Co-Design of Augmented Reality Textbook for Children's Collaborative Learning Experience in Primary Schools

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ABSTRACT

Augmented Reality (AR) is a recent technology that allows a seamless composition between virtual objects and the real world. This practice-based research uses the affordances of AR to design an AR textbook for collaborative learning experience. It identifies the key concepts of children's AR textbooks for the designing and evaluation of collaborative learning experiences. These concepts were used to develop a conceptual framework for the AR textbook that considers collaborative experience, learning and usability. Informed by these concepts, the research also has identified the design features which are unique to AR affordances which can be integrated in the school textbooks to develop a collaborative AR textbook for primary school children.

The research follows a participatory design approach to involve the users of the AR textbook in the design process. The researcher has conducted three co-design studies involving primary school children and adults using cooperative inquiry techniques. The first study uses low-tech prototyping to find the overall direction of designing the AR textbook. After the development of the first AR textbook prototype, two formative evaluations have been conducted using cooperative inquiry critiquing, and layered elaboration techniques.

Throughout these studies, a conceptual framework has been developed namely, Experience, Learn and Use (ELU) for the designing and evaluation of children's AR textbooks for collaborative learning experience. This framework is based on the adaption of Janet Read's Play, Learn, Use (PLU) model that defines children's relationships with the interactive technologies. The research proposes the ELU framework as a useful classification framework in the evaluation process, which informs the design features of the AR textbook which are related to the concepts of collaborative experience, learning and usability.

The practical component of the thesis proposes a sample of an AR textbook that is integrated in the regular school curriculum. It demonstrates the design features which can be implemented in other textbooks to support collaborative learning experiences for primary school children. The documentation of the co-design process provides a practical framework for co-designing an AR textbook with children, as well as an evidence of using the ELU framework in practice.

This research also contributes in bridging the gap between AR and Child-Computer Interaction (CCI) communities, through the use of common CCI methods in the AR development. This research has resulted in key design principles which contribute original knowledge to the literature of the AR for children's education considering the CCI perspective. These important principles are informed by the collaborative experiences, learning and usability aspects that establish a framework for the design and evaluation of collaborative AR textbook for children. The eight identified principles by this research are, Joint Textbooks, Personalised AR Experience, Interactive AR Book, Communication-Based Learning, Rewarding AR feedback, Audio AR Textbook, Intuitive AR Markers, and Mutual AR Display. The research introduces the definition for each of the concepts and a demonstration of the related design features in the outcome of the AR textbook prototype.

Key Words: Joint Textbooks; Personalised AR Experience; Interactive AR Book; Communication-Based Learning; Rewarding AR feedback; Audio AR Textbook; Intuitive AR Markers; Mutual AR Display.

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GLOSSARY

AR- Augmented Reality is an immersive experience that superimposes virtual 3D objects upon a user's direct view of the surrounding real environment, generating the illusion that those virtual objects exist in that space(Azuma, 2017).

CCI-Child-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for children's use and with the study of major phenomena surrounding them (Read & Bekker, 2011).

PD-Participatory Design is an approach to the design undertakings which actively involves all stakeholders in the design process in order to help ensure that the products which have been designed could meet their needs and could be usable as well (Sanders & Stappers, 2007).

Co-design-The practice of collective creativity as it is applied across the whole span of a design process. It is also referred to as the creativity of designers and of the people who have not been trained in design working together in the design development process (Sanders 2000).

Collaborative Learning- The experience focusing on how collaborative learning supported by technology can enhance peer interaction and work in groups, and how collaboration and technology facilitate sharing and distributing of knowledge and expertise among community members(Dillenbourg, 1999).

Cooperative Inquiry – Cooperative inquiry techniques include a variety of innovative techniques that are appropriate for different design phases, as a co-design method specially tailored to meet the challenges of working with children aged 8 - 10 years old, and adults from different expertise (Druin, Guha & Fails, 2013).

I. INTRODUCTION

I.1 Overview

Augmented Reality can be explained as a technology that allows for a seamless composition between virtual objects and the real world(Carmigniani & Furht, 2011). The virtual objects could include any form of digital media such as videos, motion graphics or 3D animations

which can be displayed with a head-mounted or a hand-held device, a personal computer or a laptop and today, with any smartphone or tablet (Figure 1). Wu *et al* (2013) argued that viewing AR as a concept rather than a type of technology would be more productive for educators, researchers and designers. It shows future promises for different domains and education is one of them.

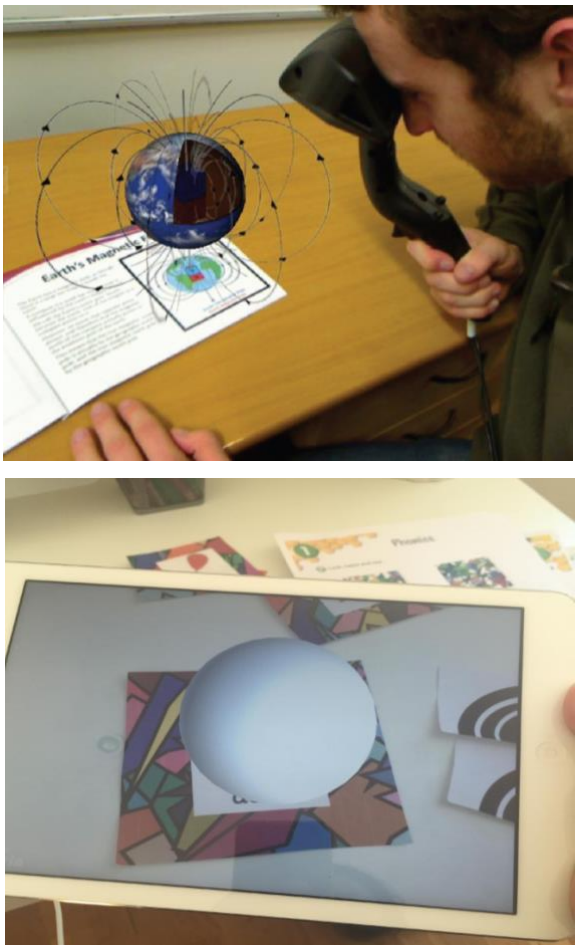


Figure 1: Augmented Reality using hand-held device (Billinghurst&Duenser, 2012), and using tablet.

When examining AR for collaborative learning, the term collaboration can be understood as an experience shared between peers or groups of students using the affordances which are offered by AR. Looking at the definitions in academic fields, the ideas of *'co-construction of knowledge'* and *'mutual engagement'* are also stressed in defining collaboration (Lipponen, 2002). The other considerable idea is that collaboration does not, in itself, produce a learning outcome. Its results depend upon the extent to which groups actually engage in a productive

interaction (Dillenbourg, Järvelä & Fischer, 2009). Collaborative learning can be described as *"a variety of educational practices in which interactions among peers constitute the most important factor in learning"* (Dillenbourg, Järvelä & Fischer, 2009: 1).

Thus, collaboration can be effective by the interaction and mutual engagement among peers or groups to construct new knowledge. However, these concepts are not guaranteed by putting students together in groups (LeJeune, 2003). Many factors should be considered for supporting engagement and sharing of information in group based learning. In their book *The Evolution of Research on Computer-Supported Collaborative learning,* Dillenbourg, Järvelä & Fischer (2009), summarised two decades of researches on Computer-Supported Collaborative Learning. The key idea that has emerged regarding this is namely the fact that collaboration among peers can be '*designed*'. Basically, the fact that collaboration has to be designed was emphasised upon in Dillenbourg *et al.*(1996: 6), *"an important part of the use of collaborative technology is how the technology is implemented, for instance, in school settings".*

Further, from a child-computer interaction perspective, Hourcade (2008) argued for the need for developing approaches and frameworks that could be useful for designers and developers to follow and recommended for focusing on certain aspects such as interactive and effective collaborative learning experiences for children. This research aims to use the affordances of AR to design a collaborative learning experience for children through focusing on certain aspects of the collaborative learning experience.

Since different considerations are required in the design to meet the intended users' needs, especially when these users are children therefore, Co-design is adopted in this research as an effective way to engage children in designing their AR textbook. Designing interfaces and usage of the same are central dimensions of design practice according to Grand(2012: 158)*"we have thus to consider that artefacts and interfaces are never completely predetermined but are co-designed in their use by the users"*. Co-design is considered as an area of participatory design and has been primarily adopted in the field of CCI. Child-Computer Interaction is a research area within Human-Computer Interaction (HCI) that has become well established and is mainly driven by interests in technology utilization within education and schools(Read & Bekker, 2011). It takes into account the special characteristics of children and aims to develop

special applications that combine entertainment and education taking the usability also into account (Nijholt, 2012).

The proposed practical outcome of the AR textbook is based on an educational English textbook for use in Saudi Arabian primary schools. This textbook was used as a sample for the purpose of the study, not having been concerned with the educational system or learning content. Instead, it will be used to present how AR can be integrated into a school textbook using its content, focusing on the design concepts related to the collaborative experience, learning, and usability. The participants in the co-design process are children from Saudi Arabian primary schools with adults from different academic backgrounds, in order for the researcher and the participant to work within the same cultural and social circumstances. Doing this research for different countries would align the researcher to a *'contextual haze'* where less cultural differences is possessed and more '*socially excluded'* the researcher might get from the co-design participants and the school environment (Crouch & Pearce, 2012: 7). Even though that means the practical outcome contribution would be minimal, it is important to be explicit about the researcher's position and the context of designing. However, the design features found by this research and implemented in the proposed outcome can be applicable in other AR textbooks that intend to support collaboration.

This research will also contribute to the understandings about the key concepts to inform the design and evaluation of children's AR textbook focusing on the collaborative experience, learning, and usability. It will propose a conceptual framework for the design and evaluation of AR textbooks for children, which has not been covered in previous researches. Further, it applies the methods of co-design with children in researching about AR. Although CCI researches have acknowledged that involving children in the design of the technology is crucial, very little work can be found that involves children in designing AR textbooks. This research offers a practical framework for data collection and analysis development based on frameworks of key scholars in PD and CCI, which can serve as a starting point for further research that uses co-design in the context of AR for children.

In conclusion, this research has generated three types of outcomes that constitute an original contribution to knowledge in the areas of co-design with children, CCI and AR for education.

1. Eight key concepts of AR textbooks are associated with children's collaborative learning.
2. Five design features were implemented in a sample of AR textbook prototype which use the affordances of collaborative AR for the integration in school's textbooks.
3. Suggestions on co-design with children in the context of AR text books, based on PD and CCI perspectives.

