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riding the wave
of technology

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# Message from the Programme Chairs

The South African Institute of Computer Scientists and Information technologists (SAICSIT) has, over a number of years, developed into a highly acclaimed and respected forum for exchanging and sharing knowledge. The annual SAICSIT conference has steadily gained recognition not only in South Africa, but also internationally. Significantly more international researchers are submitting contributions to the conference and a substantial proportion of the programme committee is from the international research community.

At this year's conference, much like previous years, we have strived to provide an opportunity for academics in Computer Science, Information Systems and Information Technology to review, present and discuss research in their respective fields. We have also maintained the international participation in the conference, specifically as far as the programme committee is concerned. Out of a total of 69 reviewers, 45% of them were from the international research community. We would like to thank our international reviewers for their much valued contribution. We trust that the Programme Committee will remain involved in the conference and will advertise the work and opportunities provided by the SAICSIT conference in their fields of influence.

This year's conference once again comprises of two sections: a main conference of which this is the proceedings, as well as a post-graduate Research Symposium aimed at supporting and developing young researchers from a capacity building perspective. A total of 22 submissions of work-in-progress or proposal reports was accepted for presentation at the Research Symposium.

The main conference received 80 submissions of which 33 were accepted for presentation at the conference, resulting in a 41% acceptance rate. All papers were subjected to a single blind peer-review process (identities of reviewers were not revealed to the submitting authors) with each paper receiving a minimum of three reviews from the international programme committee. We have no doubt that the process yielded papers of high quality and would like to thank the reviewers for their efforts in this regards.

We, as programme chairs, would like to thank everybody who has so tirelessly contributed to make SAICIT 2008 a great conference. It was indeed great to work with such a dedicated team.

Reinhardt A Botha & Charmain Cilliers
2008 SAICSIT Programme Chairs

# Designing Technology for Young Children: What we can Learn from Theories of Cognitive Development

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## ABSTRACT

The majority of guidelines and principles for design of technology are aimed at products for adults. The limited guidelines available for design of young children's technology do not focus sufficiently on age-related requirements or they offer high-level advice that is only useful in the planning stages of design. This paper reports on research aiming to develop a set of guidelines for the design of technology for children aged five to eight years. We believe that the existing knowledge base on child development provides an ample starting point for setting up a useful framework of such guidelines. This paper demonstrates how the knowledge contained in psychological theories of child development can be translated into guidelines for the design of technology.

## Categories and Subject Descriptors

D.2.2 [**Design Tools and Techniques**]: User interfaces; H.1.2 [**User/Machine Systems**]: Human, factors, Human information processing, Software psychology; J.4 [**Social and Behavioral Sciences**]: Psychology; K.3.1 [**Computer Uses in Education**]: CAI.

## General Terms

Design, Human Factors, Theory.

## Keywords

Children's technology/software, Design guidelines, Psychological theories, Cognitive development, Cognitive skill development.

## 1. INTRODUCTION

### 1.1 Background and Motivation

If an information technology (IT) designer is suddenly faced with the task of designing a product to support young children's cognitive development, what would he or she use as a starting point in the design process? There is no set of tried and tested design guidelines equivalent to Dix et al.'s [12] usability principles, Nielsen's heuristics [29], Shneiderman's eight golden rules [37] or Preece, et al.'s [33] usability principles, that we can apply to technology aimed at young children. The limited guidelines available for children's products do not distinguish sufficiently between different age groups (e.g. [15, 24]) and they mostly offer high level advice that are only of value during the initial planning stages of design (e.g. [24, 41]).

This paper provides an extract from research through which we aim to develop a useful, widely applicable set of guidelines for the design of age appropriate technology for five to eight-year-old children. We work from the assumption that the wealth of theoretical knowledge on children's cognitive development can provide valuable input into the formulation of a framework for the design of technology. In doing this, we appreciate the value of user input and usability testing in the design process and admit that no set of guidelines alone will guarantee design success. We do, however, believe that proper guidelines can substantially reduce the amount of usability testing required and hence the cost of design and development. If the potential user group is small – as would be the case with technology for children from some indigenous language groups in South Africa – large investment in design and development may not be justifiable. Software developers that do not have the infrastructure or resources for extensive usability testing and cooperative enquiry can benefit from a reliable set of guidelines.

The relationship between human-computer interaction and cognitive psychology is eminent [11, 34, 37]. Using technology requires perception, attention, memory, information processing, decision making, and more. This is true for adult and child users. In this paper we focus on the link between child-computer interaction and cognitive development. There are computer applications with the purpose of teaching adults specific skills, such as flying an aeroplane, but usually, when adults use technology, it is to perform a task and not to develop a skill. With children, especially young children, the situation is different. Any interaction young children experience may have an influence on their development. How this happens or whether it is good or bad depends on the characteristics of the interaction. Interaction with computers may improve children's cognitive skills but it can also deprive them of other kinds of interaction that may be more beneficial. It is therefore important that designers of children's technology be informed about the nature of children's cognitive development.

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Little has been published about the relationship between developmental psychology and the design of children's technology. Baumgarten [1] provides a useful account of developmental issues in children's interaction with the Internet, but fails to make the relevant underlying psychological theory explicit. Similarly, Fishel [20] provides specific age-related information with regard to designing for children, but because she covers a wide age range, does this superficially. Wyeth and Purchase [41] refer to specific psychological theory, but end up with only six high-level guidelines. Our attempt to construct a useful set of age-related guidelines that are explicitly grounded in specific respected theories of development is thus justified.

## 1.2 Research Aim and Methodology

The aim with this paper is to demonstrate that it is possible to translate psychological theory into guidelines for the design or evaluation of technology by performing a systematic investigation of respected theories of cognitive development.

Following TerreBlanche and Durrheim [39], our research can be described as descriptive, applied and qualitative. It is *descriptive* in the sense that we aim to give narrative-like developmental characteristics of children aged five to eight that may have some bearing on their relationship with technology. It is *applied* as the results of our research will assist people with problem-solving and decision-making in the context of designing technology. It is *qualitative* because the data will be in the form of written language that we will analyse by identifying elements, themes or patterns that may play a part in achieving our research aim.

