing the learning into new areas of exploration (Rogoff, 1990). The third characteristic of scaffolding is that the scaffold is gradually withdrawn as the learner becomes more competent. Palincsar (1986) suggested that this notion reinforces the metaphor of a scaffold as used in the construction of buildings since the means of support in this context is both adjustable and temporary. In the educational context the final goal is for the learner to become independent, having internalized the knowledge required in order to complete the task.

Generally, the concept of scaffolding has been accepted and applied in educational settings. In fact, it has come to represent a number of different strategies or mechanisms where learning can be supported. Rosenshine and Meister (1992) suggested that a scaffold may be either a *tool*, where a scaffolding device such as a cue card is provided for the learner, or a *technique*, that is, a strategy that the teacher implements in order to support a learner. The latter conceptualisation of scaffolding is probably the most prevalent in the research literature and usually implies a temporal component, with respect to both *type* and *extent* of scaffolding provided.

Scaffolding has been conceptualized as beginning with the selection of a suitable learning task (Gaffney & Anderson, 1991; Wood et al., 1978) The task must engage the participants with abilities that are emergent, but yet to be mastered. Furthermore, the task needs to be engaging so that the learners may sustain interest (Graves, Graves, & Braaten, 1996). Prior to embarking on the task with the learner, the activity must be evaluated in terms of the difficulty it is likely to pose for the learner (Wood et al., 1978). Rosenshine and Meister (1992) suggested that a teacher should anticipate errors before implementing an activity in order to steer students away from flawed or destructive paths. Additionally, strategies for adjusting the learner's role (Greenfield, 1984) need to be developed, in case the task is incompatible with the learner's understanding.

The application of scaffolds during the task may be structured in tasks of simple skill acquisition or they may be dynamic and generative, for instance, when teaching higher-level cognitive skills where step-by-step procedures are not appropriate (Rosenshine & Meister, 1992). In addition, scaffolding may relate not just to cognitive skills but to other aspects such as emotive or affective factors. Wood et al. (1978) refer to the process of *recruitment* where the scaffolder needs to catch the child's interest in the task and then later to frustration control in which the scaffolder needs to emotionally support the learner if they are discouraged. Schetz and Stremmel (1994) also describe encouragement as an important scaffolding strategy.

Considerable information is available regarding the strategies that may be used to support a learner's thinking processes during a task. Palincsar (1986) identified modelling, questioning and explanation which can be used to make the task requirements explicit. Pearson (1996) suggested that teachers could also use cueing, coaching and corroboration. The critical role of feedback has also been identified (Bliss, Askew, & Macrae, 1996; Rosenshine & Meister, 1992; Schetz & Stremmel, 1994), while Applebee and Langer (1983) pointed out a need to represent appropriate approaches to the task. These aspects were also considered by Wood et al. (1978) who suggested that a scaffold may involve reduction in the degree of freedom during a task. Additional strategies provided by Wood et al. (1978) included direction maintenance, marking critical features and demonstration.

Finally, scaffolding includes post-task activity or follow up. Graves et al. (1996) offered a number of strategies that could be used by teachers to support students in post-task phases. These included checking for understanding, re-teaching key points, discussion and encouraging various representations of concepts inherent to the task. In this way the scaffolding was designed to support the use of higher-order thinking skills and the creation and maintenance of effective problem-solving strategies and their monitoring.

2. Scaffolding in computer contexts

There is a considerable range of research that investigated the *use* of various *types* of scaffolding in traditional subject areas of schooling, such as language, particularly reading (e.g. Beed et al., 1991; Graves et al., 1996; Wollman-Bonilla & Werchadlo, 1999), mathematics (e.g. Coltman, Anghileri, & Petyaeva, 2002) and science (e.g. Flick, 1998). However, the study of scaffolding in which the computer or associated software constitutes a scaffold is less extensive.

Scardamalia and Bereiter (1996) developed the Computer Supported Intentional Learning Environment (CSILE) to facilitate the interaction of experts, teachers, parents and students in a "knowledge building society" (p. 6). In this environment the computer software acted as a scaffold to support the creation and development of conceptual understandings. The online environment was also used by Oshima and Oshima (1999) who were interested in investigating the types of computer-based environments that supported students and the interactions between the students, the computer and the teacher in such contexts. Cuthbert and Hoadley (1998) also used CSILE and employed it to allow students to work together on building design problems. Their research focused on the actual design problems presented to the students and how the structure of the problem could scaffold thinking and knowledge integration. These research examples provided rich descriptive case studies of the ways in which CSILE supported knowledge building via scaffolding by the computer, teachers and peers in a positive way, and thus provided support and extended the notion of learning from the socio-cultural perspective within the ZPD.