I.2 Research Context

I.2.1 Augmented Reality

The phrase '*Augmented Reality'* was coined by Boeing researcher Thomas Preston Caudell in 1992. He used the phrase to describe a system that would assist the workers in the assembly and installation of electrical cables in aircraft(Caudell & Mizell, 1992). In the following years, AR technologies have been primarily developed by research labs and universities worldwide (Azuma, 1997). In the last decade, the technology has slowly begun to migrate from research laboratories to the commercial market in applications ranging from education to entertainment, marketing and advertisement. Looking at the rapid pace of the development of technology, it is not difficult to imagine that very soon smart phones and tablets capable of displaying augmented content will become ubiquitous(Nijholt, 2012).

The meaning of the term Augmented Reality can be better understood as opposed to the more familiar concept of Virtual Reality (VR). While in the case of VR, a user is immersed in a virtual environment completely created at the computer; in the case of AR the virtual elements are overlaid and integrated into the real physical space. This is essentially the opposite process of VR. By means of suitable displays and interaction devices, AR allows users to access information directly relevant to their contexts of use, overlays layers of digital information to the physical space, while at the same time allowing interaction with those digital elements as if they actually belonged to the real world.

From a technical perspective, Augmented Reality relies on the recognition and tracking of the physical world around us with the goal to render and visualise virtual objects composited in

the real world. The architecture of AR can be categorised depending on the scene capturing, detection/tracking method, user interaction and visualisation. AR applications can be categorised by location-based (Geo-based) and vision-based (target-based) variants. Location-based AR uses GPS and compass technologies in smart devices to trigger the virtual objects and orient it onto the real world being viewed by the smart device camera. Whereas the vision-based AR uses image recognition to view the virtual object overlaid onto the image pointed by the camera. These images can be devoid of any marker or marker-based (Billinghurst, Clark & Lee, 2015).

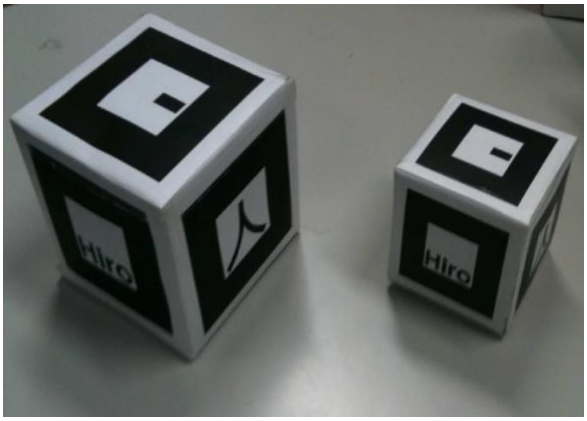


Figure 2: Common AR Markers (Aasterud, 2010).

Markers can be attached to walls or tagged to objects or embedded in books such as in AR Books. Compared to the marker-less versions, marker-based examples can efficiently run on small processors, providing us with accurate information regarding the scale and position of real world objects and information contained within the marker. Marker-less images detect interest points in the physical world using methods called Natural Feature Tracking (Azuma *et al.*, 2001). The marker-less versions, though, are gaining popularity and the mobile implementation seems to become feasible together with the more advanced mobile devices and sensors entering the market (Hawkinson, 2014). The advantage of using a marker-less version in AR Books is that the printed material does not need to be prepared with markers. Instead, it can be tracked by using the images in the printed book. When an AR application recognises that a marker has come into view through the user's camera, an action of displaying the digital content is generated.

There are several reported projects which have been used that feature AR to support teaching vocabulary and learning characters in Chinese(Rose & Bhuvaneswari, 2016), learning Filipino and German vocabulary(Santos *et al.*, 2016), helping in pronouncing new English words(Solak & Cakir, 2015) or generating flash card interactions for English(Li *et al.*, 2014). Typically, in these applications, the word to be learnt will either be illustrated or will be attached to the physical object it represents or is associated with. The concrete visual connection to the item is likely to help in retention of knowledge in addition to increased motivation of the students (Godwin-jones, 2016).

The definition of AR includes three properties which could describe it in a proper manner including the interactivity and real-time environment; the registration of virtual objects in 3D and the combination of real world elements and virtual objects (Azuma *et al.*, 2001). Billinghurst(2002), defined AR with the seamless transitions of reality to virtual, meaning the user can step from the real world into the virtual world without noticing the phase of transition. This is useful in a learning context, in which students will be provided with immediate assistance of digital content based on the printed material.

I.2.2 Co-design and Participatory Design

The notion of co-design has been growing in the area of participatory design within the design research landscape (Sanders & Stappers, 2007).Scrivener, J.Ball & Woodcock (2000)'s book titled *Collaborative Design: Proceedings of CoDesigning 2000,* was comprised of 49 papers which were relevant to co-design methods and Participatory Design approaches. Participatory design has been emerging in the Scandinavian countries and has been influenced by the longer history and more developed area of user-centered design, which has been led by the United States of America. Participatory design is, *"an approach to design that actively involves all stakeholders in the design process in order to help ensure the product designed meets their needs and is usable"* (Sanders & Stappers, 2007: 2). It allows the designer to gather similar information from different sources through combining diverse data sources which optimise the quality of the data.

Participatory Design, as defined by Spinuzzi(2005), emphasised on co-research and co-design as researcher-designers must come to conclusions in conjunction with users. Participatory

Design is a broader term than co-design and has emerged in various forms from two different needs. The first need, coming mainly from the United States of America, was for technological rationalisation where IBM and other significant industrial institutions sought to engage with users to ensure efficient designing of systems with initiatives, like a joint application design board. The second need was the social and humanist approach that considered user participation to be necessary for collective security and individual autonomy. This latter movement had support in the UK and Scandinavia, with key contributions being socio-technical and contributions from the Tavistock institution and Norwegian work experiments (Simonsen & Robertson, 2013).

Today's language of co-design was revealed from the landscape of generative research, where generative tools seeded a mindset of collective creativity in co-design workshops (Sanders, 2000). The *'make tools',* as termed by Sanders(2002) are a co-design language for designers and users focused on what people make and create from the toolkit provided for them. It was used with children aged between 7 and 9 years of age, where they generated various idea interpretations (Vaajakallio, Lee & Mattelmäki, 2009). The roles of a designer and a design researcher became mutually interdependent in approaches of design research and practice that have emerged and methods of doing research into design processes are now widely used in the academia (Sanders & Stappers, 2014).

Co-design as a method of conducting design research with children are built on *'rethinking'*, *'envisioning'* and *'making'* and are based on a belief that all people are creative and can contribute to design formulation if provided with an appropriate setting and tools (Vaajakallio & Mattelmäki, 2014). Co-design merges the roles of researcher, designer and user where they all play a large role in knowledge development, idea generation and concept development through the tools provided by the researcher for ideation and expression (Figure 3).

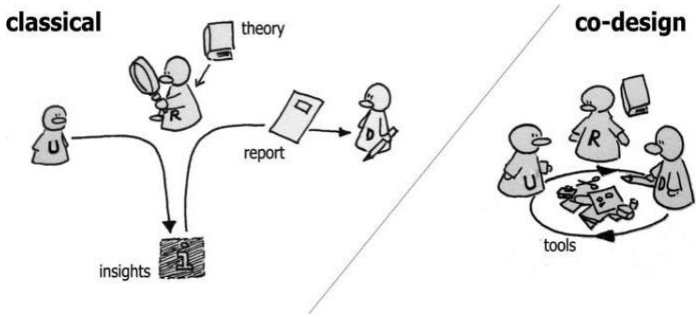


Figure 3: Roles of researcher, designer, and user merged in co-design (Sanders & Stappers, 2007).

The phases of making tend to take the form of a prototype that is built to test whether the concepts should be further pursued. *"Iterative prototyping can be viewed as growing early conceptual designs through prototypes into mature experience"* (Sanders & Stappers, 2014: 6). In research through design, Stappers(2013) emphasised that prototypes can play a number of roles such as evoking a focused discussion in a team because it's *'on the table'*, which allow them to experience and consider the concepts\features explicitly. Prototyping is integral to the PD approach since it involves heightened user participation and *"supports mutual learning by promoting cooperative communication"*(Carmel, Whitaker & George, 1993: 45). PD guides emphasis on the methodological strategies and development process where the primary focus is collaborative participation in an iterative prototyping of ideas and *'co-determination'* of design concepts (Foth & Axup, 2006). Esko Kurvinen & Ilpo Koskinen (2008) developed four guidelines for properly analysing prototypes as social objects,

- *Ordinary social settings.*
- *Naturalistic research design and methods.*
- *Openness.*
- *Sufficient time span.*

These guidelines are applied in the prototyping of the AR textbook because they are based on a participatory approach where people are involved in co-design processes. In addition to this, the consideration of openness where prototypes are experienced and explored without forcing the children to use it in a predefined way, must be absorbed to formulate the guidance for designing in this discipline. The guideline of allowing a sufficient time span is also applied where the prototyping of the AR textbook has been conducted throughout the three years of the research and a sufficient time is provided between each of the three studies for essential

reflection. The intermediate prototypes used in the two evaluation studies were developed into high-fidelity prototypes of the AR textbook to increase the effectiveness of the research evaluation results.

I.2.3 **Child-Computer Interaction**

Child-Computer Interaction is a research area within Human Computer Interaction (HCI), also referred to as *Interaction Design and Children*. CCI is the, *"part of Human Computer Interaction where the humans are children"*(Abdulaziz, 2013: 1). However, it was driven by interests in technology utilization within educational sectors and schools, mainly focusing on the special characteristics and requirements of children in developing educational technologies that are both playful and usable (Nijholt, 2012). The early and highly influential individuals to the CCI are Symon Papert, the theorist of '*constructionism',* together with the psychologist Jean Piaget and his *'constructivist learning theory'*(Piaget, 1955). While developing his theory, Papert recognised the opportunity that computers presented to allow children to learn in relation to their own interests and investigated how '*constructionist learning'* can be implemented in technologies and educational practices (Papert, 1983). It is considered that CCI is even more significant than HCI because of the limited knowledge and skills of children which could hinder their ability to use non-interactive technologies.

Much of the early literature in the 1990's was not only in HCI but also in journals about computers and education and in the 21st Century, the attention paid to CCI has also grown significantly (Read & Bekker, 2011). The nature of CCI can be explained by analysing the similarities and differences that set CCI apart from HCI.

