A New Environment for Computer Aided Design:
Combining Constructionist ideas and Augmented Reality technology to create a concrete learning environment for digital content

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Abstract

According to Piaget (1970) most adults operate in what he termed the ‘formal operations’ stage, where our cognitive ability allows us to make logical sense of and manipulate symbolic terms internally, independent of immediate experience. Papert (1980) later elevated the role of concrete experiences, believing that for some people certain abstract thinking needs to be grounded in more concrete contexts. This paper looks at the learning environment in which computers play a primary role, Computer Aided Design (CAD) being the example investigated, and asks the questions; is this learning environment at present too static, and is there substance in the argument for altering the current computer-user interface to provide a more active, interactive and concrete learning experience?

As a response to the research enquiry the ARC learning experience was designed, which allows users to view a virtual representation of their 3D CAD model within a real-environment setting. A concrete learning experience is created as the digital CAD model becomes more tangible and real-time interaction between user and design is achieved. The virtual prototype can be viewed in relation to real objects and people, giving a more solid basis on which to make design decisions e.g. related to size, scale and proportions. A case study was conducted where a multiple source method of data collection was employed. The analysis from the research showed findings that support the research enquiry.

Keywords

Technology, Constructionism, Abstract/Concrete Thinking, Active Learning, Digital Learning Environment, Interactive Digital Content, Tangible User Interfaces, Augmented Reality.

1. Introduction

"We live in a complex world, filled with myriad objects, tools, toys, and people. Our lives are spent in diverse interaction with this environment. Yet, for the most part, our computing takes place sitting in front of, and staring at, a single glowing screen attached to an array of buttons and a mouse." (Wellner, Mackay, & Gold, 1993, p. 24)

Ubiquitous computing refers to the blending of computers into our everyday lives. Tangible User Interfaces (TUIs) support this as they seek to create technology interfaces that are more natural and akin to our normal way of functioning. This paper explores how Augmented Reality (AR) could improve the Computer Aided Design environment making it a more active, interactive and concrete process, and subsequently more natural to a design environment.

Looking at the current learning environment for CAD through a critical analysis lens, has led the author to seek to address some of the drawbacks. The one at the centre of this paper is the physical set-up of the learning environment in which CAD takes place. The CAD learning process itself may be an active one; but the environment remains quite static. Students remain seated at a desk in front of the computer. The software element of CAD is subject to constant development, with yearly versions, and various competing software providers. However, little has changed on the physical side of the CAD process; keyboard and mouse devices for inputting commands and monitor for viewing output. This paper argues the need for change to this traditional set-up, where increased interaction between user and digital content would exist and collaboration between users would be supported.

It is argued in this paper that a more active and interactive environment would increase learners understanding of 3D models, and that greater visualisation of design concepts and 3D models would lead to better understanding and evaluation of concepts. The view is also put forward that by creating a more concrete CAD environment and putting the learner physically into the learning experience that students will understand and relate design information such as anthropometric data to direct experience, thus leading to greater understanding and application of such information.

2. Literature Review

2.1 The concrete process

> *"concreteness is not a property of an object but rather a property of a person's relationship to an object".* Wilensky (1991, p4)

Concrete learning is often associated with physical tangible objects; in mathematics, the pie being cut to understand fractions, or a child (and sometime adults!) using their fingers to count. However, it is not necessarily the object itself that is the 'concrete' thing; it is the method. Have you ever used your fingers to count - and not moved them? It is the movement or active process that makes the method concrete, but the tangible objects (the fingers) are needed to support the process. So although Augmented Reality does not produce a physical tangible object the fact that the 3D CAD model appears to be present in the real space and the movement of students around it concretises the process.

Concrete thinking was seen as inferior to abstract or more 'formal' thinking with Piaget's placement of it at the lower stages of cognitive development (Piaget, 1972). Subsequent research showed some contradictions to Piaget's model, with researchers finding that many higher level students and adults still function as concrete level thinkers in certain cognitive aspects (Meyers, 1986; Tomlinson-Keasey, 1972) and that the progression from concrete to abstract thinking is not always a smooth transition (Ackermann, 1991). Hodgkin (1985) puts forward the view that abstract thinking should not always be assumed superior to concrete thinking, and that the ability to move readily from between the two is a practice of even the most creative people. During the design process students have to engage in very abstract conceptualisation of design ideas. The question is should this abstract process be supported with a more concrete learning experience?

