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The general design methodology applied to the research domain of physical programming for computer illiterates

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Abstract

Here we discuss the application of the 'general design methodology' in the context of a physical computing project. The aim of the project was to design and develop physical objects that could serve as metaphors for computer programming elements. These physical objects would then be used by computer illiterates to construct the logic of a computer program.

Keywords

Computer illiterates, GameBlocks, iterative design, physical computing

Introduction

Our overall research interest is the development of mechanisms that will make it possible for people in developing regions to construct simple computer programs. We distilled this as being the challenge of enabling computer illiterates to program a computer without using a keyboard or mouse. If realised, such mechanisms will "push the computer into the background" (Weiser, 1991:66 - 75) and allow the computer illiterate user to participate in the Information Age. After all, "normal users are actually not very interested in interacting with computers" (Streitz, 2008:55-60). In order to meet this challenge we initiated a project called GameBlocks and applied the 'classical' iterative design methodology (Bailey, 1993:198-205).

In this paper we report our observation on three iterations of the 'classical' design methodology as it was applied to the GameBlocks project. We limit our discussion to the design considerations of the GameBlocks physical user interface. Other design considerations such as the technical mechanisms that determine the interaction between the physical user interface and the computer are not considered here.

Section 2 presents background by briefly describing the GameBlocks project and what 'design' is. Section 3 gives an overview of the system on which this paper reports. Section 4 describes the evaluation of the three design iterations. Section 5 discusses the four dimensions along which the design changed as the project progressed. Section 6 concludes.

Background

The aim of the GameBlocks project was to develop a system that empowers computer illiterates to 'construct' elementary computer programs. In this context, the envisaged system substitutes the computer keyboard, screen, and mouse as the programming mechanism with an arrangement of physical objects called GameBlocks. In such a system the user defines the logic that constitutes the program by arranging the GameBlocks objects in a particular order. Our research interest lay in the development of the physical objects that would serve this purpose whilst considering that the intended target user group are anonymous computer illiterates in a developing region. How the physical objects are used to define the program logic is not covered in this paper; for this the interested reader is referred to Smith (2007:147-150).

What is design?

Adjusting a concept repeatedly to better suit its intended purpose requires both creativity and innovation. Nelson and Stolterman (2002) calls this activity "design". According to Nelson, design is not simply being creative, but includes the innovation component which requires “reflective thinking, productive action and responsible follow through.” Design often involves an incremental process of development, testing and improvement. According to Salen and Zimmerman (2004) the iterative design research methodology is based on a cyclic process that involves the creation of a prototype which is tested, analyzed and then refined. Design research can take many forms and Salen and Zimmerman view iterative design as a method whereby research is integrated into the actual process of creating a new artefact. They promote the idea of being open to ideas and insights from the outside world and integrate these into the design process.

A distinction should also be made between the activities called design, and design research. According to Vaishnavi and Kuechler (2004) the design process is embarked on with a clear vision of the required artefact that should be the result of the design and implementation activities. Design research, in contrast, is initiated with an awareness of what is required to solve a given problem, but the solution is not known at this time. Rather the solution is suggested, then implemented, and ultimately evaluated. This constitutes one cycle of the design research process. The design research cycle makes provision for an initial implementation which does not solve the problem in a satisfactory way.