> *The Nature of CCI is therefore considered to be a study of the activities, behaviours, concerns and abilities of children as they interact with computer technologies, often with the intervention of others (mainly adults) in situations which they partially (but generally do not fully) control and regulate (Read & Bekker, 2011: 7).*

They defined CCI by mapping it onto (ACM SigChi) definition of HCI:

> *A discipline concerned with the design, evaluation and implementation of interactive computing systems for children's use and with the study of major phenomena surrounding them (Read & Bekker, 2011: 3).*

A newer definition by Read & Markopoulos of CCI is:

> *An area of scientific investigation that concerns the phenomena surrounding the interaction between children and computational and communication technologies. It combines inputs and perspectives from multiple scientific disciplines informing and supporting an area of research and industrial practice that concerns the design of interactive systems for children (Read & Markopoulos, 2013: 1).*

The key CCI researchers Markopoulos &Bekker(2003), emphasised on the need to consider the involvement of children in the design process. In CCI, the participatory design approach is commonly adopted and children have become participants in the design process. When the technology could become cheaper and more accessible, a large number of children will have access to interactive technologies, thereby removing the last barrier in using technology to facilitate learning among children. Offering the new technology of AR to child education requires the method of co-design to understand the children's perspectives and inform the design process based on their educational needs. Similar to the role of user in PD, the role of children in CCI moves from an end user to become more active and responsible in earlier stages of the design activity (Read, Markopoulos & Druin, 2011).

The field of CCI brings together the fields of interaction design, HCI and PD. It also connects all those attributes to education, since it is concerned with new technologies for children to support and facilitate learning. These relationships serve as linkages for this multidisciplinary research, whereas CCI community provides methodological guidelines regarding the adaptation of PD with children. This research brings all these perspectives to the area of AR, bridging the gap between CCI and AR communities.

I.2.4 **Collaborative Learning**

In 1996, computer-supported collaborative learning (CSCL) was suggested as an emerging paradigm of educational technology (Koschmann, 1996).Published research suggested that a

student's level of understanding is higher and information retention capability becomes longer when students work collaboratively compared to those who work individually (Gokhale, 1995). Computer-supported collaborative learning also allows for *'edutainment'* which enables students to move seamlessly between education and entertainment (Bruckman, Bandlow & Forte, 2003).

As explained by (Dillenbourg, 1999: 1),*"CSCL is focused on how collaborative learning supported by technology can enhance peer interaction and work in groups and how collaboration and technology facilitate sharing and distribution of knowledge and expertise among community members".* Collaboration, as defined by Roschelle & Teasley (1995: 96), is a "*process by which individuals negotiate and share meanings relevant to the problem-solving task at hand. The purpose of CSCL is to create an environment in which students' interactions and sharing of information can occur effectively".* Cole & Wertsch(1996: 251)stated that, *"knowledge emerges through the network of interactions and is distributed and mediated among those (humans and tools) interacting".*

Lipponen(2002) relates it to the idea of interaction and mutual engagement again, in which, collaboration involves the mutual engagement of group members in social interaction. Hiltz(1994) further emphasised the importance of social interaction as a *'natural way'* of children's learning. Kreijns, Kirschner & Jochems(2003) also considered social interaction to play a crucial role in children's learning. Interactive activities which involve collaboration between students are most important in learning since it facilitates learning by enabling students to engage with other learners as well as the educational content at the same time (Chi, 2009). It can be argued that collaborative activities allow for deeper learning as students consider different perspectives and direct each other to study different aspects of the educational content.

According to Dillenbourg (1999: 4), *"The idea of collaboration as mutual engagement appears to imply synchronous activity or even a situation of face-to-face interaction".* The interaction itself was related to the communication cuesand face-to-face interaction, where meanings are mediated through social cues such as faces, gestures, spoken language and intonations of speech and computers can act as instruments of a collaborative action (Roschelle & Teasley,

1995). It is suggested that one other feature of interaction which is central to successful collaboration is a rich supply of external resources, such as computers(Crook, 1998).

> *Members of the community are critically dependent on each other. No one is an island. No one knows it all. Collaborative learning is not just nice, it is necessary for survival (Brown, 1994: 10).*

In conclusion, the collaborative aspect is one of the important aspects in learning and I contend that offering children this recent technology of AR to create effective collaborative experience can have a great benefit for their education and for their future collaboration in different domains. Augmented Reality has the potential for creating the presence of mutual engagement and social interaction to facilitate successful collaboration. This research aims to exploit the affordances of AR to design a collaborative experience for children that can be embedded in classrooms through the use of the school textbooks as the main interface.

I.3 Research Questions

This research aims to answer the following three research questions:

1. What are the key concepts that inform the design and evaluation of children's AR textbooks for collaborative learning experience?
2. What are the design features of the AR textbook related to these concepts?
3. How co-design methods can be applied in the context of AR textbooks for children?

The researcher has conducted three co-designs which resulted in the Experience, Learn, Use, conceptual framework, for thinking about the design of collaborative AR textbooks for children, which answered the first research questions. The practical contribution of the AR textbook prototype demonstrated the design features related to the identified concepts, which addresses the second research question. Answering the final research question is represented by the explicit documentation of the co-design studies planning, data collection sessions and analysis process, while illustrating the underpinning methodological perspectives.

I.4 Research Significance and Potential Benefits

> *The past decade has seen vast changes in children's media, including the release of modern smart-phones and tablets, as well as countless other digital devices especially for children. The pace of new industry breakthroughs is likely to continue at an exponential rate and it is crucial that research stays concurrent. Unfortunately, it is extremely difficult for researchers to keep up the same pace. The next decade will undoubtedly witness exciting advances in children's interactive media. The challenge for researchers will be to provide useful, timely information to industry, parents and teachers to help ensure that new media are beneficial to children (Troseth, Russo & Strouse, 2016: 59).*

Augmented Reality has reached certain levels of maturity in educational environments and the effectiveness has been widely proven(Garzón, Pavón & Baldiris, 2017). It is reasonable to assume that, with time, the use and influence of AR in education delivery is likely to become more significant. While there has been some progress in this direction, there is still a dearth of research and unanswered questions on how AR can be embedded in the educational curriculum for different learning stages and how AR affects different aspects of learning such as collaboration. Kaufman, one of the leading researchers in AR for education, supported the idea of questioning the effectiveness of specific aspects of AR,

> *The potential of each AR feature needs careful reflection in order to be actually translated into educational efficacy. The matter is not about questioning whether or not AR is useful to enhance learning. The matter is to understand how to effectively exploit its potential (Kaufmann, 2003: 4).*

Garzón, Pavón & Baldiris (2017) conducted a literature review of 50 studies published between 2011 and 2017 of AR for education and determined the trends, affordances and challenges of this emerging technology in educational settings. They acknowledged that there are still issues that need to be addressed in order to obtain the best of this technology and ensure the most appropriate integration of AR into education. One of these directions that need to be explored is the integration of AR into an unexplored field of education. Further, Bujak *et al* (2013) introduced a theoretical framework for designing AR learning experiences from three perspectives namely, the physical, the cognitive and the contextual. Of the contextual

dimension, the authors argued that AR facilitates collaborative learning that generates a more motivating and personalised learning experience. However, in their conclusion they wrote:

> *Not many AR learning systems are specifically designed for multi-person collaborations……. Although AR shows great promise to education, there is much research to be done. Researchers will need to better understand how to design specific experiences to teach specific topics (Bujak, et al, 2013: 7).*

The literature suggests that there is a need for studies that extend our understanding of how specific technologies and applications may support collaboration between children in an educational context (Hoda *et al.* 2014). Specific for Augmented Reality, a recent survey of the current status of AR in education(Wu *et al.* 2013: 7) highlighted the following recommendations for the researchers:

- *Highlighting the features and affordances of AR to reveal educational values unique to AR learning environment.*
- *Examine the learning effects of AR through the development of substantial educational content on AR for learning subjects other than sciences and mathematics.*
- *Explore possibilities and solutions of integrating AR into regular school curricula.*
- *The empirical evidence from these studies could inform theories and help generate a set of instructional patterns and design principles of AR.*

Similar studies have shown that AR provides a great potential for collaborative learning, however, the effectiveness of a collaborative learning experiences is not created by any AR technology itself. Instead, it is actually manifested by the potential factors of successful and effective collaboration that are implemented in the application. These factors need to be considered as the essential elements in designing AR applications to enhance collaborative learning.

One of the purposes of this research is to fill the perceived gap in the literature by identifying the design features for the collaborative learning experience through the unique affordances of AR. These features are demonstrated in a practical outcome of an AR textbook proposed as a sample of an English textbook for a primary school in Saudi Arabia. This AR textbook is designed to allow students to gain insight about educational material while engaging in

collaborative activity, with the support of AR features. The collaborative experience can take advantage of an interactive AR interface, in addition to the educational affordances of the conventional textbook. A unique feature of this research is the integration of AR in the curriculum through implementing the required AR features into the actual textbook, which will subsequently work effectively with the tablet application.

Other researchers in AR for education are focusing on developing the AR applications with its own educational content, differentiating it from the existing curriculum. There appears to be only one study that had discussed this, specifically, a textbook-based AR by Zulkifli *et al* (2014), but this paper only reviewed the AR features from the literature as a useful guidance for future research. However, this research identifies the design features based on co-design with children as well as the related literature. The proposed practical outcome is an indicative example of how AR features, specific for collaborative experience, can potentially be integrated into school textbooks for other subjects and for different curricula in other countries.

Importantly, apart from introducing an AR textbook that offers the affordance of this recent technology to primary schools, this research has many potential applications that can be seen from other perspectives. From the PD and co-design perspective, this research presents a practical framework and design guidelines for involving children in co-design of AR Books. From CCI perspectives, Antle(2013) for example, argued in her identification of future research needed in CCI, that little is known about how interactive technologies can be designed to effectively support children to learn, play and interact with each other.

Read and Markopoulos (2013) illustrated the need for this kind of research that is of significant value to society:

> *In terms of technologies, history tells us that some of what is being researched now will come rapidly into the marketplace. Tangible interfaces which appeared in the research literature in the Mid-Nineties are by now widely available commercial products. Smart boards and interactive tablets are now in children's homes and*

classrooms. ….. In the future, children will have technologies and will be in places that cannot yet be imagined. Thus, one of the key challenges for the CCI Community is to provide a body of research to better inform the designs of those technologies and the shape of those spaces. Clearly empirical work, design driven research and the development of robust methods are all needed (Read & Markopoulos, 2013: 4).

It should be noted that this research is capable of benefitting the growing field of CCI by proposing a conceptual framework that can inform the design and evaluation of children's technologies which are specific to collaborative AR experiences. The overarching goals of this research are to contribute to the knowledge of co-design and CCI in the context of AR for children and generate insights from this research to inform design of AR textbooks for collaborative learning experiences.