Papert (1993) showed how abstract thinking can be successfully supported through the construction of 'meaningful artefacts' or using 'objects to think with'; his studies using the LOGO programming language and the computer-controlled 'turtle' (the tangible artefact) to teach geometry (the abstract concept) to young children supporting the theory. Again, he explains that learning is achieved, not necessarily solely with the transitional object but instead in the way the child can relate their body to the turtle to figure out certain tasks. This places the child at the heart of the learning experience, where their direct actions form and control the learning experience. This 'body syntonics' was something he describes as *"a kind of learning that happens without being taught"* (Papert 1980, p202). Although Papert's theories are based on studies involving children, his reasons and methods of 'concretizing the formal' could be transferred to more advanced learning situations. It is the idea of using the body as the main learning mechanism that is of primary interest in this paper, along with creating an active and concrete learning experience.

2.2 Making Sense of it

Relating to the idea discussed above about the concrete process involving movement and direct experience, findings from the literature also suggest that the addition of this extra 'sense', a kinaesthetic sense, improves the learning process. Frayer, Ghatala and Klausmeier (1974) describe 'instance perceptibility' as the varying degrees of understanding of concepts based on the extent to which instances of the concept can be sensed, (seen, touched, smelt, etc.); the more instances available the easier the understanding. Trogler (1972) found that even at a young age children could engage with some of the main principles of architecture. Activities involving the whole body (walking around cardboard walls, through playground objects) allowed them to relate aspects such as size and scale to the proportions of their own size. It was through their physical interaction with objects and spaces that they come to understand otherwise complex abstractions. So, looking at the design process, should the idea of kinaesthetic sense be explored – if it helped students' understanding of a concept?

Currently the kinaesthetic element of the design process takes place at the stage of physical model-making or prototyping. Building physical prototypes that can be touched, walked around, etc. relative to body size are a key element in the process for providing the designer with full visual and kinaesthetic feedback (Design Museum 2010, p75). However, in an educational context, model-making and prototyping are often replaced with CAD – time, resources and practicality being limiting factors in the use of physical prototyping. Providing a virtual prototype through augmented reality would be a way to bridge the gap between physical models and CAD models.

2.3 Augmented Reality

Augmented Reality (AR) is where virtual data is overlaid on a real-world scene, enhancing reality. Azuma, Baillot, Behringer, Feiner, Julier, and MacIntyre (2001 p34) state that it does not try to replace the real world but instead: "*supplements the real world with virtual (computer-generated) objects that appear to coexist".* In an educational context, one of the expressed benefits of AR, as highlighted in The Horizons Report (Haywood, Johnson, Levine, and Smith, 2010, p15), is that the learner is now provided with a way to "*construct new understanding based on interactions with virtual objects that bring underlying data to life."*

As a supplement to CAD, AR can create a virtual prototype, thus bridging the gap between the physical prototype and the digital computer model. Bone and Johnson (2009) explore virtual prototyping as a design technique that allows them to experiment with different materials, a selection process that Bone (2009, p200) reveals can sometimes be *"a leap of faith,* but with virtual prototyping they can: *"minimise the risk".* Billinghurst, Dunston, Hampson and Wang (2002 p1) promote the advantages of AR over current 3D modeling software and call for *"more modes of interaction with design content"*. Fiorentino, de Amicis, Monno and Stork (2002) developed the Spacedesign AR system stemming from this need, a system which allows free flowing curves and surfaces of a digital sketch to be projected as a virtual model. Krogh (2000) praises the ubiquitous qualities afforded by AR, advocating the idea that "*digital objects are not limited to the picture tube but can, and presumably will, be part of everyday life",* promoting its use in architectural design for this reason.

2.4 Conclusion

There is a need for improving the current CAD process in design education, specifically by improving the computer-user interface and by making the process more active, interactive and concrete. Applying the underlying ideas of the Constructionist theory i.e. providing a learning environment that allows learners to gain direct experience and connection with the digital design content could lead to solving this research problem. Providing students with a virtual model that appears to co-exist in reality, that they can walk around and relate their body size to, would further enhance this learning experience and environment.

3. The Study

3.1 Design

As part of this research study a learning experience (ARC) was designed to integrate augmented reality into the CAD process. The system is made up of three elements: CAD software, handheld viewing device with camera, and physical marker that the virtual model appears on [Figure 1]. The student draws a 3D model of their design in the usual manner using Google Sketchup software. They then view it using an augmented reality plug-in (an add-on to the software). This augmented reality system works by means of a 'marker' – a physical symbol that the computer recognises [Figure 2]. When the user selects 'view' the interface on the screen changes from the CAD software to the camera view. The user then sees whatever the camera is pointed towards i.e. the room setting, plus the 3D model appears in a virtual state (viewed on the hand-held screen) as if physically positioned on the marker [Figure 3].