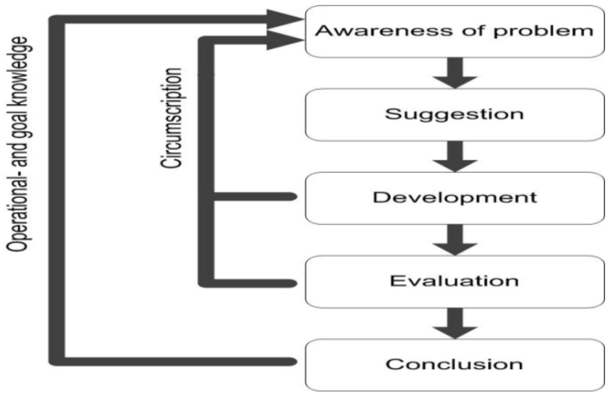
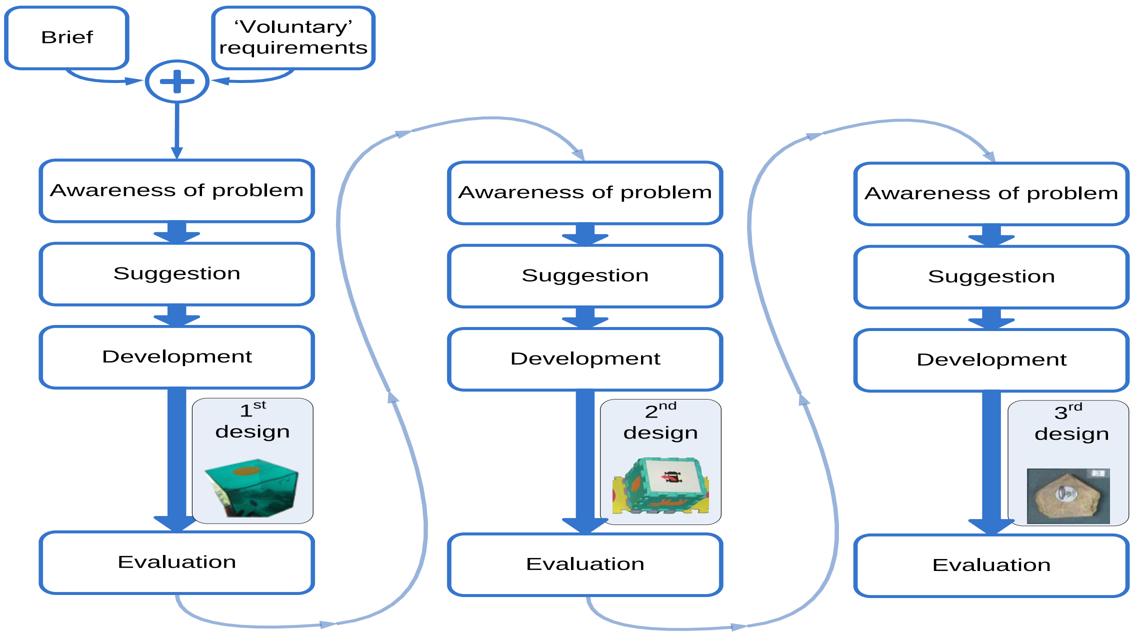


Figure 1. The general methodology for all design research (Vaishnavi and Kuechler, 2004) (based on (Takeda et al., 1990:37-48))

Vaishnavi and Kuechler (2004) base their design research discussion on “the general methodology for all design research” (Figure 1), as originally conceptualised by Takeda et al. (1990:37-48). According to Vaishnavi and Kuechler’s discussion, additional insight into the problem to be solved is gained once the artefact has been created. At the same time an awareness emerges amidst the designers that predictions are inaccurate, and that the theory on which the design is based is incomplete. This additional insight is attributed to the creation of the artefact. Information thus gained from the evaluation is used to improve the next iteration of the design. The flow of the design iteration, from the development or evaluation step to the awareness of problem step, is called circumscription. Figure 2 shows the general design research methodology applied in context of the GameBlocks project.

Figure 2: The general design research methodology in the GameBlocks project context.



Methodology

Research methodologies that have humans as the object generally require that the target group be known and studied. However, in this research project a detailed target group was not defined because we were interested in the evolution of a system which would loosely address the project brief, as opposed to treating the GameBlocks as an engineering project. We anticipated that the research project's solution space would be limited by a well characterised (detailed) target group and made the decision not to define the target group tightly. Therefore, at the onset of the project the target group was broadly defined as consisting of school going children situated in South Africa.

The given brief for the GameBlocks research project was to conceptualise and implement a programming environment that will enable computer illiterates to compose simple programs. Evaluations were conducted with anonymous school-going children over a period of three years at independent annual science festivals hosted in Pretoria and Grahamstown. In addition, evaluations were conducted with children from Montessori Kindergartens at one site in the eastern suburbs of Pretoria and another site in the Johannesburg region.

Our knowledge of the evaluation groups was limited; the anticipated age range was that of pre- and school-going children in South Africa and being of mixed gender. Access to the evaluation groups was in general not possible during the suggestion and development phases due to the geographical distance between the engineer (one of the authors) and the target groups.

The engineer was tasked to design, develop, and evaluate the GameBlocks system. From an engineer's perspective the primary design concern of an interface is that of functionality and not usability. This perspective had a significant influence on the design result of the initial iteration. What follows are a description of the major design results of the three iterations.