A research project reported by Wood and Wood (1996) provides an example of the ways in which the computer can act as a scaffold via the use of a software program which acted to tutor and guide learning to specific outcomes. Similar strategies were also engaged by Luckin (2001) using a program called *EcoLab* that required children to build food webs and by Revelle et al. (2002), who developed a computer-based search tool to search for information on animals in a hierarchical structure. Mercer and Wegerif (1999) also focused on the role that computer software could play in supporting children's learning, with the use of TRAC (talk, reasoning, and computers) software which was used to scaffold children's use of language as a tool for reasoning and collaborative activity. In a different approach, Baron (1991) considered computer hardware itself to be a scaffold that could facilitate social interaction. In this sense, she suggested that the computer served as a tool for the teacher to foster social interactions and subsequent cognitive skill building.

In these studies the term "scaffolding" was often viewed in a broad way to describe any aspect of interaction between a teacher, the computer and the student. Bull et al. (1999) discussed scaffolding within a computer-mediated environment by separating the computer-based supports from the teacher and peer support that was provided when children were working on the computer-based tasks. They suggested that scaffolding could be provided online via techniques such as visual cueing, links to web-pages with directions, downloadable help pages and communication forms to contact the instructor or peers. They also considered and described scaffolding strategies in terms of the teacher's role in supporting students using online tutorials. They claimed that "there are many kinds of scaffolding as many as there are techniques of teaching" (p. 243) and then went on to describe a broad range of teaching aspects such as explaining, resolving questions, inviting participation to those on the periphery, modelling problem-solving with think aloud strategies and providing evidence to support or refute statements.

One of the few studies that focused on the teacher's role in scaffolding computer implementation was situated in a preschool setting (Schetz & Stremmel, 1994). The findings from this study indicated that the role of the teacher was critical regardless of the software used. It was also noted that the type and amount of scaffolding varied according to student needs and the objectives of the task. Barbuto, Swaminathan, Trawick-Smith, and Wright (2003) also examined the role of the teacher in supporting children using computers. They worked with novice computer-using early childhood teachers in the "Tech4PreK" program. Barbuto et al. found that teachers who demonstrated constructivist pedagogy and were enthusiastic about using computers scaffolded the children effectively, even though they had no prior computing skills.

Our previous work (Yelland & Masters, 1994, 1995a, 1995b) has shown that not only does scaffolded instruction support learning and influence depth of understanding concerning a concept or use of strategic processes, but also that it can influence self-efficacy and levels of interest that children display in novel problem-solving tasks. We have worked in computer-based contexts in which children have worked with partners of similar ability, based on either the decision of the teacher or their performance on a non-verbal intelligence test (Colored Progressive Matrices) or both. The pairs were then scaffolded in computer-based tasks, which always contained an off-computer component, by a teacher/researcher, and were also encouraged to work collaboratively and question and support each other during the task solution. Thus, our work has differed from previous work, since:

- We incorporated children working in pairs who were of similar ability
- We used computer contexts characterized by tasks which enabled children to actively construct and play with mathematical ideas and concepts in an environment that supported a problem-solving approach, if the learner had the skills to recognise and make use of them in context.

This work has also illustrated the need to reconsider the types of scaffolding that we used with children. We have used the term *cognitive scaffolding* to denote those activities which pertain to the development of conceptual and procedural understandings which involve either techniques or devices to assist the learner. These include the use of questions, modelling, assisting with making plans, drawing diagrams and encouraging the children to collaborate with their partner. The nature of the collaborations in fact proved to be important in the problem-solving process. The children were more used to working individually in the classroom and in computer-based work. One of the major factors that had promoted effective problem-solving in our previous work was the ability to work collaboratively to plan and implement strategies and also to be able to listen to alternative viewpoints, reconcile them with your own and reach a consensus about what to do next (e.g. Yelland, 1998; Yelland & Masters, 1994). Thus cognitive scaffolding also included aspects of social cognitive behaviour which we had shown to be effective in the development of higher-order thinking. *Technical scaffolding* related to the fact that we were working with computers. Features of the program meant that the tasks and the environment both had the potential to act as mediators for learning since their design incorporated the use of inbuilt constructs to facilitate understandings and problem solution. As facilitators, we needed to highlight them and other features of the technological learning contexts which had the potential to effect learning outcomes. Finally, we found that the children we worked with needed *affective scaffolding* of varying amounts not only to keep them on task but also to encourage them to higher levels of thinking and operating when engaged with a variety of learning activities.

Further, we did not take the view that as teachers or experts we knew the optimal way to reach the task goals. We first observed the spontaneous problem-solving of pairs in order to generate effective strategies for scaffolding that would support their initial understandings and attempts to solve the problems. In the first instance this included scaffolding that was simultaneously cognitive, technical and affective but once the children became used to the computer environment and their confidence grew, the latter two forms were reduced and ultimately, of course, the need for cognitive scaffolding diminished.