Research methodology has three elements, namely sampling, data collection and data analysis [16]. We believe that multiple case sampling [27] is necessary to establish a trustworthy profile of five to eight year old children and used reputational case selection [27] in choosing four theories of development. There is no clear distinction between data collection and data analysis in our study. We started with a process of familiarisation with and immersion in the chosen texts followed by the identification and coding of elements that potentially relate to design guidelines. We explored these elements further, translating them into guidelines and finally identified themes and categories according to which we organised the guidelines into a useful framework.

## 1.3 Delineation of this Study

There is a vast body of knowledge on children's development and a range of different theories. It would be presumptuous to claim that we can cover all of this in the scope of one study. We have therefore chosen four prominent developmental psychologists whose work represents the development of the field over the last century.

The focus is on informing the design of technology aimed at children aged five to eight years. Since we emphasise the importance of age-appropriateness of technology, the results are not intended for generalisation to other age groups. There are several reasons for focusing on this specific age group:

- This is a period of rapid growth in cognitive abilities.
- It is the age when children start their schooling and appropriate products can enhance their school readiness and support the acquisition of cognitive skills like reading, writing and story construction.
- More research has been done on software for older children, especially with regard to the influence of technology on cognition.

While focussing on a specific age group and trying to establish a user profile of five to eight-year-old computer users, we do acknowledge the variability of children's development. We strongly support the idea of adaptation to individual variation.

## 1.4 Organisation of this Paper

Section 2 contains a brief review of the literature on young children and technology. In section 3 we describe the theories of four prominent developmental psychologists and identify design-related factors that can potentially be translated into design guidelines. In section 4 we organise the design guidelines identified in section 3 into a logical framework. In section 5 we demonstrate the usefulness of the proposed framework and conclude the paper in section 6.

A note on style: Throughout the paper we indicate the derived guidelines with an arrow (→) in the left margin and reference label in brackets thereafter. The first letter of the label refers to the specific theory from which it was derived.

# 2. YOUNG CHILDREN AND TECHNOLOGY

Computers will never replace important play and learning material such as paint, blocks, sand, water and books [28], but technology does provide new and exciting opportunities for childhood activities. Computer technology makes it possible for children to easily apply concepts in a variety of contexts [35]. It exposes them to activities and knowledge that would not be possible without computers. A literature survey by Roschelle et al. [35] revealed the general finding that the use of computer aided instruction or, in some cases, ordinary applications such as word processors, improve achievement in the following areas: writing skills, remedial writing, verbal and nonverbal creativity, mathematics, phonological awareness, learning time, positive attitude to learning, auditory skills, language skills, story telling, meta-cognition, reasoning skills and independent thinking.

People opposed to the use of computers by young children have warned against some potential dangers such as keeping children from other essential activities, causing social isolation and reduced social skills, and reducing creativity. There is general agreement that young children should not spend long hours at a computer, but computers do stimulate interaction rather than stifle it [22]. Current advances in technology make it possible to create applications that offer highly stimulating environments and opportunities for physical interaction. New tangible interfaces are changing the way children play with computers [32]. An argument against early computer use is that children are being 'rushed'. Clements [8] responded that the possibility that children can be pushed to learn to write to soon do not make us keep pencils and paper away from them until they are ready. The important thing is to allow children to perform activities on the computer that are at their level of development. For Clements [9] developmental appropriateness means 'challenging but attainable for most children of a given age range, flexible enough to respond to inevitable individual variation, and, most important, consistent with children's ways of thinking and learning' (p.161). According to Haugland and Wright [22] the benefits of developmentally appropriate computer experiences for young children are:

- It provides opportunities to acquire and construct knowledge through active participation.
- It provides a holistic learning environment in the sense that by exploring virtual environments they acquire knowledge and skills in different domains of development.
- It promotes intrinsic motivation to learn by providing children with challenge, control, fantasy and feeding their curiosity.
- It provides children with scaffolding that enables them to acquire skills faster. (For example, children can type letters on a keyboard before they can make proper letters with a pen and this makes it possible for them to communicate through writing earlier.)
- It connects children to the world by providing access to people and resources throughout the world.
- It gives them access to a huge amount of information.

In general, technology is not regarded as a threat any longer and the potential benefits of young children's exposure to it are generally accepted.

Clearly, technology has become an important element of the context in which today's children grow up and it is important to understand its impact on children and their development. According to Druin [14] we should use this understanding to improve technology so that it supports children optimally. The development of any technology can only be successful if the designers truly understand the target user group. Knowledge of children's development and familiarity with the theories of children's cognitive development is thus essential when designing for them.

## 3. FOUR THEORIES OF DEVELOPMENT

Cognitive development progresses through continual adjustment, expanding and reorganising of mental structures [7, 30, 40]. Different theories of cognitive development explain this process in different ways. Piaget regarded the development of general cognitive structures as a necessary prerequisite to learning [19]. His structural theory represents a monolithic view of development where cognition depends on universal logical structures and learning happens from within the individual. Vygotsky demonstrated that the learning of concepts and strategies lead to the formation of more complex cognitive structures and viewed development as contextually determined and driven by external factors [2]. Case [6] believed that both these approaches explain aspects of cognitive development and his neo-Piagetian theory finds a balance between them. Building on Case's theory, Fischer [19] describes development as a constructive web, where skills develop in a specific order but with great variation due to contextual, biological and emotional factors.

These four theories are representative of the historical progression in developmental psychology. Work of other important theorists such as Siegler [38] and Gardner [21] may also be relevant, but the scope of our study does not permit inclusion of them all.

In the remainder of section 3 we demonstrate that it is possible to translate psychological theory into design guidelines. Section 3.1 looks at aspects of Piaget's theory of cognition, section 3.2 discusses three key concepts from Vygotsky's work, section 3.3 considers Case's cognitive structures and section 3.4 looks at Fischer's dynamic skills theory.