System overview

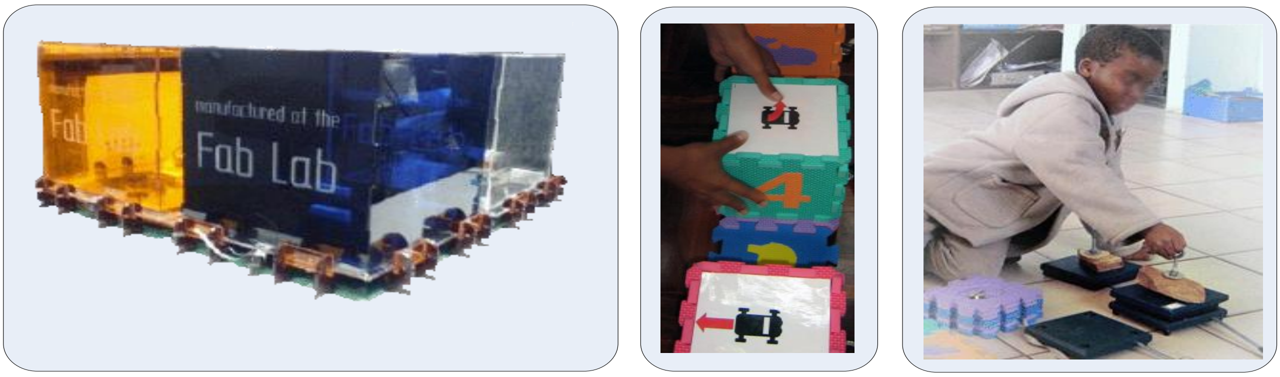
The following is an overview of the three GameBlocks design iterations.

- The first design (Figure 3, left) consists of acrylic cubes of various colours (Smith, 2007:147-150).

- The second design (Figure 3, centre) also consists of cubes, but incorporates smaller foam sides instead of hard and brittle acrylic panels.
- The third design (Figure 3, right) is significantly different from the first two; it functions primarily in two dimensions whereas the first two could intuitively be rotated in three dimensions (Smith, 2008:157-160).

The next section describes the results of each design iteration in greater detail.

Figure 3: The results of three design iterations.



Evaluations

Design 1

An engineer formulated the first design, and implemented it, by using the project brief and experiential engineering knowledge. Engineering materials and an engineering design approach was evident in the artefacts that resulted (Figure 3, left). It appears as if little or no consideration was given to the intended users. Evidence to support this conclusion can be found in the use of hard acrylic surfaces which are 'lifeless' to the human touch. This material constituted the surfaces which the user came into contact with. The sharp corners which can be found in the first design also demonstrate the lack of consideration for the user.

Design 2

User evaluation outcomes of the first design informed the second design iteration. As a result the second design substituted the acrylic surfaces with soft and colourful closed-cell foam panels (Figure 3, center). Sharp corners were consequently replaced by soft and rounded corners. In general, this design was quite well suited for the intended purpose. However, a problem emerged when the user tried to place the objects in a sequence. The problem was to accurately align the object with a mat that contained sensors. A slight misalignment between the object and the mat would render that object ineffective as it would not be sensed.

Design 3

As for the previous two design iterations, outcomes from the Design 2 user evaluation influenced Design 3. However, the 3rd design (Figure 3, right) differs significantly from the first two.

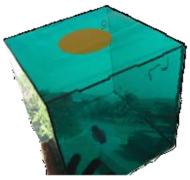
The result of the third design iteration is an artefact that is likely to be better (if compared to the first two) suited for introducing computer illiterates in developing regions to computer programming. This is because some of the complexities have been removed from the previous two designs. These complexities are two-fold:

- In the first two designs, the artefact had to be rotated along three axes to identify and select one spatial orientation from the 64 that are possible. This added an additional mental burden to a user who is probably already confused by the abstract concept of programming. This complexity has been removed in the 3rd design where the number of axes is limited to one, and the number of spatial orientations has been reduced to four.
- The materials used in the 1st and 2nd designs were not indigenous to the area where the targeted computer illiterates are located. Rather, the materials used in the third design are natural and can easily be obtained and shaped by the target group using simple tools at almost no cost. A second complexity has thus been removed.

Summary of the design iterations

Five significant design dimensions were changed in the transition from the first two to the third iteration. These dimensions are described in this subsection and Table 1. Table 1 summarises the important design dimensions of each design. What we consider to be positive and negative aspects of each design are respectively indicated by a tick (√), and cross (×) in Table 1.

Table 1: Selected dimensions of the three designs.