3. The studies

The research presented here took place over a two-year period, with two different cohorts in the same primary school in an inner city location. We set out to examine the strategies and interactions of pairs of children as they solved novel problems in a computer context. The research was an exploratory case study (Yin, 1994) that investigated the ways in which young children solved novel problems in computer-based tasks. We were interested in both the spontaneous problem-solving and scaffolding the children to promote the use of *metastrategic* processes (Davidson & Sternberg, 1985) that are characteristic of the deployment of higher-order thinking skills. The exploratory case study approach was effective since we were examining learning in authentic classroom settings with multiple sources of evidence (teachers, children and classes). The conceptual framework of the study was based on the research literature that considers the importance of problem-solving, how computer-based learning contexts can impact on what is learnt and how it is learnt and the role of scaffolding in the learning process. The project was innovative because it considered both the spontaneous and scaffolded learning of young children on both computer-based tasks and non-computer planning activities. Additionally, the scaffolding techniques were considered in a new framework (i.e. cognitive, technical and affective) that provided rich information for both the teachers and the researchers, to illustrate the ways in which children could be supported in their problem-solving and how they might be able to extend this learning in computer contexts.

In the first year of the project we observed children as they spontaneously solved mathematical problems. We only intervened when they were showing signs of frustration or when they were stuck on a task. This usually involved making simple, task solution orientated suggestions but also included *technical* and *affective* support so that they could continue with the task to an acceptable (to them) solution. We then used this information to develop scaffolding techniques for the second year of the study, with another cohort, that was informed by our initial observations of the strategies deployed while the children spontaneously solved problems in the previous year.

The context for the study was a mathematics program for schools called *Investigations in Number, Data and Space*[1] and in particular, a unit of work entitled *Turtle Paths*. The computer software for the units in the series is called *Geo Logo*.[2] The unit consists of a series of activities that incorporate both on and off-computer work. The tasks were varied and included some with defined outcomes while others were open-ended and let the children decide what the final product would look like.

The children were in year 3 of the state school. In the first year of the study the average age of the class was 7 years and 9 months with a range from 7 years 1 month to 8 years 2 months. The participants in the second year had an average age of 7 years 9 months and ranged in age from 7 years 3 months to 8 years 4 months. We used intact classes and all the children worked in pairs. The children were video-taped while they solved computer-based tasks and this input was digitally mixed with video tape of the computer screen using a device called a multi gen. Thus, the data afforded the opportunity to consider the interactions of the children while they worked on the tasks which were also visible. In the second year the researcher was also an integral part of the interactions and this was recorded in the video-taped episodes.

We present the findings from three tasks that were very different in structure and purpose. The first task, called *Get the Toys*, required the children to direct a turtle to a particular toy in order to retrieve it and then return to the original location. They were directed to do this in as few moves as possible, so that the turtle did not run out of energy in the process. A meter at the top of the screen

[1] Investigations in Number, Data and Space. Glendale, IL: Scott Forseman.

[2] D.H. Clements (1998) SUNY at Buffalo.

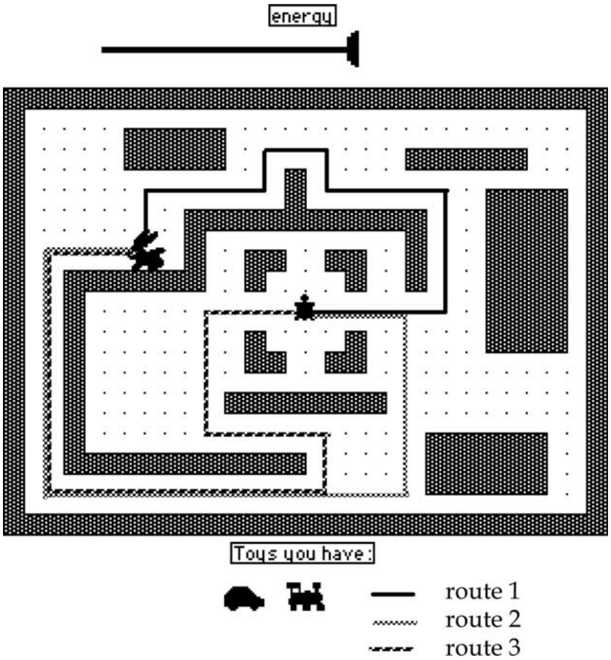


Fig. 1. Get the Toys: level 3.

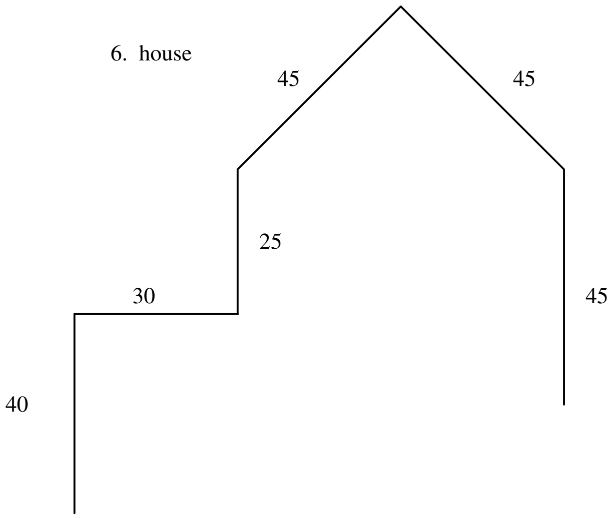


Fig. 2. Missing Measures: house (planning sheet).

indicated the amount of energy available. There were three levels of difficulty for this task and the diagram shows the most complex of these, level 3.