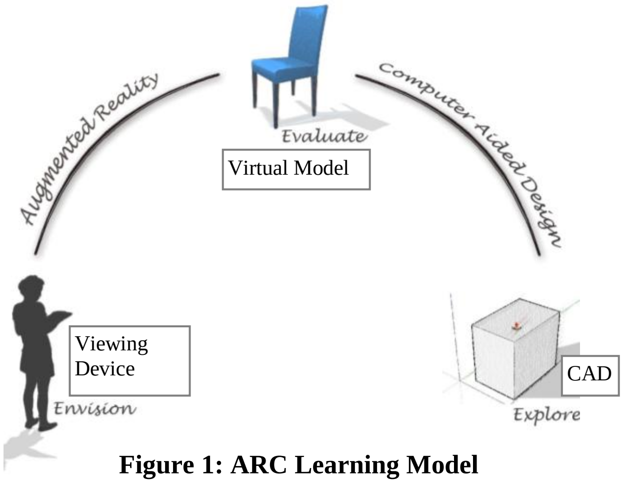

Figure 1: ARC Learning Model

Figure 2: View of real room setting showing physical 'marker'.

Figure 3: View showing virtual model (as through the viewing interface). The couches and room setting are real; the table a 3D CAD model.

The ARC system allows the learner to view a virtual representation of their 3D CAD model, taking the model out of the computer into a real-environment setting. The design is thus viewed in the context of a real setting, allowing a greater 'sense' of the object and an increased opportunity for better understanding is given to the learner. Real-time interaction between learner and design is achieved. The main features of the learning experience along with the learning achieved are outlined in the Table 1.

The Need for:	The Features:	Learning achieved:
Increased instance perceptibility of concepts	**Increased senses** Adding to seeing a 3D object on the screen the user can now walk around it, beside it, increasing the instance perceptibility of the concept. A kinaesthetic sense is created between user and object.	Concept is easier to understand as there are now more instances available to the learner. Improved sense of the size and scale as users can relate size of object to their own size.
Supports for concrete thinking	**Concrete thinking support** Provision of a more tangible object to think with. Relationship and closeness to the object is increased with its appearance as if situated in the real environment.	Abstract thinking during concept stages is now supported by a more tangible object. Movement between abstract and concrete is facilitated. Concrete learning experience formed.
Evaluation and comparative system	**Virtual prototype** Virtual prototype that can be viewed in relation to real environments, physical objects and people. Realistic comparisons can be made.	More informed judgements made allowing for improved designs. The 'value' aspect of creativity being met.
Increased Interaction	**Active participation and interaction** Active participation and interaction with the object. Ability to walk around the model and view from different angles in real-time.	Improved sense of the size and scale of the design. The active approach creates a concrete experience which learner can draw on in later work.
Enhanced visualisation	**Realism** Overall realism of the 3D model. Shown in context within a physical environment. Real-time view.	Aspects such as overall aesthetics and proportions can be better understood.
Fostering experimentation and exploration of ideas	**Instant feedback and editability** Instant feedback and ability to make and see changes. The quick view-edit-view process allows greater room for experimentation. No commitment to individual ideas so increased output.	More innovative output. Not afraid to try out imaginative ideas as no commitment required. The 'originality' aspect of creativity met.

Table 1: Features of the ARC Learning Experience

3.2 Case Study

A case study involving 14 third level students, from CAD and Furniture modules, was conducted to gain initial feedback of the ARC learning experience. All students were familiar with the CAD software used and at the time of the study, only one participant was aware of the term ‘augmented reality’. Data collection included visual methods - observations, screen captures, photographs, and video footage. Questionnaires and informal group interview provided participant feedback. The participants engaged with the learning experience and took turns to view their model using the hand-held graphics tablet with attached webcam. Participants worked in pairs or threes; while one looked through the viewing interface, another interacted with the model and in some cases a third person manoeuvred the camera. Each group were given sufficient time to view their designs as virtual models and altogether the learning experience took two hours. The findings of the study are discussed in the following chapter.

4. Findings and Analysis

4.1 Concrete experience

Figure 4: Participants using own body size to judge size/scale of designs.

There is strong evidence from the video footage, screencasts and photographic data sets [Figure 4], of participants using their own body size in relation to the virtual model, showing high engagement with the kinaesthetic element to the process. The person viewing through the hand-held device benefits from seeing their design in relation to a real person and in particular in a real-context. The other participant (who sees AR view in facing laptop) benefits from being at the direct centre of the learning experience, similar to Papert's child acting as turtle (Papert, 1980). They begin to understand design aspects such as size and scale in a real and natural way. Interacting with digital content in this way provides a concrete experience to draw back on in future design conceptualisation.