The literature of design principles for AR in learning has been limited and the need of such principles in the design of AR is crucial when considering the methods of CCI. Until recently, studies of AR in education have relied on the three design principles found by Dunleavy & Dede(2014) as a foundation for their design and evaluation of AR for learning (Vanmeerten & Varma, 2017). This research contributes important design principles of AR which are specific to children's collaborative learning. This contribution can bridge the gap between CCI and AR communities. In conclusion, this research aims at achieving the following specific primary objectives:

1. To contribute a conceptual framework for children's AR textbook design.
2. To contribute AR design features to facilitate collaboration with children in schools.
3. To suggest a co-design approach for the development of AR applications for primary school children.

II. LITERATURE REVIEW

Introduction

After clarifying the research context, the processes of this research started with a review of literature related to the research context. The researcher reviewed relevant literature aiming to

understand the current state of knowledge in related fields, and to gain insights that could inform the development of specific research questions. The main three subject areas are CCI and co-design, including their relation to the PD approach and a discussion of the involvement of children in the design of interactive technologies. Then, the work has been related to AR for learning and collaborative AR Books focusing on the design requirements and recommendations of these studies. Details on the works of these contexts have been reviewed and discussed in this chapter.

II.1 Child-Computer Interaction and Co-Design

The connection of CCI and PD

Studies of PD with children tend to focus on several inter-related philosophical arguments around the involvement of children in the practice, including the examination of methods to facilitate children's involvement and on the quality of the products and ideas that are generated during PD (Simonsen & Robertson, 2013). The Interaction Design and Children (IDC) community often considers PD as a preferred methodology for studies involving children in the design of new technology for children. Since its inception in 2002, of the 195 long papers published at the annual IDC conference, 35 have included at least some aspects of participatory design (e.g. Thang *et al.*, 2008; Iversen & Smith, 2012). The effectiveness of PD in terms of gathering ideas and inspirations from children has been discussed within the IDC community (Read, Fitton & Horton, 2014). Many other papers on PD have been published at the annual CHI conference (e.g. Dindler *et al.*, 2010).

A core value for the field of CCI is that the interests of children are represented and respected in the research and design processes (Yarosh *et al.* 2011). Participatory design has become related to the CCI literature in terms of methodology, tools and techniques. In particular, the Scandinavian co-design practices provided a valuable resource for setting an agenda for CCI research that explicitly addresses ideals and values in research and practice.

According to as Iversen & Dindler(2013)*, "The use of co-design activities such as low-tech prototyping tools to capture and demonstrate new technology has been established as the very hallmark of PD in CCI".*PD with children had two underlying principles, namely that children

are contributing to make better technology and that children contribute their voices for empowerment. The work on co-design by (Druin, 2002) has been highly influential in this regard. The Human Computer Interaction Lab at the university of Maryland pioneered a co-design practice where small teams of children worked for several weeks on design projects with adult participants (Druin *et al.* 2001; Guha *et al.* 2005).

Following the PD approach, a substantial body of research also examined how children can be involved in the design processes. The most influential in this area is the work of Allison Druin who represented the relation of the various roles children can play during the design process (2002). Druin is one of the key scholars in the field of CCI, who has been designing with children for over 20 years and has found that children offer honest feedback as well as ideas and design directions, which would not have been as effective as with an adult-only sample. Her model in Figure 4 shows that the role of children can vary by simply being the end-user of a technology that is designed by adults, to the most involved role as members of the design team, who are active participants and equal design partners throughout the design process.

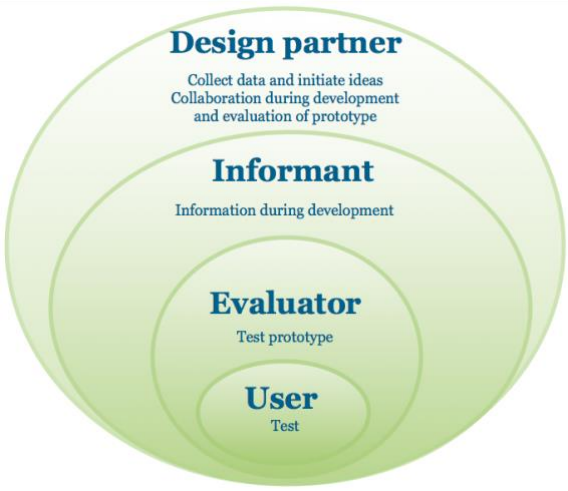


Figure 4: The role of children in the design of new technology (Druin, 2002).

The role of children in the design process is not something new. The discussion had started to evolve in HCI papers in the late 1990's (Druin, Stewart & Proft, 1997; Scaife *et al.*, 1997; Druin, 1999). Inkpen (1997) discussed the characteristics of educational multimedia systems that are important for HCI researchers and further emphasised on user-centered designs for future reseaches. Markopoulos & Bekker (2003) emphasised on the participatory design

approach for children's technologies. This idea is strongly supported by Druin who emphasised that the involvement of children in the design of a technology for learning not only impacts the technologies that are created, it also, *"can lead to new theories for education and new teaching practices with technology"* by creating a better understanding of how children learn (Druin, 2002: 9).

Bruckman, Bandlow & Forte(2003) also emphasised the need to involve children in the design processes. The characteristics of children that can impact the processes and outcomes of evaluating the technology could be the capacity to verbalise their thoughts, to concentrate and for abstract thinking (Markopoulos & Bekker, 2003). Whereas Read & MacFarlane explained three valid reasons for asking children for their opinions of interactive products,

> *One is that adults and children live in different worlds and for that reason adults may not understand what children want. Secondly, there is a move to include children in decisions about their own environments. This has arisen from a greater awareness that children are actors and participants rather than onlookers in society. A third reason for talking to children about their interactive technologies, perhaps for some people the most motivating, is that involving children in the design and evaluation of their own artifacts is rewarding for researchers, developers and, more importantly, for children (Read & MacFarlane, 2006).*

CCI work and co-design of children's technologies

Druin *et al* (2001) involved children as design partners with adults in the design process of a digital library for children. At different stages in co-designing, children can play a combination of all of these roles to establish common goals and participate in collaborative development activities. Early research in CCI examined the interaction of children and technologies developed for adults, realising the need for products that are specially designed for children to fit their educational needs (Papert, 1983). Examples of the early work are Druin & Solomon, (1996); Scaife *et al.* (1997). These publications were followed by the significant part of the CCI research that focused on methods of design and evaluation, as the community sought to find how best to design and evaluate products with and for children (Read & Markopoulos, 2013)

Designing and evaluating applications for learning has been gaining much research attention by CCI researchers. CCI studies have interests in book-related technologies for future children's books (Freed *et al.* 2011). Collaborative learning, for example, was the focus of (Antle *et al.* 2011) in developing a game play on a digital tabletop. The example of The Mad Evaluation Session with School children or on MESS day, was used by the Child Computer Interaction (ChiCI) group and involved a mix of several techniques unified by the goal of evaluating new technologies that support playfulness, and are easy to use and engaging (Medicherla, Chang & Morreale, 2010).

Zaman & Abeele(2007) discussed a framework for evaluating the likeability of children's software that takes into account five areas: '*challenge and control'*; '*social experiences'*; '*fantasy'; 'creative and constructive expressions'* and lastly, '*body and senses'*. New insights and modifications for an interview method with children as user experience were carried out as an evaluation exercise (Zaman & Abeele, 2010).

While there are many benefits of involving children as design partners, there are also inherent challenges, such as losing track of the generated ideas and data. One way to tackle this problem is to use a combination of approaches to capture data, such as journal writing, video camera observation, team discussion and adult debriefing (Alborzi *et al.* 2000). As a result, most designers tend not to engage with children until at the testing stage only, but their inputs will be limited to the feedback on what is presented to them. Also, the information children bring to the design in the early stages can be critical because it helps collect complete data about specific user requirements in a primary school educational context. It is recommended that adult designers must assess the needs of the project to make the best decision regarding when children should be invited into the co-design process (Druin, 2002).

Other recommendations made by Xie *et al.* (2012) to HCI researchers interested in co-designing with children and older adults include supporting distributed collaboration, elaboration, working primarily in small groups or pairs, giving time for large group discussion with older adults only, using art supplies with children and using post-it notes for children and older adults. Read & Markopoulos(2013) underlined four key challenges in the field of CCI for researchers and designers to focus on, which are the link between theoretical work and

interaction based design practices; the role of children's participation in the design process, bringing families in the focus of play and learning and a return to the concept of storytelling.

In most of cases which have been identified in the literature review, CCI researchers used methods that are not adapted for children. The need for methods that are tailored specifically to be used with children is crucial to guide practitioners and researchers in the field (Jensen & Skov, 2005). There are a number of methods and techniques that design researchers have applied and are identified in the CCI literature to support participatory design with children and adults.

One of them is referred to as Kid Reporter, which is considered to be suitable for children and is also appealing in terms of participating in design (Bekker *et al.* 2003). A brainstorming technique called Mixing Ideas was created to involve younger children, principally aged 5 and 6, in a design brainstorming process by encouraging each child to generate ideas and combine them with the ideas of others in a group (Guha *et al.* 2004). Another approach was referred to as Mission from Mars provided a method for children to express their ideas on everyday life by communicating with an adult researcher in another room, who represented someone that did not understand life on Earth (Dindler *et al.* 2005). A storyboarding technique uses the story of a system design, drawn onto large sheets of paper, to establish a timeline so the design team can provide critical feedback (Truong, Hayes & Abowd, 2006). A newer technique called Obstructed Theater allows children to be prompted at the beginning of a design session without influencing their designs (Read, Fitton & Mazzone, 2010).

Children and co-design of non-desktop systems

A recent study revealed how children engage in participatory design of wearable. Kazemitabaar *et al* (2017) described their participatory design process, in the iterative development of a new wearable construction kit for children that uses a tangible, modular approach to wearable creation. They used cooperative inquiry techniques with children and adults including low-tech prototyping sessions for brainstorming design ideas in which several recurring themes emerged. At later stages, they used the semi-functional prototypes to test the design and get feedback from children. Kazemitabaar *et al* (2015) in previous studies also

used participatory design with children to design a shoe-based interactive wearable experience. Following participatory design approach to design wearable and tangibles for learning, (Norooz *et al.* 2015) conducted an iterative design process with children for the development of three prototypes of an interactive e-textile shirt for body learning. They also used low-tech prototyping and cooperative inquiry for evaluating the final prototype.

Chen *et al.*(2004) involved 10-11 years old children in the development of web-based user interfaces for community websites. The evaluation found these interfaces to be more usable than a popular commercial user interface. Also, Höysniemi, Hämäläinen & Turkki (2004) worked with seven to nine-year old children in order to find out the most intuitive movements for game controls and to evaluate the relationship between avatar and player actions. They were able to learn how children would naturally move their bodies to accomplish tasks in the game. Van Mechelen *et al* (2013) argued that the advantages of tangible user interfaces, in terms of usability, learning, collaboration and entertainment, need to be supported more sufficiently. In addition to this, they recommended the need for design-driven research to explore relevant design concerns in the context of realistic design problems.