The second task was called Missing Measures. The children were given a sheet on which there were six incomplete pictures. The task required that they complete the drawings. Our data analysis focuses on the final item (Fig. 2).

In the final task of the unit the children were required to design and draw a project which could be any item of their choice.

4. Get the Toys

When *spontaneously* solving this task it was apparent that the children did not use several of the cues/strategies that were presented in the (class) introductory section. For example, they did not plan their route but immediately launched the turtle to go forward and planned "on the fly" as they went, they were reluctant to change moves once made and did not use the built in scaffold (technical) wherein each dot represented 10 steps which could be used to determine the distance. This was interesting because it serves to illustrate the fact that as teachers we give children instructions and information that will assist them to complete the tasks, however, the children do not always use them as anticipated. It was evident that an effective solution to this task depended on a number of factors:

1. Planning a successful route (i.e. one where the turtle would not run out of energy) before the children commenced the task.
2. The realization that each dot represented 10 turtle steps facilitated the accurate use of distance commands. In this way when moves were accurate they did not have to be "topped up" with additional amounts and thus were more energy efficient.
3. The ability and willingness to combine moves which reduced the energy load and was a more effective way to task solution.
4. The level of collaboration of the pairs – the most effective being those who demonstrated a shared understanding of the task and its requirements and also questioned each other and helped with suggestions.
5. The ability to determine the success or usefulness of each move in terms of the overall goal as it was made.
6. Understanding and applying the concept of a turn.

When the children embarked this task with minimum support, as previously described, those who were not successful did not tend to use any combination of these strategies. Three of the 8 pairs ran out of energy and could not get the turtle back while the rest only achieved the return with one or two moves, at most, to spare. Additionally, we noted that in previous studies (Yelland & Masters, 1995a, 1995b, 1999) we had spent considerable time with the children in group sessions discussing possible strategies and plans *before* a task was started and *afterwards* for sharing ideas. We did not do on this occasion.

Thus, in the second year of the study we focussed our *cognitive* scaffolding strategies around these observations and these may be summarized as

1. *Modelling appropriate moves in the introductory session.* This included emphasis of the role of the dots in guiding decision making for moves and demonstrating how to combine moves to save energy. This was achieved with the whole group in a participative demonstration session. The first level of the game was used as an example. The teacher said to the children; "The aim is

to get the turtle to the toy in as few moves as possible and back to the elevator. How can we do that?" The teacher encouraged all responses so that the children were able to critically evaluate each and discuss the meaning of the task requirements, that is, how to determine which was the most direct route that used the least amount of steps. Further, she used the fact that the dots each represented 10 steps so that the decision was linked to their existing knowledge about the relative size of numbers.

2. *Planning a route before embarking on the task and comparing it to other possible routes for efficiency*. The need for this became more apparent as the tasks became more complex. At level 3 it was more complex to determine which route was the most effective in terms of number of moves. The planning which was also evident by modeling involved using an overhead projector with a diagram of the screen copied on to it – with one of the group recording suggestions as they were provided.
3. *Questioning the children about the effectiveness of moves as they were made and assisting them to evaluate and modify plans where necessary (i.e. being metastrategic)*. This was particularly important where the children had to consider a number of elements about the movements at once. In one instance the difference was a final last turn, which if taken made the turtle run out of energy and thus the game was over. If the children, in their planning had suggested that the turtle should be moved forward 20 and then forward 30 for example, which moved the turtle nearer the toy, the teacher would say: "We just used two moves Fd 20 and Fd 30 to get closer to the toy. Is there a better way to do this if we want to save on energy. Can we make that one move? How can we do that?The following occurred in one of the initial sessions with a boy and girl pair:

   B: OK fd um mm…
   T: What do you think?
   G: fd
   B: 180
   G: Well
   B: No no no
   T: Are you sure?
   B: 90 90 90 90
   T: What do you think Rebecca?
   B: 90
   T: No hang on
   G: I've…
   T: Hang on, just have a think before you rub that out
   G: I think bk 120
   T: Where is his head pointing?
   G: down
   T: Which direction is he going in?
   Both: Forward
   T: forward you are right
   B: forward 90
   T: Now have another think…
   B: Where's … I can't see the dots….