### 3.1 Piaget's Theory of Cognition

According to Piaget, cognitive development progresses as changes in knowledge structures [30]. Knowledge is organised into schemes that are sets of physical actions, mental operations, concepts or theories [2]. In the process of cognitive development new schemes are created and existing schemes are reorganised through *organisation* (integrating schemes into more complex structures) and *adaptation* (changing schemes to fit environmental demands or moulding the new information into existing schemes). The developing child actively takes information from the environment and processes and reorganises it in order to maintain a balanced and coherent state of equilibrium [31]. The mind adapts to the environment in two ways: through assimilation or accommodation. *Assimilation* is the process of applying one's current knowledge to interpret the external world [2] (e.g. a young child calls a cat a dog). *Accommodation* happens when current knowledge does not fit the environment and new knowledge schemes must be created or old ones changed to accommodate feedback from the environment (e.g. the child who called a cat a dog sees a cat and a dog and realises they are different things). According to Piaget these two processes form the basis of a child's ability to reverse mental actions and move back and forth through a set of elements, such as numbers or actions [19].

Piaget believed that every child goes through the following four stages of development (and that these stages are universal): the sensorimotor stage (0 to 2 years), the pre-operational stage (2 to 6 years), the concrete operational stage (6 to 12 years) and the formal operational stage (12 and older). Although, on the surface, different patterns of behaviour occur in a particular stage, Piaget concluded that there is one common structure that underlies each stage respectively [13]. To move from one stage to the next therefore requires fundamental re-organisation. Still, he believed that development is continuous and that there are no clear breaks between the stages. Although not all children move from one stage to the next at exactly the same age, the order in which they move through the stages is universal.

Piaget believed that before a child can learn certain skills, the cognitive structures that support those skills must be in place [2]. Therefore, to think about a situation that requires specific reasoning skills, children must possess the logical reasoning schemes and these, according to Piaget, they only acquire from the age of seven or eight. To design software that supports this view:
→ Designers must be well informed of all the knowledge schemes that underlie every activity they present to the child (P01).

To support cognitive development, technology must produce changes in the child's knowledge schemes. In Piagetian terms this means:
→ A product must make it possible for the child to

- fit the information presented into existing schemes (assimilation),
- adapt existing schemes so that the new information can find a place (accommodation), or
- combine existing schemes to form more complex schemes (organisation) (P02).

Piaget's theory puts children aged five to eight years in the pre-operational stage or in the beginning of the concrete operational stage [31]. They begin to acquire the skills to think about objects, events or people that are not physically present and can use symbols such as words, numbers and images to represent real objects. They use language to communicate effectively and they engage in pretend play. This means that when using technology, children in this age group should be able to distinguish software-based characters and objects from real-world characters and objects. This means that:
→ Technology aimed at five to eight year olds may use symbols and images to represent real-life situations (P03).

Piaget regarded reversibility and decentration as important foundations for many skills [13]. The concept of reversibility depends on the development of operational structures [13]. In Piagetian terms an operation is an action carried out in the mind, such as the combining, ordering, separating and recombining of elements. It always forms part of an organised system of operations which Piaget calls a group or grouping. When a child's thought has become operational, it means that he or she is now able to reverse any action (operation) mentally. So, where a child of three (pre-operational) can put objects in a row, move them around and then move them back, a child of seven or eight can perform these actions mentally. The mental operations are still concrete in the sense that they involve thinking about actions that can actually be performed physically.
In support of reversibility:
→ Include activities that require children to mentally reverse actions such as combining, ordering, separating and recombining of elements (P04).

→ Software aimed at younger pre-operational children should allow users to physically move objects, e.g. by dragging them with the mouse (P05).

→ Children older than six should be allowed or even expected to perform operations that involve combining, ordering or separating objects, mentally (P06).

Another Piagetian concept that develops during the late pre-operational stage and the concrete operational stage is decentration [13]. At first children are unable to identify a point of view different from their own. In the physical sense this means if a three year old looks at an object from one side and another child looks at it from a different angle, the three year old will assume that the other child sees exactly what he or she sees. They cannot 'decentre' in their imagination. According to Piaget they only acquire this skill from the age of eight or nine. (Later research showed that this can happen earlier [13].) With regard to decentration, computer software lends itself perfectly to teaching children to see physical spaces from different points of view. Designers can:
→ Present children with three-dimensional images that they can manipulate with the mouse or with virtual physical spaces through which they can navigate using the mouse, keyboard or other input devices (P07).

For decentration on a more abstract level – for example, imagining what someone else feels or thinks – designers can:
→ Employ narrative-based activities where children must help on-screen characters to solve problems and make decisions that may be influenced by or have consequences for the actions and thoughts of one or more other characters (P08).

According to Piaget, operational children can compare different states of the world and are interested in explaining things. It would therefore be age-appropriate to:
→ Present children with activities that allow them to experiment with changes of state in a way that explains the differences (P09).

## 3.2 Vygotsky: Context, ZPD and Scaffolding

According to Vygostky, material artefacts and social practices form an integral part of cognition [10]. Children's mental development is closely tied to the social context in which they grow up. Vygotsky regarded play as an important part of children's growth and saw children's games and the things they use as toys as the means by which culture is integrated with development [23]. Cognition does not happen only in the mind, but in the interaction between the mind and material artifacts and social practices. Through these cultural elements knowledge is transferred from one generation to the next [10]. His theory is appropriately also referred to as cultural psychology.

Children normally experience computer applications in a context of social exchange, e.g. with peers in a computer laboratory at school, but the context of computer experiences goes beyond the place and time of the specific encounter [26]. The child's previous experiences, the creators of the application and their cultural context, the learning goals associated with the technology and the events leading up to the experience are also ingredients of the broader context of use.

Designers of technology are thus creators of artefacts that may become elements of children's cognition. Context applies at different levels:
→ Designers must know the cultural context of their intended users (V01).
→ They must acknowledge their own context and how that may consciously or subconsciously influence their design practice (V02).
→ They must consider the specific learning or entertainment goals of the product and how these goals fit the context of different kinds of users (V03).