An alternative study, authored by Benford, O'Malley, Simsarian, *et al* (2000), asserted the use of co-design method to design a technology for children to encourage collaboration. It argued that '*encouraging collaboration'* is more proactive than only '*enabling collaboration'* and is not as rigid as '*enforcing collaboration*'. This principle was implied through adding features to the technology, *"that allows children to work as individuals, but gives added benefits if they choose to work together"* (Benford *et al.* 2000: 8). The principle of *'encouraging collaboration without enforcing it'* was supported by the design concepts found by these research studies.

Moraveji *et al* (2007), used comics as a way to scaffold idea generation from children and called this technique Comic Boarding. The study concludes that Comic Boarding is considered as a low budget technique, but it has resulted in many unexpected observations. Mitchell(2011) experimented with this technique by using incomplete comic stories and invited the children to complete it by drawing a design idea in the final frame. The technique appeared to offer potentials on the range of ideas and on the positive role of children in the co-design process. However, they claimed that the variety of ideas resulting from the Comic Board activity

confirms the argument proposed by the previous study that involves a small number of children in participatory design is not likely to lead to representative results.

Williams, Jones & Fleuriot (2003) involved children as informants in two workshops to assess the potential use of wearable computing by children. It was reported that children were able to conduct dialogues with researchers but there was no elaboration of ideas. The same team involved children as informants again to conceptualise the digital augmentation of physical space and to self-author within an outdoor space (Williams *et al.*, 2005).

A recent field study adopted a participatory design approach with children for designing a tangible to support socio-emotional learning for primary school children. It involved 9 children and 2 designers to design the evolving versions of the tangible through the cultural probe, the technology probe and through the interactive prototype. It presented the participatory design process using mixed methods of logs and surveys (Gennari, Melonio & Rizvi, 2017). The participatory design process in this study was similar to that in the process of planning, actions in the field and reflections over their results which advanced the design features in the prototype. In terms of the data collected, it was only concerned with the usability and the user experience. It would benefit from the ELU framework since it not only considers the user experience and usability but also the learning aspects which are missed in the data collection of this study even though the design is intended to support an aspect of learning.

A participatory design study aimed to understand children's perspectives on technologies that are best suited to enhance their engagement with practice of well-being skills (Yarosh & Schueller, 2017). It involved children in cooperative inquiry session using post-it notes, sketches, and prototypes for children's ideas. The children's ideas and prototypes revealed specific facets to understand their perspectives on these technologies. It was noted that desktop or laptop solutions were lacking but other ideas varied between mobile apps and embodied computing technologies.

In terms of co-design with children of e-books, Landoni (2010) involved children in co-design process to build a bookshelf of engaging e-books for children, considering the interface design, the content of the e-books and the social side of reading at age of 6-9 year old. This work

progress into exploring children requirements of the reading experience in order to set up the co-design process that will result in innovative models and interfaces for more engaging children's eBooks(Colombo, Landoni & Rubegni, 2012). They used Cooperative Inquiry techniques with 9-11 year children at a children's library to design the engaging eBooks for children (Colombo & Landoni, 2013). They experimented with low-tech and high-tech prototypes by introducing tablet computers (iPads) as tools for supporting co-design. In 2014, their paper proposed some recommendations from the cooperative inquiry study that resulted in design guidelines for more engaging e-books (Colombo, Landoni & Rubegni, 2014).These guidelines suggested that the eBook should be designed to be flexible, allow for personalisation and adding gamification features to enhance the e-books.

Developing AR systems for learning has been reported in many empirical studies often conducted in lab settings which lack the actual context of the classroom environment. One study used co-design for AR learning environments which, used in classroom contexts, has resulted in important design principles (Cuendet *et al.* 2013). However, it conducted the co-design process of prototyping and testing with teachers only without the involvement of children. The design principles of this study have been fed into this research in identifying the themes of the first prototype and developed more specific concepts for collaborative AR textbooks through co-design with children.

Khaled & Vasalou(2014) used the common PD methods of low-tech prototyping and story-boarding in the early stage of design for idea generation. Informed by this experience, they proposed a new PD method that was developed at the later stages of the game design to scaffold ideation that supported and represented core concerns of serious games.

II.2 Augmented Reality and Education

Augmented Reality was previously used for high-end applications such as those in military aircraft, surgery training, manufacturing and entertainment (Azuma, 1997). However, with time and developments in software and hardware supporting AR, the technology has been applied in a wide range of contexts. With time, the use of Augmented Reality in education has been realised and actively pursued by researchers and practitioners (Billinghurst, 2002).

Educational researchers have recognised AR as a technology with great potential to deliver effective and cognitive learning outcomes. In recent years, the learning tools based on AR have been highly recommended to be applied in educational sites, to enhance students' interests in learning as well as reduce their cognitive loads(Chang & Yu, 2017). Although AR is acknowledged for supporting the learning experience in many aspects, very little research work has been carried out to substantiate these claims (Ibáñez *et al.* 2014).

AR potential to education

Augmented Reality enables an experience where the learner can interact with the environment as compared to more traditional technologies including e-books, projectors, computers and CD's, etc. which allow the users limited interaction with the environment. Using AR, it is possible to augment printed material so as to make the whole environment richer by adding multimedia and virtual 3D objects to the printed material. In a study conducted by Sumadio & Rambli to determine user acceptance of AR use for education, and the usefulness perception of it, the participants showed very good feedback and enthusiasm for AR use in education (Sumadio & Rambli, 2010). Mat Sah, Teck Chyan & Hisham(2014) used AR to create art books to promote Malaysian traditional games, and found that AR was able to enhance information delivery and attract attention which could be effective in learning. An experimental comparative study aiming to know the effects of the intervention on the students' learning achievements in Portugal, suggested that the augmented textbook contributes to better learning results than the traditional textbook(Gomes, Gomes & Oliveira, 2017).

Dunleavy(2013) determined three design principles for designing the AR learning experience, which could be mapped onto the three characteristics of *'intrinsically motivating instructional environments'* proposed by (Malone, 1981). These characteristics are termed '*challenge', 'fantasy'*, and '*curiosity'*, and the AR design principles by Dunleavy were mapped correspondingly as '*enable and then challenge'*, '*drive by gamified story'*, and '*see the unseen'*.Shelton & Hedley(2002)developed an AR for undergraduate geography students, and they found a significant overall improvement in students' understanding. Correspondingly, Maier, Klinker & Tonnis(2009)and Chien, Chen & Jeng, (2010) developed an AR educational tool to support students' spatial ability skills to navigate in 3D space. Squire & Klopfer(2006) explored the potential of handheld AR on engineering students. AR-Dehaes is one of the AR

Books developed for education (Martín-Gutiérrez *et al.*, 2010). Students' motivation was also explored using AR. For example, Di Serio, Ibáñez & Kloos, (2013) showed that AR has more positive impact on the motivation of middle-school students than obtained in a slides-based learning environment. Also, Wei *et al.*(2014) presented a creative design teaching scheme focusing on the motivational aspects, showed that the proposed teaching scheme significantly improves learning motivation, student creativity, and the teaching of creative design.

Unlike other educational technologies, AR applications are user-friendly, open-access, and can be used by teachers to create daily teaching activities (Figueiredo *et al.*, 2014). It can also be cost effective using off-the-shelf tablets such as the Apple iPad. It can be seen that different types of AR such as interactive AR Books for education should continue to be explored in different levels of education, subjects and learning environments in order to contribute significantly in the wider area of education.

AR and educational theories

In terms of the construction of a theoretical framework, AR has been linked to different educational theories through various features to be found in AR. For example, Rigby & Przybylski(2009)determined that AR can be linked to the *'self–determination theory'* which defines learning that occurs through motivation. Bressler & Bodzin(2013) linked AR to the *'flow theory'* in a way that people who are engaged in meaningful activities are more likely to stay focused, and that AR connects the real-world surroundings to learning in a new and engaging way. It is suggested that AR does not generate consequences for students' actions as needed compared to a behavioral learning environment(Lin *et al.*, 2013).

When focusing on the collaborative learning, AR is considered to be grounded in *'situated learning theory'* and *'constructivist learning theory'*(Dunleavy & Dede, 2014). Situated learning theory assumes that learning takes place within a specific context and the quality of the learning is a result of interactions among the people, places, and objects within and relative to that given context (Brown, Collins & Duguid, 1989). Whereas constructivist learning theory sees learning as an active process of constructing knowledge through experience (Bruckman,

Bandlow & Forte, 2003). Constructivism also encourages students' collaboration, and collaborative learning as an educational aspect (Barron, 2000).

As a constructivist, Papert argued that children acquire knowledge through experience, and makes the point that in classrooms saturated with technology there is actually more socialisation, and that the technology in classrooms often contributes to a greater social interaction among students and among students and instructors (Papert, 1983). Dunleavy (2013) concluded the result of that AR is well aligned with the situated and constructivist learning theory with this explanation,

> *As a cognitive tool or pedagogical approach, AR positions the learner within a real-world physical and social context, while guiding, scaffolding and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation (Dunleavy, 2013: 32).*

Concerning the psychological aspect of social interactions and their development. Yuill & Rogers(2012) proposed three core mechanisms of behavior that can support or obstruct collaborative working, namely: the *'awareness of one's own and others' gestures'*, *'actions, movements and mental states'*, '*control over interactions'*with the interface and availability of the background information; and expectations that users bring with them. The design framework should consider these psychological aspects in addition to the technological features to successfully support collaboration. In designing a collaborative handheld application, the key events in the collaborative processes were introduced as *'task co-ordination'*, '*synchronisation of the task'*, *'negotiation and discussion'* and *'support for individual and group achievement'*(Patten, Arnedillo Sánchez & Tangney, 2006).

Augmented Reality Books

Augmented Reality Books, like any other AR application, allow virtual objects to be superimposed onto the real world. The distinction is that an AR Book uses a normal book as the main interface, enabling users can use their book as usual. However, if they look at the pages through the AR display, they will see the virtual objects appearing attached to the pages of the book (Figure 5). AR Book has a great potential for educational innovation because it

allows the student to interact with an expanded and enriched book using 3D animation and different types of digital media.

Figure 5: AR Books (Billinghurst et al. 2001), (Billinghurst & Duenser, 2012), (Kato et al. 2007).