4. *Encouraging collaboration by providing opportunities for pairs to question, compare and evaluate decisions as they were made and to value each others contribution.* When the pairs of children were planning and working on the computer, the teacher encouraged them to explain to each other and to question their partner about the decisions that were made. For example:
   G1: That was a good one…. hang on… you did forward 110 and this is less so how much should I do?
   G2: Well lets look at the dots as they are 10 each and there is 2 less… so that is
   G1: fd space 90…. yeah! (as the turtle reaches the point she wanted it to)
5. *Creating an environment for problem-solving that was responsive to the needs of the children and which encouraged them to explore and take risks in their problem-solving by realising that any "errors" could be immediately changed.* This was achieved in a number of ways, via the sharing of strategies in whole group sessions as well as supporting the pairs and individuals to try their ideas out by showing them that anything that they were not happy with could easily be changed in this computer-based task. This type of affective scaffolding was integral to creating an environment where the children not only felt confident about testing their ideas and strategies but also supported each other when an idea did not initially work with suggestions about how to remedy it.
   T: What do you think you're going to have to do very first off?
   G: forwards 3?
   T: Remember?…
   B: No
   T:.. we want to save this energy don't we (pointing to energy meter) so…
   B: rt 90, rt 90 I reckon
   T: Ok before you even think of your first move, what do you think you should do?
   B: We should check it
   G: Count it!
   T: You should count your moves … so we get to find the quickest way
   B: rt 90… so the first moves should be rt 90
   T: have a look at what Virginia (his partner) is doing.. she's tracing with her finger to try and find different ways to go
   G: I found a way but I don't know how many moves it is
   T: OK. Let's just count it, Virginia say go across which is one…
   G: 2
   T: 3,4,5,….8
   B: And then we could go this way…..2,3,4,5
   G: The fifth way, the one that John thought of!

The task was designed so that there were multiple ways to achieve the desired outcome of reaching the toy and getting back to the elevator. It was also possible to discriminate between the routes chosen on the basis of efficiency of moves, with the minimum amount of moves being considered the optimal and included in the directions for the task. In this way, it was beneficial to keep account of the number of moves made as it impacted on the energy level of the turtle and a consideration of this was essential to the task since when the energy ran out the turtle could not move any more.

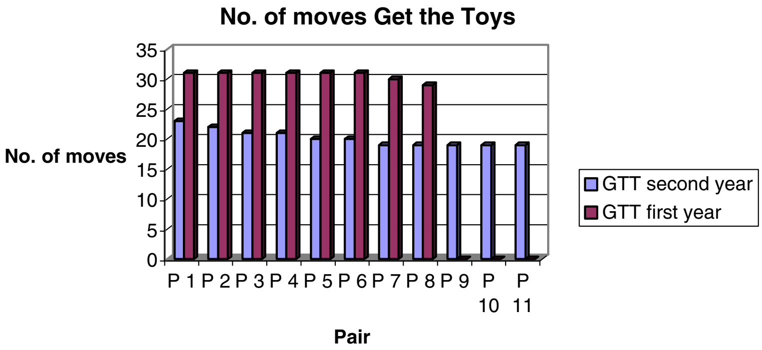


Fig. 3. Graph showing the number of moves made to complete Get the Toys (level 3).

Fig. 3 compares the number of moves used to solve the task, Get the Toys, level 3, by the two different cohorts. The lower numbers by the second, or scaffolded group, indicating their ability to use moves more efficiently, after they had received support in Levels 1 and 2 to assist them to solve the task. In the scaffolded context not only did all pairs complete the task more effectively, that is, based on the criteria required, but it was apparent that their level of understanding of task requirements for successful problem-solving was more advanced than in the non-scaffolded context of the previous year. Such behaviours and strategies were not shown by the first, or non-scaffolded pairs.

For example: *Planning the most effective route.*

G: Ok we have to figure out which is the quickest way
B: Yeah, get the paper and we can count the dots to see…
G: but don't forget the turns… which one should we try first… I know…. Turn first to point here (using a pencil on the paper) then forward…
B: (counting the dots) 10,20,30,40,50,60.. 60 write 60 then turn left. That's 3..
G: Forward (silently counting dots with pencil as guide) 60! Again and left 3 and two more … 5!

The pair continue to plan the way discovering that this route (see Fig. 1 route 1) needs 16 moves. They then repeat this process for a second route along the bottom of the paper (Fig. 1 route 2). They discover that this only needs 10 moves.

G: That's it. Let's go
B: Hang on are there more? … No that's it let's go!. Me first and you can do the turns!

Additionally, it was also apparent that the level of interactions of pair members was much higher in this context. The quality of the interactions seemed to have a positive effect on performance since it resulted in metastrategic processes (Davidson & Sternberg, 1984) being used effectively. This included planning as stated above as well as the ability to:

- *interpret and understand* the task requirements and translate this into relevant actions;
- *reflect* on the effect of their plans in action;
- *predict* the consequences of action before it was initiated;

- *monitor their progress* and modify plans with new commands when necessary;
- *discuss* and *analyse* the result of a particular move and making connections between the relative sizes of different moves in relation to the distance that needed to be traveled;
- *ask questions and information* from each other about the task and the general features of the environment.

It was also evident, as one would expect, that not all pairs required the same type or frequency of scaffolding. One girl pair in the second year of the study, in particular, was given a lot of *affective* scaffolding in the form of encouragement in order to assist them to complete the task.