Computer-based tasks for children should always be embedded in scenarios that children can relate to. These scenarios are important elements of the context of use:
→ If a product is aimed at children from a variety of cultures designers may settle on one generic scenario, but it may be difficult to find one that all children can relate to (V04).

Alternatively:
→ In the same way as some applications allow users to pick a language of choice, children may be given a choice of scenarios (V05).

Vygotsky [40] introduced the concept of the *zone of proximal development* (ZPD) which he defined as 'the distance between the actual developmental 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 able peers' (p. 86). Technology can play two different roles in the ZPD: it can act as skilled tutor that helps the novice towards skill development or better understanding, or it can be a

tool that a human expert can use to help the novice. The first view offers quite a challenge to designers.
→ The software should assess children's level of understanding of a concept or their competence in a skill and so determine their ZPD for this specific concept or skill (V06).

Groups of learners or children of the same age do not necessarily have the same ZPD, so technology must be designed in a way to:
→ Determine each user's individual ZPD and then use that knowledge to direct further action (V07).

Learning in the ZPD assumes that some shared knowledge have been established between the learner and the tutor. This shared knowledge will determine the choice of scaffolding. Designers should:
→ Make sure the application and its user share the required common knowledge (V08).

For children to maintain motivation and persistence they must have the opportunity to successfully negotiate learning tasks – if they repeatedly fail at a task they will lose interest:
→ Present children with tasks that they are capable of performing (so that they can get the reward of being successful at those tasks) and provide them with opportunities to practice newly acquired skills (V09).
→ Then give them challenging tasks that are just beyond their reach, providing supportive scaffolding (V10).

This will enable children to move to a next level of understanding or skill [36, 40].

## 3.3 Case: Facilitating Skills Development

Case's theory falls under the broader category of 'Information Processing' theories. These see the mind, metaphorically, as an information processing device that encodes information into symbols in working memory (using information extracted from long-term memory) and transforms it into knowledge [5]. Different internal processes manipulate this information through *recoding* (revising its symbolic structure to make it more effective) and *decoding* (interpreting its meaning using existing knowledge) [25]. These operations prepare the information for use in problem solving and making sense of the world and we can compare them to Piaget's concepts of accommodation and assimilation.

While Piaget regarded logical structures as the basis for cognition, Information Processing theorists and consequently the neo-Piagetians, analysed cognition through a set of information-processing structures [2]. They attributed development to increases in information processing capacity and believed that there is an upper bound to the level of structure that children can construct at any age. This upper bound depends on the size of working memory and the speed with which they can execute basic operations in working memory [6]. Case identified knowledge and control structures that are more specific than Piaget's system-wide logical structures [7]. These structures transpire in the child's mind as categories, event scripts, strategies, rules and plans [19]. This process depends on the context as well as on prior learning history [6]. Case specifically attempted to explain in detail how individual structures are modified and provided a sequence of structural development.

According to Case, a child's cognitive development depends on the structures they have available that relate to their current task or situation, what they can do with that information, and their mind's capacity for information processing. He recognised domain-specific developmental changes that are influenced by the nature of the tasks and children's varying experience [25]. For example, a child who often listens to or tells stories, but never draws will have more advanced conceptual structures in the story domain than in the drawing domain. He further acknowledged the way culture presents children with opportunities for development and how different cultures provide different tools for problem solving [4].

Although the neo-Piagetians place strong emphasis on the variability in the way children learn and develop, they still support the idea of stages of development [5]. In Case's reformulation of Piaget's stages each stage involves a distinct type of cognitive structure. Transition within a stage depends on the growth of working memory and on the learning of more complex executive processes. [4].

When the goal of a computer-based activity is to help a child acquire a new skill, Case's theory suggests that:
→ Designers should

- identify all the underlying operations that a child will use when learning the new skill,
- determine whether the child can perform these operations,
- find out if the child has the mental capacity for the new skill,
- present the child with problems that require the use of two operations independently, and then in succession, and
- present the child with activities that facilitate merging of the two operations into one that forms part of the new skill (C01).

When the child acquires an operation or a skill, designers should:
→ Present opportunities to practice a skill until it becomes automatic (C02).

Once an operation becomes automatic some working memory becomes available for other operations. Since working memory is so important in development, designers should:
→ Strive to relieve children's working memory of extra processing that may prevent them from moving forward with the coordination of knowledge structures (C03). For example, interpreting and navigating the user interface must require as little working memory capacity as possible.

Children in the same age group may have different upper bounds of memory capacity:
→ Support should be adaptable to variation in memory capacity (C04).

According to Case's theory, children younger than six years have conceptual structures that focus on one dimension of a task or situation [2]. When told a story they can only follow a single story line. From around six years of age the central conceptual structures can coordinate two dimensions and they will be able to combine two storylines into one plot. Only from around age nine can they handle multiple dimensions.

→ Children younger than six should be presented with activities that require them to deal with only one dimension of a situation. From six to eight they can be presented with activities that involve two dimensions (but not more) (C05).

Case acknowledged the way culture presents children with opportunities for development and how different cultures provide different tools for problem solving. He attributed variations in children's patterns of development to cultural and sub-cultural differences, specific problems that are typical within that culture, and the models that the culture provides for solving those problems. Designers should acknowledge the culture or sub-culture of the intended user and should:
→ Identify particular problems that are important in that culture and the tools typically used to solve that kind of problem (C06).

For example, presenting a mathematical problem in the context of paying a restaurant bill may be suitable for some cultures, but many children may not have scripts for 'eating in a restaurant'. Whether a child is capable of a particular activity depends on the information processing structures that they have available that relate to that activity:
→ Designers should not assume that if a child can solve a specific kind of problem in one domain that they can transfer that skill to a different domain (C07).

Some children may, for example, make the connection between music timing and mathematical fractions, but others will need explicit instruction about the link before they grasp it.