The pioneers of the concept of AR Books are Billinghurst, Kato & Poupyrev(2001) who proposed the '*Magic Book'* which was the first attempt at creating a transitional AR interface using a normal book as the main interface and a handheld display. Several researchers were inspired by this idea and their inspiration led to the creation of several AR Books with the first commercial AR Book becoming available in 2008 (Billinghurst & Duenser, 2012).

While more AR Books entered the market after that, the research has been steered towards the technological development of AR Books (Gupta & Jaynes, 2006; Grasset *et al.* 2007; Kato *et al.* 2007).Cheng & Tsai(2014) provided the implications for AR Book as future pedagogical applications. AR Petite Theatre is an augmented story book designed to support children's empathic behaviours. The experimental study had resulted in more empathic behaviors in the AR group and concluded that AR Petite Theatre had the potential of expanding children's ability to empathise with others (Ha & Woo, 2014).

Some researchers have started to explore the potential of AR Books in education and have presented several AR Books as instructional tools. For example, an AR Book for teaching and learning geometry shapes for elementary students was called AGeRA. A preliminary usability evaluation concluded that AGeRA enhanced the textbook value as an educational material, supported the learning process and triggered greater interest and curiosity in students (D.Corrêa *et al.* 2013). Other researchers have limited the evaluations to preliminary or informal

evaluations on the usability of AR Books such as (Sin & Zaman, 2010;Al-Khalifa & Al-Khalifa, 2012; and Margetis *et al.* 2013). Others such as (Clark & Dünser, 2012;Matcha & Awang Rambli, 2012; and Tomi & Rambli, 2013), have left the evaluation for future work. It can be noted that most of the researchers were focusing on the technological development and implementation of their proposed AR Books, rather than the design requirements and concepts for the specified purpose and their specific user group.

AR Books for primary schools

Looking at AR Books for primary schools, Ellie's book was an AR Book based on elementary schoolbook for English alphabets, however, the evaluation was left for future work (Papadaki *et al.* 2013). Gancedo (2012) developed an AR application for primary school children using handheld devices. The thesis concluded that handheld devices and tablets in particular, are excellent tools that can be used for a wide spectrum of interactive educational applications with more possibilities than standard desktop applications. AR Books for primary schools have been widely studied for learning English as a foreign language. For example, MOW is an AR game for Portuguese primary school students for learning English. The study indicated that AR has a positive pedagogical impact on the learning process concerning primary aged children, specifically in the progressive domain of recognition of words and concepts and their written forms (Barreira *et al.* 2012).

The Seed Shooting Game is also an AR Book for teaching English as a foreign language for primary school students in Thailand. The quasi-experiment presented an example of the successful convergence of AR Book in classrooms and that it played a significant function to increase both the process and the learning outcomes(Vate-U-Lan, 2011). Another English-teaching AR Book was designed for teaching the English alphabet to Malaysian pre-school children. The preliminary results indicated that the unique interface of combining real and virtual objects acts as a natural attention grabber as well as an engaging and fun learning tool for this age group (Tomi & Rambli, 2013). Similar work in Malaysia also evaluated the motivational aspect of an AR Book for English language for primary schools and showed that students were motivated in their specific learning session(Mahadzir & Phung, 2014).

One of concerns of the teachers using AR-based learning in a classroom environment is that if students experience this type of knowledge acquisition, they will not go back to their previous ways of learning. However, Annetta *et al* (2012) expressed the view that AR can be an activity to engage students in future units and discussions. Teachers have reported students taking responsibility and ownership of their learning in which educators using AR are becoming facilitators to their students (Kamarainen *et al.* 2013). Even within the elementary grade levels, teachers play a very important role in engaging the students, especially when introducing complex technical equipment to their students so they can take part in AR activities (Enyedy *et al.* 2012).

As has been shown in the literature that integrates interactive AR technology in learning, the lessons will be more meaningful to the young learners as Barreira, Bessa, Pereira, *et al.* (2012) indicated by their work of using AR in classroom:

> *The use of AR has a positive pedagogical impact in the learning process concerning young children, more exactly in the progressive domain of oral recognition of words and concepts and their corresponding written forms. Accordingly, we strongly believe that AR will be, in a short term, an important tool in the class activities in some areas of education (Barreira et al., 2012).*

> *Primary school will be the best platform to enhance the development of English language learning skills by integrating interactive technology in learning, so that the lessons are meaningful to learners. Knowing English language has become an added advantage and also an economic commodity (Mahadzir & Phung, 2014 :27).*

It is possible to conclude that this exciting way of learning through interactive technology can make it possible to enhance students' interest in learning English as foreign language. It is agreed that primary schools will mostly benefited from this recent technology to support learning English in Saudi Arabia. The level of the language skills often differs from one student to the other in the same grade and so in this context, in which the collaborative interaction that can be afforded by AR is likely to help children to get advantages from each other and increase chances of co-construction of knowledge.

II.3 Augmented Books and Collaborative Learning

Textbook-based AR

One of the most important purposes of an educational environment is to promote social interaction among users located in the same physical space (Kaufmann, 2003). Textbook-based AR allows multiple students to share the virtual scene and interact with it through the tablet interface. Using a tablet as the real-time interface creates opportunities for collaboration that fosters a deeper understanding of the content. A comparative study focused on paper books and paper augmented with digital media found that the book's ergonomics provide a flexible interface which support collaboration between children in educational settings (Tallyn *et al.* 2005). Informed by the belief that learning is inherently a social activity, Patten, Arnedillo Sánchez & Tangney, (2006) argued that the unique attributes of handheld applications facilitate learner collaboration and support knowledge sharing. Using the school textbook combines the benefits of the paper ergonomics and the benefits of the tablet interface.

In their field study of collaborative AR, Morrison *et al* (2011) identified the need for AR developers to create opportunities for collaboration among children. A study on lessons from AR books for children, it was emphasised that AR Books support collaborative learning through the use of a book as interaction metaphor and tangible elements that bring playfulness back into learning(Dünser & Hornecker, 2007). It should be noted that although the influences of AR on education are gradually becoming more considerable, studies that present a thorough exploration of AR for collaborative learning remain limited. According to Azuma *et al.* (2001: 6)*"the major trend of interaction research is the development of collaborative AR interfaces"*. Within this research trend, the question of the key concepts and design guidelines for effective collaborative AR interfaces is still open for debate.

Collaborative AR for education

Examining the work of AR in collaborative learning, Studierstube is one of the earliest AR applications in education to create a collaborative environment (Schmalstieg *et al.* 1998). It was followed by the Construct 3D which was based on the Studierstube system for engineering students(Kaufmann, Schmalstieg & Wagner, 2000). Kaufmann, (2003) reflected on the work of the two previous systems and emphasised that comprehensive evaluations of the practical

value of such educational tools will require the development of substantial educational content that is put to real use in classrooms. The key elements to be considered for collaborative AR interface as proposed by Billinghurst, Wagner & Schmalstieg(2006) are providing a mechanism for sharing user views to establish shared understandings, enabling users to work in parallel and preserving the ability to share verbal and non-verbal face to face communication cues.

Another study of collaborative AR, on this occasion for the subject of inorganic chemistry study, has explained the implementation of classroom set up with webcams and markers, but without defining the concepts behind that implementation(Nuñez *et al.* 2008). An evaluation study on AR to improve the pedagogical effectiveness of collaborative learning process in urban design education used a previously developed theoretical frameworks for the analysis and the result showed that AR can enhance the design activities in some collaborative work (Chen & Wang, 2008). An AR-based framework was developed for e-learning platforms that allows the creation of collaborative activities for mobile devices (Javier Barbadillo, Nagore Barrena, V´ıctor Go˜ni, 2014).

Boletsis & McCallum(2013) used game design for a collaborative AR for chemistry education and Lin *et al.*(2013) developed collaborative AR and focused on evaluating learners' knowledge construction. Aasterud(2010) developed an AR tangible interface for primary schools and suggested that using AR in a learning situation can yield positive results depending on how it was implemented. Although the study focused on exploring the collaborative aspects, the developed application was not user-tested due to the study time limit, since it was a Masters dissertation. A recent study presented a literature review of previous studies of AR games for learning for different learner groups, learning subjects and learning environments and concluded the most reported effects for AR learning in the literature were the enhancement of learning performance and the learning experience in terms of fun, interest and enjoyment. They especially found that collaboration among students was encouraged by AR learning games (Li *et al.* 2017).

Design concepts and special affordances of AR

Naseem & Khan (2017) analysed the literature to understand the key factors for AR to education and reported the concept of *'collaborative knowledge construction'* as a potential benefit and design consideration of AR technology as applied to learning. One of the studies of design requirements for AR to be used effectively in primary schools is the work of (Kerawalla *et al.*, 2006). These authors have compared the use of AR and more traditional teaching methods, and revealed the design requirements of flexibility, and that the content should be taken from the curriculum. They also suggested a user-centered design approach to consider other requirements. Cuendet *et al.* (2013) followed that work, and proposed five principles for designing a collaborative environment for a classroom recommended to be instated through a participatory design process. These are defined as, '*integration*, '*awareness'*, '*empowerment', 'flexibility'* and *'minimalism'*.

Looking at the work of collaborative AR for children, the shared display was a common constant device which was employed, exemplified by a projection of AR displays onto a classroom wall with one student controlling the experience (Pasqualotti & dal Sasso Freitas, 2002). Others used shared displays such as a PC monitor or TV (Dünser & Hornecker, 2007; Theng *et al.* 2007). However, using one shared display allows for one child to control while the others only observe the experience (Bujak *et al.* 2013). The *'mutual control'* was emphasised in the literature as an element of successful collaborative experience. Based on the psychological literature on processes of social development, CSCL and HCI, Yuill & Rogers (2012) have abstracted three core mechanisms in behavior through which multi-user interfaces can support successful collaboration and natural interaction, namely '*mutual awareness'*, '*mutual control'* and '*availability of digital information'* related to the content.

These mechanisms in behavior were claimed to provide the improved collaboration based on the definition of Roschelle & Teasley (1995: 70), who stated that, *"Collaboration is a coordinated, synchronous activity which is the result of a continued attempt to construct and maintain a shared conception of a problem"*. They also argued there is a considerable scope for designers to shape the interface to support collaboration having a limited view into the shared virtual space, even when using the handheld display will prevent the mutual awareness.

Because learners need to see each other and discuss the virtual content at the same time, it is important for the virtual space to be anchored to landmarks in the real space. The AR Book can be a solution for this issue, in which it can be the anchored landmark and the reference points to the collaborators. It combines face-to-face collaboration with access to virtual learning content, permitting learners to have their own perspectives and control over the virtual content, while maintaining visual contact with their collaborators.