G1: Oh no we have run out of energy! What will we do?
T: Have you checked that this is the quickest route?
G1: yes look we knew this was the least. Show the paper… Sally…. (G2 holds up the paper)
G2: See ours is 10 and these are longer…. We can't do it!
T: Yes you can.. lets have a look… we see here… you went forward..
G2: But it is all wrong …
T: No but it can be changed. You went forward 20 then 30 then 10 and used 3 moves. How can that be changed
G1: why?
T: You used 3 moves…
G1: yes but the turtle got there..
T: but when you counted on the sheet you only used one move – forward 60. Why did you use 3 here
G2: we thought we might get it wrong…. so we did it slowly
T: Well let me show you again how to change it (the teacher then shows the pair how to delete the 3 commands and to make it one command and asks them the number that they should type).

Once they realised that they could try out moves/strategies without dire consequences they had the confidence to approach the task with a high level of cognitive skill. Getting them past the confidence hurdle was a major task and they could only move on from this after a series of successes, which served to increase their belief that they could solve the task. In contrast another pair showed a high level of cognitive and technical skill but were not very good at collaborating. In fact they even sabotaged each other's moves by deleting them and putting in their own when they had control over the keyboard. We thus spent a great deal of time encouraging the children to collaborate and a minimal amount on cognitive scaffolding.

5. Missing Measures

In Missing Measures, the pairs had to complete drawings on screen that were presented to them on a worksheet. There was space on the worksheet to plan and write what needed to be done in order to finish each item. This task provided a contrast to the *Get the Toys* tasks since efficiency was not as important as accuracy in considering the selecting possible ways to complete the task requirements.

The analysis reported here pertains to the final object of six items, called *house*. A completed example is shown in Fig. 4. Again we found that when the children attempted to solve the tasks spontaneously they could but were often inaccurate in replicating the items precisely and also used less sophisticated strategies than when *cognitively* scaffolded using the following techniques that we derived from observing the non-scaffolded group. These included:

Creating an environment for problem-solving, in which the children were given a context for the tasks to assist them to make it more meaningful and relevant to their own experiences. For example, providing a scenario in which they had to complete the plans for an architect who was called away and the project needed finishing. For example:

T: In this one we have to imagine that we want to finish drawing the house so that the builder can start. We need to make sure that the plans are accurate or else what might happen?
C1: the house will leak when it rains?
T: That is a good reason! What else?
C2: We don't want it to fall over!

Encouraging collaboration between pair members, so that they were able to share strategies.

T: Peter has said that this side will have to add up to 65. What do you think Toby?
C1: I dunno
C2: Yeah it has to be 65 'cos look over here (pointing) … this bit's 40 … and this other bit is 25.. and they… have to be the same.
T: What is 40 and 25 Toby? Do you need a calculator?

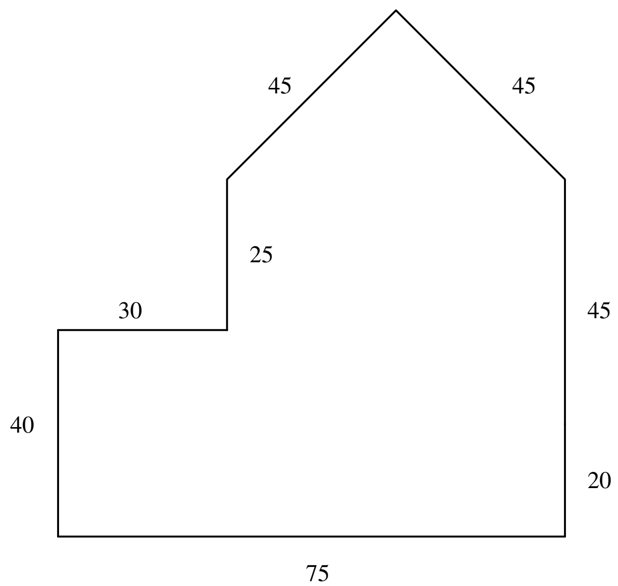


Fig. 4. Missing Measures: house (completed on computer).

C1: No … that's easy it's 65
T: So do you see why Peter thought it was 65? How he figured it out?
C1: Yeah…. it has to be the same otherwise the house will be crook… it has to be this (pointing to the left side 40) and this (pointing to 25) to make it straight and the same… right Pete?
C2: yeah… that's what I said!

Questioning the pairs, so that they were aware of important features in the examples given. For example, regarding the relevance of the numbers which indicated the lengths of sides and how they could be used to determine unknown lengths. This is shown in the scenario above, where Peter realized the significance of the numbers, and then with questioning Toby came to the realization about how the number was derived.

Modelling the application of the operations in order to calculate the varying side lengths

Planning and calculating the lengths of each side, with the aid of a diagram, before embarking on the task to ensure that they would be the appropriate size.