## 3.4 Fischer: Dynamic Skills Theory

Dynamic skills development integrates the results of many different theoretical viewpoints into a theory of nonlinear development [19]. It combines three ideas that were previously regarded as irreconcilable or contradictory, namely

- independent skills development in different domains,
- similarity of development across domains, and
- a universal framework or scale for cognitive development.

The basic units of analysis in this theory are skills [17]. Fischer acknowledges that many of the classic principles of cognitive science and hence, cognitive skill development, are applicable across a range of knowledge domains. He does, however, not support the idea of a single, overarching mental structure, saying that 'development and learning occur along many parallel, independent strands that have similar properties even though they are from separate cognitive structures' [19].

In a typical task children use different skills and to succeed they need to differentiate and coordinate these co-occurring competences [19]. The process of coordination and differentiation, which is influenced by the social and emotional context, may lead to the formation of new skills so that next time the task will be easier to perform. It may take several attempts at the task before a child acquires the new skill and sometimes this will only be possible with assistance. Coordination and differentiation can also occur between skills from different task domains. For example, storytelling involves skills of pretending or imagining, verbalising and ordering of ideas. Through constructive generalisation and repeated rebuilding, a skill that begins as task or context-specific can gradually be extended to other contexts [19].

In contrast to earlier views of development as a ladder of stages that go across domains, dynamic skills theory describes development as a web of strands which represent skills in different domains [17-19]. A strand forks when one skill splits into two independent skills and two strands come together when two skills combine to form a single more general skill. In the web there will be separate but parallel strands for the same skill in two different domains, and these can at some point in development merge to form one skill across both domains. A skill does not develop synchronously in all the domains where it is pertinent, but the sequence of milestones for acquiring a specific skill is fixed within a domain. Every person's web of development is unique. The web metaphor also reflects the fact the people act on multiple dimensions at the same time and different aspects of development may occur concurrently along different trails [19]. Two or more children can collaborate in the construction of their webs [17].

Following dynamic skills theory, designers would ideally:
→ Support independent development of skills in different domains, while at the same time considering how a skill is applicable across domains (F01).

For example, when children have accomplished simple division problems in a scenario where they have to help a character share a specific number of biscuits fairly with a number of friends, a program can present similar problems in a purely mathematical context. To help them generalise the division skill the program should then make the link between the two contexts explicit.

→ A task or activity chosen to develop a specific skill should be one that can be naturally associated with that skill (F02)

Dynamic skills theory regards skills as task specific, context-specific, dependent on emotion, culture, experience and biological maturation [17]. We use a product called *TimezAttack* [3] to illustrate how this relates to children's use of technology. In this discussion we refer to the skill of using the software rather than the multiplication skills the software supports. *TimezAttack* requires users to navigate a character through rooms and passages in search of keys to open doors. This requires some level of *experience* with the mouse and keyboard. A 'key' has the form of a multiplication sum. When a key is found, the program takes the child through a sequence of events that helps to systematically build up the answer to the sum (children can only do this if they have *experience* with basic addition up to the number 12). Typing the correct answer opens the door. Now they are confronted with an ogre that requires them to answer the multiplication sum just encountered again (and maybe some that were done earlier). Only when the ogre is satisfied that the child knows the answers does he let him/her through to go search for the next key. Although the little alien searching for keys and the ogres are *culturally* neutral, children who have had exposure to computer games will relate to the application easier than those who haven't. Navigation requires well-developed hand-eye coordination and the ability to use the mouse and keyboard simultaneously (so, it assumes a specific level of *biological maturation*). The game has an *emotional* effect on children as the user is embodied as the alien searching for keys. Excitement is high when a key is found and some degree of anxiety is unavoidable when the child has to give the answers. Highly excitable children may find it more difficult to provide the answers in the given time than those who can keep their cool.

From this example it is clear that designers should:
→ Carefully consider the role of culture, experience, emotion and biological maturation in the skills they require or want to develop (F03).

→ Investigate how different cultural groups use or teach the skills that the product will support (when a product is aimed at children from different cultural groups) (F04).
→ Know the minimum requirements of the intended product with regard to biological maturation (F05). Children should not be expected to perform actions that they are physically not yet capable of.

With regard to task and context-specificity, this program teaches multiplication tables in the context of a 'conquer-the-ogres' game:
→ Designers should not assume that children will transfer the skill to the real-life or school education context and need to make the connection explicit (F06).

A child's emotional state influences his or her skill acquisition.
→ A designer does not have control over factors outside the game environment that may influence the child's emotional state, but can use game elements to evoke emotions that may enhance skill development (F07).

In a typical task children may use a variety of skills which must be differentiated and coordinated [17]:
→ Designers should identify all the skills involved and support differentiation and integration of these skills in their design (F08).

Using *TimezAttack* as an example again, the following skills are at play: using the mouse, typing on the keyboard, following the stepwise building up of the answer, locating and typing the correct number keys fast enough, doing the calculations presented by the ogres and memorizing the answers. Some of these skills are from the same task domain and some are from different task domains, but they have to be coordinated in order to reach the goal.

Designers should:
→ Know the sequence through which the skills to be addressed develop (F09).

Being informed of these sequences will be of great value, helping designers to model all the domains, skills and tasks that are relevant to their product in one or more constructive webs that can then be used as a starting point for the design.

Although most of our examples relate to mathematics skills, the guidelines identified apply to technology that supports all cognitive skill areas.

# 4. DISCUSSION: ORGANISATION OF THE DERIVED GUIDELINES

Our investigation of four theories yielded thirty five guidelines for the design of technology for young children. Because of their origin, all of these belong to an overarching category, namely 'guidelines that support cognitive skill development'. A refined categorisation scheme will, however, assist designers in their application of the guidelines. A process of analysing, integrating and grouping of the emerging guidelines led to the identification of six appropriate categories, namely:

1. General skill development guidelines.
2. Specific skill development guidelines.
3. Guidelines that support age-appropriateness.
4. Guidelines relating to user support.
5. Culture, context and prior experience.
6. Guidelines that support engagement.