	Design iteration		
Dimension ▼	1st design 	2nd design 	3rd design 
Design methodology	'general methodology for all design research'		
Functional Shape	Cubic		Flat
Number of possible spatial orientations	4 x 4 x 4 = 64		Four

Spatial manipulation	Rotation around three orthogonal axes.		Rotation around a single axis.
Material	√ Transparent sheets make contents visible. × Artificial. × Brittle, hard to the touch. × Sharp corners.	√ Soft to the touch and colourful foam. × Artificial. × Obscures the contents.	√ Natural soft rock. × Obscures the contents.
Construction	× Can be disassembled and re-assembled for storage/transportation, but with difficulty. × Factory product.	√ Simple to disassemble and reassemble for storage/transportation. × Factory product.	√ User can shape it by using simple hand tools.
Symbology	× Not intuitive, has to be learned.	√ Simple to understand.	√ Simple to understand.

By removing complexities in the design that a computer illiterate user might experience, it becomes more likely that the goal of the GameBlocks project could be realised.

Discussion

In this section we discuss four dimensions along which the GameBlocks design changed during the design iterations.

Functional shape

The first change dimension we consider is the functional shape of the design. Whereas it is immediately clear to an observer that the first two designs can be manipulated in three dimensions, the third design can clearly only be manipulated in two dimensions. Removing one manipulation dimension from the object simplifies its use, albeit making it less flexible in its application. The affordance (Norman, 1988) offered by a simplified object is immediately clear to the user; consider for example a spoon, knife, and fork as three distinct items. Contrast this with a complicated object such as the Spork (Feancis, 1874) which integrates these three items. It is not immediately obvious to the novice user how to use this multi-purpose device. The same principle holds for programming environments; when introducing a novice programmer to a new programming language it is best to hide the complexities of the language until the initial concepts have been mastered. Therefore, limiting the affordance of an object to two dimensions has its benefits when designing a physical interface for computer illiterates.

Number of spatial orientations

The second change dimension is the number of spatial orientations that are, to the user, obviously possible when manipulating the physical object. The first two designs can be oriented along three axes, resulting in a total of 64 potential spatial orientations. In contrast, the third iteration limits the obvious spatial orientations to four. As described immediately above, limiting the number of options made available to a novice has its benefits. The cognitive burden placed on the user is now appropriate for a novice.

Number of axes

The third change dimension, which relates to the previous one, is the number of axes around which the object can be rotated. Rotation in the third design is limited to a single axis, as opposed to three axes in the first two designs. This limitation aids the novice user in mastering the programming system.

Material

The fourth change dimension is the material used for implementing the design. The first two designs utilised artificial materials, typically imported from developed countries. In contrast, the third design implementation used natural materials (soft rock), commonly found in developing regions. To elaborate, the soft rock used in the GameBlocks project was salvaged at no cost along a local suburban road. This dimension has probably had the greatest impact on the GameBlocks project. The reason for this is described next.

The soft rock used in the third design stands in stark contrast to the artificial materials used in the first two design iterations. Hand tools can now be applied to the soft rock to shape and form it according to the user's preference. It may indeed be argued that it is preferable to present the unfinished product to the user. This will afford the user an opportunity to customise it by chipping and filing the soft rock. This process of semiogenesis (Boradkar, 2010) distinguishes the resulting object from all others, even if they perform the same function. We anticipate that the user/crafter will take personal ownership of, and will have pride in the finished object which now contains intrinsic emotional value (Nam and Kim, 2011:85-98).

Conclusion

From the given brief, the engineer envisaged a system with which a computer illiterate person can use physical objects to define the logic of a computer program.

The 'general' design methodology was applied as follows: As per the general methodology of design research (Vaishnavi and Kuechler, 2004), the brief is used as the initial design start point. As is often the case, the designer adds additional requirements to this brief, thereby refining the brief to incorporate the designer's own understanding of the objective which the brief wishes to address. The first design is then produced.

The general design research methodology (Vaishnavi and Kuechler, 2004) guides the subsequent activities through a number of evaluations and adapted design iterations, where the adapted design uses results from the previous evaluations to adjust the design.

In this paper we have shown how the general design research methodology was applied with the objective of creating a tangible programming environment aimed at computer illiterates in a developing region. The result of three design iterations were given and discussed. The fourth design iteration differed significantly from the first two along four dimensions which can be described as the three-dimensionality, and the tactile properties, of the resultant artefacts.

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The challenges of pedagogical design and implementation of web-based collaborative learning: A case study at Cape Peninsula university of Technology

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