4.2 Active and interactive

The visual studies (video, photograghs, screencasts, direct observation) were essential in analysing how participants engaged with the learning experience and the level of participation and interaction that occurred during the activity. The movement of people and their interactions with the digital models and the process itself was evident [Figure 5]. High levels of collaboration emerged as an unforeseen outcome.

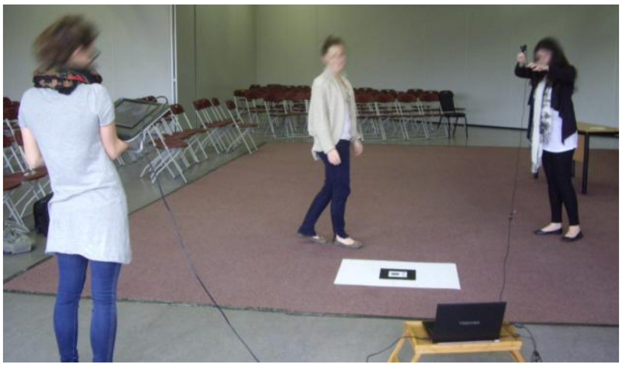

Figure 5: Active nature of ARC experience

4.3 Visualisation, understanding and subsequent design judgements

The post-activity questionnaire data showed the majority of the cohort (12 of the 14) agreed or strongly agreed that the virtual model helped them with visualisation, with 11 agreeing that their understanding of their design improved because of the system. From discussions with participants during the activity, it was noted that design decisions were being made based on new understanding of the designs. On seeing his chair (that was at design completion stage) in relation to a person, one participant revealed *"that's big, look at that"*. Another participant, whose design involved a high enclosed back [Figure 6], realised that even when the seat was at the right height the back was out of proportion, *"it's the back that needs to be…"* She explained how she struggled with the measurements for the back. The virtual model acted as a direct prototype in the case of these two students in evaluating their designs.

Figure 6: Concept Evaluation

Another participant revealed that she didn't like her concept at all when she saw it as a virtual model, and more importantly she realised: "*in reality it doesn't quite work"*. This participant was at the initial stage of the concept creation stage and so the ARC system provided her with instant feedback and allowed her to spend her time (that she would have probably spent on this concept) on exploring alternative ideas. Others made reference to this 'early editing' feature in the questionnaires.

4.4 Realism brought about from AR

The quantifiable responses from the questionnaires showed that 12 of the 14 agreed or strongly agreed that 'Viewing the model through AR made it more real'. Analysis from the video footage gives direct evidence of initial reactions with utterances of *"that's cool"* and *"oh that's good"* when seeing the virtual model for the first time showing that they were impressed by the realism aspect of the ARC system. They also saw benefits of this realism aspect: *"It's always better to see your design as real as possible. Automatically you are getting a better understanding of what you are doing"*. Seeing their design concepts in a real environment and in comparison to real objects and people did appear to increase the connection felt with the digital content and make concepts more real for the students.

6. Conclusions and Future Work

> "*computers are infinitely plastic and can reinforce old patterns as well as allow us to live out new ones".* Papert (1980, p209)

It is important that we decide on the learning environment we want to create and mould the technology to suit. This paper focused on the learning environment of Computer Aided Design and explored the potential benefits of integrating augmented reality technology into this process. Students have to engage in very abstract thinking to conceptualise design ideas and understand 3D models. The idea of supporting this abstract process in a concrete manner to improve the learning process was explored. Creating a learning environment that was more active, interactive and concrete was the guiding basis of this paper.

The main feature of the ARC system is that the 3D model no longer sits behind a computer monitor but now appears to exist in the reality where the learner can walk around the object, emulate touch gestures, and engage in physical participation in the process. The learner gains more opportunity to 'connect' with the digital content (Wilensky, 1991). Supporting this issue, it was also highlighted from the literature that kinaesthetic senses and learning activities involving the whole body make understanding easier (Papert 1980, Klausmeier et al 1974, Trogler 1972). When users interact with the ARC virtual model they are learning design principles such as scale and anthropometric information in a more natural and intuitive way than merely relying on data sourced from a book. The 'virtual prototype' created by the ARC system provides learners with 'an object to think with', to visualise and interact with in a real-life manner (Papert 1980). The virtual model is not a physical tangible object but it's presence in the real environment, albeit in a virtual state, converts the digital CAD process into a more concrete learning experience and the direct and meaningful involvement in such, leaving a longer-lasting impression on the learners mind.

Further development of the ARC system is needed, possibly looking at the mobility aspect of the hardware, allowing freer movement around the virtual model. A more in-depth case study is planned, using the feedback from this initial study as a foundation. Participant size and the early developmental stage of the system are evident limitations of this study.

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