The majority of the emerging guidelines belong in the first and second of these categories. This is not surprising as these correspond to the overarching category mentioned above. The fifth category is also well represented. This can be explained by the emphasis Vygotsky, Case and Fischer place on the role of the social and cultural context as well as prior experience on development.

Table 1 organises the emerging guidelines into the six categories.

**Table 1. The guidelines organised into six categories**

| **1. Guidelines relating to general skill development** | |
|---|---|
| 1a | Be well informed of all the knowledge schemes that underlie every activity to be included in a system (P01). |
| 1b | Identify all the skills involved in performing the activities and support differentiation and integration of these skills in the design (F08). |
| 1c | Know the development sequence of the skills to be addressed (F09). |
| 1d | Make it possible for the child to:<br>• fit the information presented into existing schemes (assimilation),<br>• adapt existing schemes to incorporate new information (accommodation), or<br>• combine existing schemes to form more complex schemes (organisation) (P02). |
| 1e | Designers should:<br>• identify all the underlying operations that a child will use when learning the new skill,<br>• determine whether the child can perform these operations,<br>• find out if the child has the mental capacity for the new skill,<br>• present the child with problems that require the use of two operations independently, and then in succession, and<br>• present the child with activities that facilitate merging of the two operations into one that forms part of the new skill (C01). |
| 1f | Relieve children's working memory of extra processing that may prevent them from moving forward with the coordination of knowledge structures (C03). |
| 1g | Support independent development of skills in different domains, while at the same time, considering how a skill is applicable across domains (F01). |
| 1h | Do not assume that if a child can solve a specific kind of problem in one domain or context that they can transfer that skill to a different domain or context (C07, F06). |
| 1i | A task or activity chosen to develop a specific skill should be one that can be naturally associated with that skill (F02). |
| 1j | Give them the opportunity to practice a newly acquired skill until it becomes automatic (V09, C02). |
| 1k | Use game elements to evoke emotions that may enhance skill development (F07). |

| | |
|---|---|
| **2. Guidelines relating to development of specific skills** | |
| 2a | Include activities that require children to mentally reverse actions such as combining, ordering, separating and recombining of elements (P04, P06). |
| 2b | To teach them about different points of view, present children with three-dimensional images that they can manipulate with the mouse or with virtual physical spaces through which they can navigate (P07). |
| 2c | To develop abstract decentration skills, use narrative-based activities where children must help on-screen characters to solve problems and make decisions that may be influenced by or have consequences for the actions and thoughts of other characters (P08). |
| 2d | Present children with activities that allow them to experiment with changes of state in a way that explains the differences (P09). |
| **3. Guidelines that support age-appropriateness** | |
| 3a | Technology aimed at five to eight-year-olds may use symbols and images to represent real-life situations (P03). |
| 3b | Software aimed at younger pre-operational children should allow users to physically move objects, e.g. by dragging them with the mouse (P05). |
| 3c | Children younger than six should be presented with activities that require them to deal with only one dimension of a situation. From six to eight they can be presented with activities that involve two dimensions (but not more) (C05). |
| 3d | Identify the minimum requirements of the product with regard to biological maturation and make sure the intended user group will be physically capable of performing the required actions (F05). |
| **4. Guidelines relating to user support** | |
| 4a | The system should ideally assess children's level of understanding of a concept or their competence in a skill and so determine their ZPD for the specific concept or skill involved (V06). |
| 4b | When a user's individual ZPD has been determined, use that knowledge to direct further action (V07). |
| 4c | Support should be adaptable to variation in memory capacity (C04). |
| **5. Guidelines relating to culture, context and experience** | |
| 5a | Know the cultural context of the intended users (V01). |
| 5b | Carefully consider the role of culture, experience, emotion and biological maturation in the skills required or to be developed (F03). |
| 5c | Acknowledge the context from which the design is done and how that may consciously or subconsciously influence design practice (V02). |
| 5d | Consider the specific learning or entertainment goals of the product and how these goals fit the context of different kinds of users (V03). |
| 5e | If a product is aimed at children from a variety of cultures or backgrounds designers may settle on one generic scenario, but it may be difficult to find one that all children can relate to (V04). |
| 5f | In the same way as some applications allow users to pick a language of choice, children may be given a choice of scenarios (V05). |
| 5g | Make sure the application and its user share the required common knowledge (V08). |
| 5h | Identify particular problems that are important in the culture of the target audience and the tools they typically use to solve that kind of problem (C06). |
| 5i | Investigate how different cultural groups use or teach the skills that the product will support (when a product is aimed at children from different cultural groups) (F04). |
| **6. Guidelines that support engagement.** | |
| 6a | Present children with tasks that they are capable of performing (so that they can get the reward of being successful at those tasks) and provide them with opportunities to practice newly acquired skills (V09). |
| 6b | Then give them challenging tasks that are just beyond their reach, providing supportive scaffolding (V10). |

With the framework presented above we have reached our aim of demonstrating that psychological theory can be translated into guidelines for the design or evaluation of technology through a systematic study of respected theories of cognitive development.

# 5. APPLICATION OF THE GUIDELINES

To demonstrate how the guidelines presented here can be used in practice we briefly consider *TimezAttack* again (see section 3.4), weighing it up against a subset of the guidelines. This application teaches children aged seven and older the multiplication tables. In Table 2 we take a subset of the proposed guidelines and briefly evaluate *TimezAttack* according to those guidelines (without repeating the guidelines). The scope of this paper and space limitations do not allow a more comprehensive evaluation.