Based on these previous mechanisms, Hoda *et al* (2014) added other pedagogical considerations from teachers and mapping design criteria of educational software for collaborative learning to the pedagogical considerations. Table 1 shows a demonstration of the alignment of these design criteria with the pedagogical considerations.

Table 1: Aligning pedagogical and technological considerations (Hoda et al. 2014).

Pedagogical considerations (teacher's guidelines and collaborative learning core mechanism)	Technological considerations (design criteria)
Children's interest-led learning	Themed content.
Valuing children's opinions and choices	Dynamically generated content based on multiple theme selection.
Mutual awareness	Orientation of content to enable peer-content visibility.
Availability of information	Uncover correct answers to enable information availability.
Shared control	Use of tangibles.
Collaboration over competition	Designed to exclude scoring and to support all players completing their turns.

Makina & Salam, (2011) studied the past researches on effective collaborative learning characteristics to apply in the AR interface designs and revealed useful concepts such as the '*communication to construct knowledge', 'promoted interaction'* and the *'diversity between the students'*. An observational study of user interaction in collaborative learning using AR, has resulted in four communication cues such as conversational turns, gestures and

gaze(Matcha & Rambli, 2011). In the following year, Matcha & Rambli (2012)identified elements of collaborative learning and implemented them in the interface design of an AR Book for children. '*Social interaction'* and *'communication'* appeared again and the third element was defined as '*engagement'*. Shared point of references was included to promote mutual engagement of group members and problem solving was used to foster the social interaction of collaborators. In 2013, the authors used these concepts to analyse the collaborative interaction of AR for learning of the sciences, and found that AR offers various types of collaboration interaction which can occur concurrently or simultaneously (Matcha & Rambli, 2013).

> *A related affordance unique to AR is the ability to blend a fictional narrative such as the 3D characters with the real and familiar physical environment such as the school textbook. This feature allows educators to continually repurpose their school environments with multiple immersive narratives to meet various teaching objectives across the curriculum* (Dunleavy, Dede & Mitchell, 2009: 20).

Dunleavy has long experience working on AR for education and in 2013 he reviewed the literature focusing on specific strategies that instructional designers can use to develop AR learning experiences. Three design principles have been revealed from the literature and from his own work (Dunleavy, 2013), defined as, '*enable and challenge', 'curiosity'* and *'see the unseen'*. These can be viewed as an attempt to either leverage the unique affordances of AR or minimise the limitations of the medium as was reported in the literature (Dunleavy & Dede, 2014). They also argued that the unique affordance of AR in teaching and learning is enabling collaboration:

> *The majority of the studies covered in this review use AR to replicate and guide the dynamic and complex nature of collaborative problem solving within a real physical environment. While the challenge of facilitating collaborative, experiential inquiry in and out of the classroom may be the best instructional problem solved by AR, researchers need to continue exploring how this approach might ameliorate other persistent educational problems (Dunleavy & Dede, 2014: 26).*

Based on research that exploits AR for educational purposes, Wu *et al* (2013) identified the affordances of AR in education in five aspects and suggested possible alignments of instructional approaches with the affordances of AR and the important notions in education such as '*contextualisation', 'authenticity'* and *'engagement'*. One of the affordances is collaborative learning which can also include '*portability'* and *'social interactivity'*. The other aspects are '*learning content in 3D perspectives'*, '*learners' senses of presence'*, '*immediacy and immersion'*, '*visualising the invisible'* and '*bridging formal and informal learning'*. Krevelen & Poelman(2010) identified the need for the AR technologies to be designed effectively and with high usability. To sum up, a summary of the previous literature has been illustrated in Table 2, as a mean of extracting the common design concepts that are used later in the research.

Table 2: Design considerations of AR for collaborative learning in different context.

	Reference	Design considerations	Implementation context
1	Kerawalla *et al* (2006)	AR should be flexible to be adapted to the students' needs. The content should be taken from the curriculum. AR should take into account the constraints of the context.	Design requirements for AR as an effective learning tool.
2	Billinghurst, Wagner & Schmalstieg, (2006)	Sharing user views to establish shared understanding. Enabling users to work in parallel. Preserving the ability to share verbal and non-verbal face to face communication cues.	Collaborative AR interface for Art history.
3	R. Chen & Wang (2008)	A framework developed from learning theories. Constructive theory. Shared communication cues.	Comparison of the AR systems with traditional methods for urban designs

4	Aasterud (2010)	Lightweight interactions. Configurable material and externalization.	AR based tangible interfaces for primary schools.
5	(Makina & Salam, (2011)	Communication. Social interdependence. Students' exploration. Promote interaction. Diversity between groups. Assessment.	AR interface design for engineering students.
6	Matcha & Awang Rambli (2012)	Social interaction. Communication. Engagement.	Interface design of an AR Book for children
7	Yuill & Rogers, (2012)	Mutual awareness. Mutual control. Mutual availability.	Multi-user interfaces design
8	Cuendet, Bonnard, Do-Lenh, *et al* (2013)	Integration. Awareness. Empowerment. Flexibility. Minimalism.	Design principles for AR in CSCL environment
9	Dunleavy (2013)	Enable and challenge. Curiosity. See the unseen.	AR affordances for education unique to AR
10	Wu, Lee, Chang, *et al* (2013)	Learning content in 3D perspectives. Ubiquitous, collaborative and situated learning. Learners' senses of presence, immediacy and immersion. Visualising the invisible. Bridging formal and informal learning.	AR affordances for education unique to AR

11	Lin, Duh, Li, Wang, & Tsai (2013)	Collaborative knowledge construction.	Comparison between 2D and 3D systems for Physics for undergraduate students.
12	Boletsis & McCallum (2013)	Game design mechanism of differentiating roles and distributing expertise.	AR collaborative game for chemistry education
13	Hoda, Henderson, Lee, *et al* (2014)	Children's interest-led learning. Valuing children's preferences. Mutual awareness. Availability of information. Shared control. Collaboration over competition.	Educational software design for children.
14	Javier Barbadillo, Nagore Barrena, V´ıctor Go˜ni, and Jairo R. S´anchez (2014)	A framework for developing the AR system with integration to the (LMS).	AR authoring tool for teachers integrated with e-learning platforms.
15	Ke & Hsu(2015)	Mobile AR for CSCL	Socio-technical interactions aspects
16	Naseem & Khan(2017)	Modern Learning Method Using Augmented Reality in Education	Collaborative Knowledge construction.

Conclusion

This chapter has framed the scope of this multi-disciplinary research, and has showed the links between the related fields. The areas of PD, CCI, and co-design are related in the literature, and these are brought to the context of AR for children's collaborative leaning. It was discovered through the literature review that not much research has been done regarding co-design of AR for collaborative experience in schools. Even less research has been done about co-design with children for prototyping AR for schools. Importantly, the literature has highlighted the design considerations of AR for collaborative learning in different context which will be elaborated on later when developing the ELU framework (III.3.3, p. 86). The literature of CCI work and co-design with children has been useful in identifying the appropriate research method. Reviewing the Literature of AR and the collaborative learning

experience was also helpful in developing the conceptual framework to be used in the studies of this research.

III. Methodology

Introduction

The methodology chapter consists of three components. The first one discusses the research methodologies and approaches which have been explored in this thesis. It examines key methodologies such as participatory action research and participatory design showing the research position within the design research perspective and approaches that emerge from the study of these methodologies, namely co-design and cooperative inquiry. Additionally, it discusses the theoretical lens and the practical framework of the research methods to further understand the broader perspectives that underpin the research methods. The second component illustrates the framework of practice that informs the methods used in the three studies in terms of planning, data collection and analysis. The planning stages are informed by Sanders and Stappers'sco-design framework for organising toolkits and probes(Sanders & Stappers, 2014) and indicate the set of protocols for each co-design session. The data collection used the techniques of Druin's cooperative inquiry which involves the thematic analysis as the most appropriate for this type of methods(Druin, 1999). The data analysis followed the procedure informed by HCI research and used the ELU framework for clustering the data. The ELU framework is based on Read's PLU model (McKnight & Read, 2011). The need of this

proposed framework and the process of the adaption will be discussed in the final section of this chapter.

III.1 Research Methodology and Approach

III.1.1 **Participatory Action Research**

The paradigm of Participatory Action Research (PAR) is framed within this research and involves researchers and practitioners actively exploring possible improvements to the practitioners' situation together. The key characteristic is an iterative intervention in work practice and learning from this by critical reflection (Avison *et al.* 1999). PAR can be defined as, *"a qualitative approach related to design-based research that involves collaboration between researchers and participants, local practices that support systematic theorising and improvement in both theory and practice"*(Wang & Hannafin, 2005: 6).

Action research was fundamental to PAR, where the limitations of an action research approach have been recognised by the inventor of the *'action research'* term, Kurt Lewin(1946). Lewin described action research as, *"a proceeding in a spiral of steps, each of which is composed of planning, acting, observing and evaluating the result of the action"*(McTaggart, 1997: 27). McTaggart has re-imagined the description of action research as, *"the aspect of reflective spiral plays important role in effective re-planning, further implementation and acting"*(McTaggart, 1991: 170).Action research is a type of *'research through design'*, as Frayling categorised:

> *Action research where a research diary tells, in a step by step way, of a practical experiment in the studios and the resulting report aims to contextualize it. Both the diary and the report are there to communicate the results (Frayling, 1993: 4).*

Further definitions are attributed to authors Pearce & Crouch, *"Action research is perhaps the most powerful and liberating form of research available to practicing designers"* (Pearce & Crouch, 2012: 143). "*Because of its inherent flexibility and openness, (action research) is a particularly suitable methodology for a design project where the final outcome is undefined"*(Swann, 2002: 58). In action research, *"practitioners themselves examine and*

evaluate their own practice, both individually and collaboratively, to find ways of living more fully in the direction of their values"(Whitehead & McNiff, 2006: 7).

Authentic participation differs from the participatory action research approach that involves conducting research on people as a focus for studies from research that involves doing research on people. Different determinations of this authentic participation in research has been identified by *Tandon (1988: 13)"as people's participation in the data collection and the analysis and their control over the use of outcomes and the whole process".*

Participatory action research has several aspects that emphasised that every participant must collaborate with others engaged in the project to improve the work and the way it is theorised and to collaborate with others in their own separate institutional contexts to create a more informed and sustainable project. The other aspect is seeing the people as active participants in the living, local and concrete process of reconstructing the culture of their group. Foth & Axup (2006) argued that participation by those most affected by research outcomes is a mean to ensure that the research is relevant.