Encouraging the children to be flexible and willing to evaluate and modify plans where necessary (i.e. being metastrategic) Sometimes the planning that the children did was inaccurate and not able to be translated into actions on screen. For example, one girl pair had calculated the length of the right side of the house to be 60 instead of 65 and then when they turned to make the base of the house they realized their mistake after they made the move of 75 to complete the drawing because it crossed the final line above the base:

G1: Oh no! What happened… it's wrong somewhere!
G2: let's look at the plan… no we did all the right numbers!…. look
G1: it's not right look we have a bit sticking down (pointing)… it's too high… we haven't come down enough…
G2: How did we work that bit out? (pointing to forward 60 to make the right side of the house plan).. or maybe the roof is too high?
G1: (looking at the sheet) This has to be the same as this (pointing)… 40 and 30 … no 40 and 25..that's not 60. Get the calculator… (G2 picks up the calculator and exclaims)
G: It's 65 not 60… how do we change that?

To complete the house the children employed a range of strategies that we characterized as ranging from naïve to knowledgeable (Yelland, 1992). The naïve strategies (level 1) included, making guesses, moving the turtle along gradually until they were happy with its position and location and using visual approximation strategies. In the latter, for example, the children would say "It looks like 10". In contrast knowledgeable performances (level 3) were characterized by the use of metastrategic strategies (Davidson & Sternberg, 1985) which included working out a plan before the task was started, monitoring progress and evaluating moves as they were made in order to determine if they were successful in terms of reaching the goal, using processes such as comparing, calculating the number needed for each side and hypothesizing in order to generate strategies and drawing on existing mathematical knowledge for problem-solving, e.g. number sense and operations on numbers in order to calculate the precise size of move needed. Those children who were characterized as transitional (level 2) exhibited the use of both naïve and knowledgeable strategies but were inconsistent in their applications of either. This

Fig. 5. Graphs showing comparative performance levels for Missing Measures: house.

was contrasted to a naïve or knowledgeable performance in which the behaviours were demonstrated consistently throughout the task.

We categorized the performances of the pairs of children according to the criteria established. Inter coder agreement was high (92%) and we found that those children who were scaffolded while solving this task showed more examples of performing at a higher level that those who were not (Fig. 5). When the pairs of children worked on the house task without assistance, all 10 pairs were characterized as using naïve strategies with only one example of the use of a knowledgeable strategy. In contrast when scaffolded, three of the 10 pairs kept using naïve strategies while all other pairs exhibited the use of knowledgeable strategies.

These data, together with more generated from the other five items, serve to illustrate the fact that when working on novel problems in computer-based tasks, those children who were scaffolded in their problem-solving using *cognitive*, *technical* and *affective* techniques, derived from prior observations of children problem-solving coupled with our knowledge of children's learning, were working at a more sophisticated level than those who completed the task without assistance. It highlights the fact that if we want to use computers for improving learning we need to provide contexts in which children can be supported to make mathematical connections and use metastrategic strategies so that they are provided with opportunities to reach the higher levels of thinking that may be initially outside of their individual (or collective) ability but within their ZPD.

6. Projects

The final task in *Turtle Paths* came after the pairs had worked on six previous activities. In this event the pairs were asked to design individual projects or pictures. The range of possibilities was endless and not only depended on the children's interests but also on their technical skill with *Geo Logo* and their cognitive ability.

An analysis of the complete projects revealed a number of interesting differences between the non-scaffolded context of the first year versus the scaffolded ones from the second.

Most apparent was the level of enthusiasm for the task. The children in the first year appeared reluctant not only to do the task but also did not spend as much time either planning or completing it, as those in the second year. The lack of enthusiasm was most apparent for them in the planning phase where they were required to indicate the way in which they would complete the task in off-computer planning sessions. It was not apparent in the scaffolded context when planning time was conducted in whole group sessions where ideas were shared, and plans drawn on paper with the relative size of items indicated by numerals, without the requirement that procedures be recorded for each of the component parts. In this way component parts were only considered in diagrams not as written procedures, which was not only difficult but also time consuming. Drawing diagrams seemed to assist with the translation of the task from the planning stage to the computer context without the frustration that often was evident when pairs realised that if they wrote down all the commands first and one was wrong, or rather did not realise the planned effect, that all the subsequent commands were redundant until changed. This seemed to have the effect of making them lose interest in the project immediately.

The most obvious differences between the two contexts, were, in fact, at the planning phase. The non-scaffolded children of the first year drew elaborate diagrams of their ideas which were very complex in their nature and detail (Fig. 6). The scaffolded children were encouraged to think about their project in its most simple form and heeded this advice to produce manageable projects for which they exhibited a high degree of enthusiasm. An example from each year is provided as a comparison of this observation (Fig. 6). In the first instance a whole group session was convened with the children. On the computer screen the teacher shared a completed project and showed the planning sheet from which it was derived. She asked the group what they noticed about the computer drawings as compared to the paintings or hand-drawn illustrations that they usually do in their work, of which she had samples:

T: If you look at the computer drawing and then at this painting and this illustration which Marian did with her Derwents. What do you notice about them? And how are they different?
C1: That one (pointing to the painting) is big and has lots of colours
C2: That one (pointing to the hand-drawn/coloured pencils illustration…) is small and has colours… but it has … birds and trees and sun and lots of people…
T: yes… How are they different to the computer drawing?
C3: that one … on the computer is not colourful and it has lots of straight lines
C4: Yeah… and it does not have birds … or anything… like in the back
T: Yes that is … good… this computer drawing was done with the turtle and you have to use all the commands we have been using to get the turtle to draw.
C5: That will be … so many….