**Table 2. Application of the proposed guidelines**

| | |
|---|---|
| **1. Guidelines relating to general skill development** | |
| 1a | Children must have mastered addition of numbers (where the sum is up to three digits) before they can start performing the activities. |
| 1b | Besides the obvious mathematics skills (e.g. addition) there are also the skills of navigating through the space, hand-eye coordination and relating the mouse and keyboard actions to the movement of the characters on the screen. |
| 1c | After they have mastered the required addition skills, children can learn the multiplications tables starting at times-2 and working towards times-12. *TimezAttack* takes them through this sequence requiring them to master one level before moving onto a next. |
| 1e | *TimezAttack* first presents the child with the process of building up the answer to the multiplication sum using addition and then links this to the multiplication operation. With practice the child finds the addition part easy and can eventually do the multiplication without using the addition operation. |
| 1f | Initially the interface is overwhelming and navigation and interaction requires a lot of working memory capacity. This can be solved by initially providing children with a session that allows them to practice the required navigation and interaction activities without the mathematical context. |

| | |
|---|---|
| 1h | A problem with *TimezAttack* is that it does not relate the skills learnt in the game context to real life or school mathematics. We have observed a child who became dependent on the game context to do the multiplication tables. She actually drew pictures resembling the interface when practicing her tables. |
| 1j | *TimezAttack* gives children ample opportunity to practice the multiplication skills at each level. |
| 1k | TimezAttack provides an exciting environment in which to develop a skill that children do not generally find exciting. The 3-D games environment with the dangers of being captured by an ogre or falling into hot boiling lava evoke highly pleasurable emotions which help keep children motivated to master the tables. |
| **2. Guidelines relating to development of specific skills** | |
| 2a | When presenting a sum, *TimezAttack* produces creatures containing the numbers required to do the calculation. Children have to catch the creatures with the mouse thereby building up the answer (e.g. for 2 x 3 they need to catch two creatures carrying a 3 each). Then they have to throw these 3s back at the ogre to build up the answer before they can type it. |
| 2b | *TimezAttack* is completely set in a 3D environment through which children must navigate. |
| 2c | The children are constantly helping the alien to keep the ogres happy. |
| **3. Guidelines that support age-appropriateness** | |
| 3c | *TimezAttack* is not really appropriate for children younger than nine as it requires users to deal with more than two aspects of a situation at the same time. They have to simultaneously keep track of where they are in the game, how to solve the specific mathematics problems presented and navigating with the mouse and keyboard. |
| 3d | *TimezAttack* requires well-developed hand-eye coordination. Children must be able to use the mouse and keyboard for different purposes simultaneously and they must be able to type the answers on the number pad of the keyboard. More reason to believe that it is not age-appropriate for children aged seven and eight. |
| **4. Guidelines relating to user support** | |
| 4a | *TimezAttack* is extremely good at assessing children's level of skill. It provides several 'tests' along the way and repeatedly sends a child back to master those tables that they struggle with. It does this carefully and in a way that helps to keep the child motivated. |
| 4b | See previous point. |
| **5. Guidelines relating to culture, context and experience** | |
| 5a | All the characters are culturally neutral, although the product uses some English when building up the answers to the sums. |
| 5b | We have already discussed biological maturation in 3d above. Children who had no exposure to computer games that require extensive navigation through screen-based spaces will take longer to learn to use the interface. Children that easily become anxious, may not be able to cope with the pressure placed on them to complete the activities in the given time. |
| 5c | The game was created by a US company who normally creates arcade games. They may therefore have made assumptions about children's abilities to use this kind of game and therefore neglected to include a familiarisation or practice module. |
| 5d | The 'conquer the ogres' context is extremely suitable for the target age group. In our observations we have found boys and girls to enjoy it equally. One can assume that children who will use this product will have had exposure to television programmes with similar characters. The main concern is the level of competence required in using the interface and the input devices. |
| 5e | Although this was not formally researched we have casually observed that the scenario used in *TimezAttack* appeals to children from different cultural groups. |
| 5g | It is left up to the parents or teachers who provide children with this product to determine whether the child has the common knowledge that is assumed. |
| 5i | Designers should investigate how multiplication tables are taught to children in different countries or cultures. |
| **6. Guidelines that support engagement.** | |
| 6a | With regard to the mathematical context *TimezAttack* starts at an easy level and gradually works towards the more advanced skill levels. With regard to interaction, children are however required to have the same level of competency right from the beginning. This may cause frustration. |
| 6b | Children are constantly presented with problems at the next level and sufficient scaffolding is provided. |

The concise evaluation report presented in Table 2 demonstrates that systematically weighing up an application against the guidelines will elicit strong and weak points. This demonstration confirms the practical contribution of our research by showing that the proposed framework of guidelines for the design and evaluation of technology for children aged five to eight provides designers with the means to evaluate the developmental appropriateness of an existing application (or a prototype of a new product) aimed at young children.

# 6. CONCLUSION

Designers should not rely on their intuition or memories of their own childhood when designing for children. They cannot merely interview some children, ask them about their preferences, give them questionnaires to fill out and come up with a profile of the intended user. Cooperative design with young children, like research with young children, is a specialised skill that requires training and experience.

This paper showed that designers can gain knowledge about children from experts such as developmental psychologists. Immersing ourselves in the work of four authorities, we discovered various guidelines for the design of technology for young children and here presented our results. Our contribution is twofold: firstly we demonstrated the process of developing guidelines from existing theory and research and, secondly, we presented a useful framework of guidelines grounded in psychological theory of development.

## 7. REFERENCES

[1] Baumgarten, M.: Kids and the Internet: A Developmental Summary. *ACM Computers in Entertainment*. 1(1) (2003), Article 2.

[2] Berk, L.E.: *Child Development*. 5 ed. Allyn and Bacon, Boston, (2000).

[3] BigBrainz: *TimezAttack*. 2005, BigBrainz, Inc.

[4] Case, R., *Advantages and Limitations of the Neo-Piagetian Position*. In: R. Case, (eds.): The Mind's Staircase. Lawrence Erlbaum Associates, Publishers, 1992, 37-51.

[5] Case, R., *General and Specific Views of the Mind, its Structure, and its Development*. In: R. Case, (eds.): The Mind's Staircase. Lawrence Erlbaum Associates, Publishers, 1992, 3-16.

[6] Case, R.: *The Mind's Staircase*. Lawrence Earlbaum Associated Publishers, (1992).

[7] Case, R.,Okamoto, Y.: *The Role of Central Conceptual Structures in the Development of Children's Thought*. Monographs of the Society for Research in Child Development. Vol. 61. University of Chicago Press, Chicago, (1996).

[8] Clements, D.H.: Computers and Young Children: A Review of Research. *Young Children*. 43 (1987), 34-44.

[9] Clements, D.H.: Computers in Early Childhood Mathematics. *Contemporary Issues in Early Childhood*. 3(2) (2002), 160-181.

[10] Crook, C., *Cultural Artefacts in Social Development: The Case of Computers*. In: H. McGurk, (eds.): Childhood Social Development: Contemporary Perspectives. Lawrence Earlbaum Associates, 1992, 207-231.

[11] Dix, A., Finlay, J., Abowd, G., Beal, R.: *Human-Computer Interaction*. Third edition ed. Pearson Education Ltd, (2004).

[12] Dix, A., Finlay, J., Abowd, G., Beale, R.: *Human-Computer Interaction*. Third ed. Pearson Education Ltd., (2004).

[13] Donaldson, M.: *Children's Minds*. Fontana, London, (1978).

[14] Druin, A., *CHIKids: A Common Ground for Kids and Adults*. In: M.J. Tauber, (eds.): Common Ground: CHI 96 Conference Proceedings. ACM, 1996, 506-507.

[15] Druin, A.,Solomon, C.: *Designing multimedia environments for children*. First ed. John Wiley & Sons, Inc, (1996).

[16] Durrheim, K., *Research Design*. In: M. TerreBlanche and K. Durrheim, (eds.): Research in Practice: Applied Methods for the Social Sciences. UCT Press, Cape Town, 1999, 29 - 53.

[17] Fischer, K.,Bidell, T.R., *Dynamic Development of Action and Thought*. In: R.M. Lerner, (eds.): Theoretical Models of Human Development. John Wiley & Sons, Inc, 2006, 313-399.

[18] Fischer, K.,Yan, Z., *The Development of Dynamic Skill Theory*. In: D.J. Lewkowicz and R. Lickliter, (eds.): Conceptions of Development: Lessons from the Laboratory. Psychology Press, 2002, 279-312.

[19] Fischer, K.W.,Immordino-Yang, M.H.: *Cognitive Development and Education: From Dynamic General Structure to Specifc Learning and Teaching*. 2002, Harvard Graduate School of Education, 1-55.

[20] Fishel, C.: *Designing for Children*. Rockport Publishers, Inc., (2001).

[21] Gardner, H.: *The Unschooled Mind: How Children Think and How Schools Should Teach*. 1 ed. BasicBooks (A division of HarperCollins publishers), (1991).

[22] Haugland, S.W.,Wright, J.: *Young Children and Technology: a World of Discovery*, New York, (1997).

[23] John-Steiner, V.,Souberman, E., *Afterword*. In: L.S. Vygostsky, (eds.): Mind in Society. Harvard University Press, 1978, 121-133.

[24] Malone, T.W.: Guidelines for Designing Educational Computer Programs. *Childhood Education*. 59 (1982), 241-247.

[25] Meece, J.L.: *Child and Adolescent Development for Educators*. 2 ed. McGraw-Hill, Boston, (2002).

[26] Mercer, N.,Fisher, E., *The Importance of Talk*. In: R. Wegerif and P. Scrimshaw, (eds.): Computers and Talk in the Primary Classroom. Multilingual Matters Ltd, 1997, 13-21.

[27] Miles, M.B.,Huberman, A.M.: *Qualitative Data Analysis*. 2 ed. SAGE Publications, (1994).

[28] NAEYC: *NAEYC Position Statement: Technology and Young Children - Ages 3 through 8*. [Web document] (1996) [cited 2004 17 February 2004]; Available from: http://www.naeyc.org/resources/position_statements/pstech98.htm.

[29] Nielsen, J.: *Ten Usability Heuristics*. (2001) [cited 16 January 2005]; Available from: www.useit.com/papers/heuristic.

[30] Piaget, J.: *The Origins of Intelligence in the Child*. Routledge and Kegan Paul, London, (1953).

[31] Pine, K., *Theories of Cognitive Development*. In: D. Messar and S. Millar, (eds.): Exploring Developmental Psychology: From Infancy to Adolescence. Arnold, 1999, 107-127.

[32] Plowman, L.,Luckin, R.: Interactivity, Interface, and Smart Toys. *IEEE Computer*. February(February) (2004), 98-100.

[33] Preece, J., Rogers, Y., Sharp, H.: *Interaction Design: Beyond Human-computer Interaction*. John Wiley & Sons, Inc., New York, (2002).

[34] Preece, J., Rogers, Y., Sharp, H.: *Interaction Design: Beyond Human-Computer Interaction*. 2nd ed. John Wiley & Sons, Inc, (2007).

[35] Roschelle, J.M., Pea, R.D., Hoadley, C.M., Gordin, D.N.: Changing How and What Children Learn in School with Computer-Based Technology. *The Future of Children*. 10(2) (2000), 76-100.

[36] Scaife, M.,Rogers, Y.: Informing the Design of a Virtual Environment to Support Learning in Children. *International Journal of Human-Computer Studies*. 55 (2001), 115-143.

[37] Shneiderman, B.: *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. 3 ed. Addison-Wesley, New York, (1998).

[38] Siegler, R.: Three Aspects of Cognitive Development. *Cognitive Psychology*. 8 (1976), 481-520.

[39] TerreBlanche, M.,Durrheim, K., *Histories of the present: Social science research in context*. In: M. TerreBlanche and K. Durrheim, (eds.): Research in Practice: Applied Methods for the Social Sciences. UCT Press, Cape Town, 1999, 1 - 16.

[40] Vygotsky, L.: *Mind in Society: The Development of Higher Psychological Processes*. Harvard University Press, Cambridge, Mass, (1978).

[41] Wyeth, P.,Purchase, H.C.: Using Developmental Theories to Inform the Design of Technology for Children. In *Interaction Design and Children*. 2003. University of Central Lancashire, Preston, UK: ACM Digital Library.