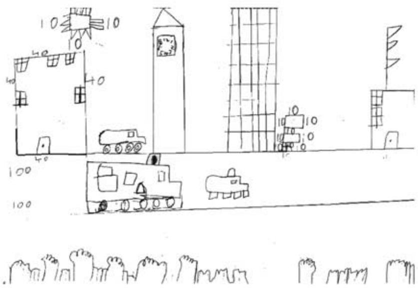
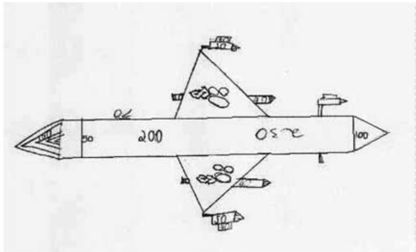
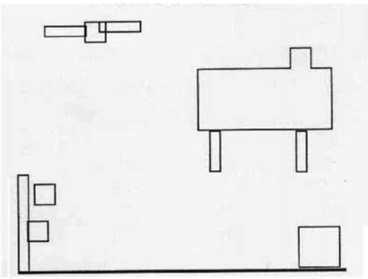
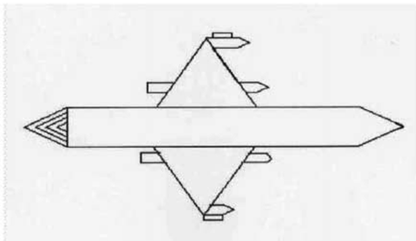
Unscaffolded	Scaffolded
Plan drawing 	**Plan drawing** 
Computer drawing 	**Computer drawing** 

Fig. 6. Projects: comparison of plans and computer drawings of unscaffolded and scaffolded pairs.

C6: wow… that will be a lot of commands…. how many?
T: Yes it will be a lot but when we do this project … we are just going to do a simple drawing first to see how we go … and then you can always add more things to it later.
C7: I want to do a house…
T: Now look at this one on the computer and look at the plan.. (the teacher goes on to discuss the way in which the planning led to the final drawing on the computer).

The next observation about the differences between the two groups of children pertained to the level of sophistication of programming style. The scaffolded group were encouraged to build their projects as a series of modules where possible, but if the shapes were complex they built them "on the fly" to save as a procedure which could later be incorporated into the final assembly. The non-scaffolded group tended to build most elements of their project "on the fly" and only considered them as an entity in the final compilation. An analysis of the transcripts from the data indicated that the scaffolded group spent a great deal more time talking about the compilation of their final picture throughout the process. In fact they spent more time talking in their collaborations than the non-scaffolded group whose products often reflected the ideas and ability of the most dominant partner. We even had one pair in this group who decided to do separate projects as they could not agree on what they wanted to achieve collaboratively.

7. Discussion and conclusions

The present study extended our knowledge, obtained in previous work (e.g. Yelland & Masters, 1994, 1995b), about the social–cognitive strategies and interactions of pairs of children and the use of scaffolding that enhanced and extended their learning in computer-based contexts. Scaffolding has often been viewed in terms of considering the expert way to complete a task and requiring children to model/mimic this by guiding them. We have considered scaffolding experiences which are responsive to the spontaneous actions that children used when independently solving the task. Effective scaffolding involves using a range of techniques and a variety of tasks that will provide opportunities for children to engage with concepts and higher-order thinking processes in new and dynamic ways. When these techniques are considered in terms of their cognitive, technical and affective qualities, it has become apparent that their usefulness can be gauged more effectively in terms of learning outcomes. Our work has also indicated that the computer and the type of tasks used create a context which is a type of scaffold, that may be complemented with suitable cognitive and affective strategies. The environment in which we conducted our studies were ones that encouraged active exploration of ideas and afford the opportunity for children to work with mathematical concepts in new and dynamic ways. However, the role of the teacher is critical in this context. Teachers should be confident in their approach and encourage children to take risks and realise that there is not always only one way to solve a particular problem. It is evident that a teacher who effectively scaffolds learning ensures that children are afforded the opportunity to maximize their potential and use higher-order thinking skills to solve problems. Teacher decisions about the level and type of scaffolding will depend on a number of factors which will include the nature of the task, the needs and interests of the children and the concept/processes involved and opportunities to share ideas with peers or present them to an authentic audience. What is clearly evident is that teachers need to be cognisant of these features and incorporate them in all aspects of their teaching and learning environment. We have found that children work more effectively and at a higher level in terms of processes used and strategies deployed, when they are scaffolded by a teacher than when they are solve tasks without assistance. Our work has also revealed that we need to consider the ways in which children spontaneously solve problems in order to be more effective in determining the level of scaffolding.

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