Participatory action research provides a theoretical basis for this research methodology for the benefits of its participatory and reflective viewpoints. It has been described as:

> *An approach to explore the process by which the participants engage in collaborative action-based projects that reflect their knowledge and mobilize their desires. (Participatory action research) sees knowledge making as occurring through the interaction among people, practices, and artifacts (Mclntyre, 2008: 5).*

Participatory action research is related to PD through the emphasis on practice and co-design processes with people rather than for people. It also aligns with PD through the aspect of the *'reflective spiral'* involved in the research practice process. The context of the technology being designed is a fundamental aspect of PD in addition to the practices within that context.

Participatory design also emphasises on the co-construction of knowledge(Wadsworth, 2005) and *"the notion of action as a legitimate mode of knowing, thereby taking the realm of knowledge into the field of practice"*(Tandon 1996: 21). The selection of method in PAR

driven studies is guided by PD, at the same time that PD study may use the PAR principles (Foth & Axup, 2006).

From these definitions, the intimate interconnection between PAR and PD is explicable and deriving from these perspectives, the PD paradigm was described as constructivist in which it sees knowledge by a practice in a certain context (Spinuzzi, 2005). As with PAR emphasis on empowering individuals through democratic processes, PD also seeks to make the design process more democratic (Iversen & Smith, 2012).

III.1.2 **Participatory Design Approach**

> *Participatory Design is a process of investigating, understanding, reflecting upon, establishing, developing, and supporting mutual learning between multiple participants in collective reflection-in-action (Bratteteig et al., 2012).*

Although PD has been seen as a design approach charecterised by user involvement, it has its own highly articulated methodological orientation, methods and techniques. This assertion also envelopes PAR, the approach on which it is based (Glesne & Peshkin, 1992).Spinuzzi(2005)also discussed participatory design as a research methodology that could be derived from participatory action research or practice research, characterising it as a way to understand *'knowledge by doing'*. He wrote, *"Participatory design's methodology is derived from PAR or, as Ehn calls it, 'practice research': Practical interventionist investigations (as opposed to gathering of data) and parallel theoretical reflection as opposed to detached theoretical reflections a posteriori"*(Spinuzzi, 2005:166). Ehn(1993: 6) argued that *"we produce both the world of objects and our knowledge about this world through practice"*.

Participatory design in design research

Traditional design research has depended on information derived from evaluation, while the contemporary design research integrated aspiration of users with design ideation using its own generative tools and a unique mindset (Figure 6).

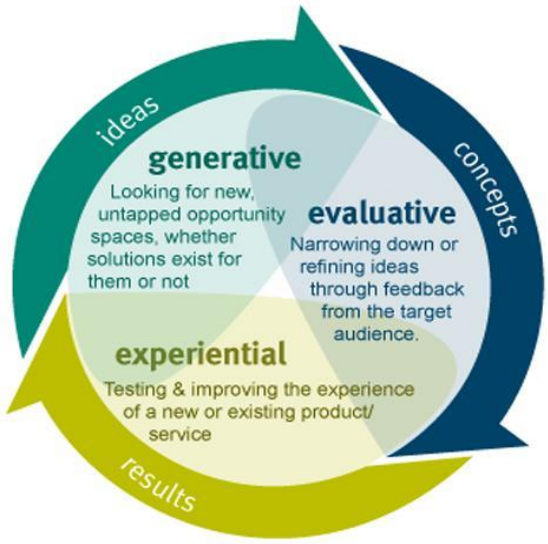


Figure 6: Design research relative to phases of design process (Scrivener, J.Ball&Woodcock, 2000).

Approaches to design research have come from a research-led perspective and from a design-led perspective. It is also charecterised by expert mindset that sees and refers to the people as *'subjects', 'users', 'consumers'* etc. and participatory mind-set that sees the people as '*co-creators*' in the design process. The diagram in Figure 7 presents these approaches in one unified landscape that is still evolving as design and research continues to be interconnected (Sanders & Stappers, 2007). Within this landscape, generative design research is positioned in the participatory design zone which spreads across both research-led and design-led perspectives.

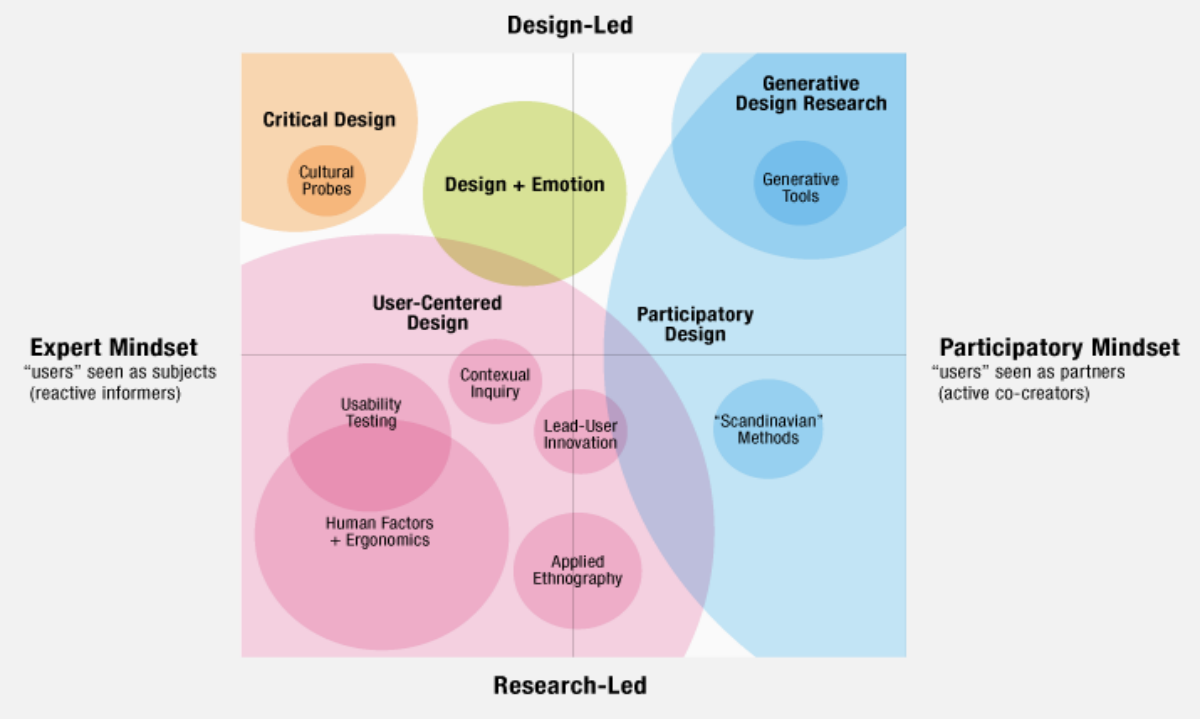


Figure 7:The evolving map of design practice and design research (Sanders & Stappers 2007).

Looking at the other side of the diagram, user-centered design which has a longer history in design research shows up as the larger zone of the design landscape. Although adopting a user-centered design approach proved to be useful in design and allows to incorporate large numbers of children into the research easily, the involvement of children is limited where they cannot initiate any change(Sanders, 1999).*"Another drawback is that the research methods such as task activities and questionnaire may be boring and/or difficult for the children to understand"*(Nesset & Large, 2004: 141).

Newly defined areas of design have emerged such as interaction design, service design and transformation design, which also incorporate more traditional design approaches within each of them. This has led to user-centered design facing challenges to address that scale and complexity of today's user experience, as has been identified by Sanders,

> *There is a shift in perspective occurring today at the collaborative edge of design and social science. It is a change from a user-centered design process to that of participatory experiences. It is a shift in attitude from designing for users to one of designing with users. It is a new design movement that will require new ways of*

> *thinking, feeling and working. Participatory experience is not simply a method or set of methodologies, it is a mindset and an attitude about people. It is the belief that all people have something to offer to the design process and that they can be both articulate and creative when given appropriate tools with which to express themselves (Sanders, 2002).*

Participatory design is considered as one of the design theories which are suitable for the specific needs of children (Nesset & Large, 2004). Participatory design, as defined by Sanders & Stappers (2007), is an attempt to actively involve those who will become the users throughout the design process to the extent that this becomes possible, to help ensure that the designed product meets their needs. Participatory design practices originated from Scandinavian countries in the 1960's and 1970's, that imagined all people as creative and could therefore be active design partners. It has been suggested that the principles of PD are the most suitable for design projects involving children (Nesset & Large, 2004).

According to Carmel, Whitaker & George (1993), there are two themes for the implementation of PD principles where one of them considers *'joint experiences'* for users and designers to teach each other about work practices and technical possibilities. The other theme is termed '*design by doing'* which is a creative-based process that Druin makes use of in her method *'Cooperative Inquiry'*, that will be used in this research (Druin, 1999).

It is important to note that the social interaction between users and designers, enabling mutual learning, shared reflection, and collaborative evaluation of ideas are essential aspects of this research. These are guiding principles of PD as Enh wrote, *"The origin of design is in involved practical use and understanding, not detached reflection and design is seen as interaction between understanding and creativity"* (Enh 1993: 62).

This rationale is supported by an observational study of AR Books for children (Dünser & Hornecker, 2007), that established that user experience and interaction design are important issues to be considered in educational AR Books. As emphasised by Melonio & Gennari(2013), the common benefits of adopting this approach are better understanding of the user requirements, building realistic expectations in target groups and *'empowerment of*

marginalised groups', since design partnering with children was found to build confidence in them academically and socially (Druin, 2002).

> *The field of PD has grown to become a valued and common design methodology in the development of new computer systems (Melonio&Gennari, 2013: 2).*

Designing a new technology of AR textbook for children's collaborative learning experience includes designing the main interface, designing the application and designing the overall learning experience. These different aspects are covered by interaction design and user experience. Interaction design can be defined as, *" The why as well as the how of our daily interactions using computers"*(Winograd, 1997: 160). The collaborative interaction was emphasised in defining interaction design, *" The art of facilitating interactions between humans through products and services"*(Saffer, 2010: 4).

User Experience and rationale of PD approach

User experience encompasses a wide range of disciplines and interaction design is at the center of user experience. As Preece, Sharp & Rogers(2015: 8) described, *"The focus of interaction design is very much concerned with practice, i.e. how to design user experiences"*. User experience is the umbrella term covering different aspects of design and is unanimously defined. Law *et al*(2009) systematically surveyed the views of over 200 user experience researchers and practitioners from academia and industry for a unified understanding and for defining of the concept of user experience. The results showed that the respondents tend to agree on a concept of user experience as *'dynamic', 'context-dependent'* and *'subjective'*, which stems from a broad range of potential benefits which the users may derive from a product. The term *'user-experience design'* claimed to be a reminder or motivator to designers to pay attention to people's experience of technology as well as to be an indication that a particular user experience can be designed(McCarthy & Wright, 2004)

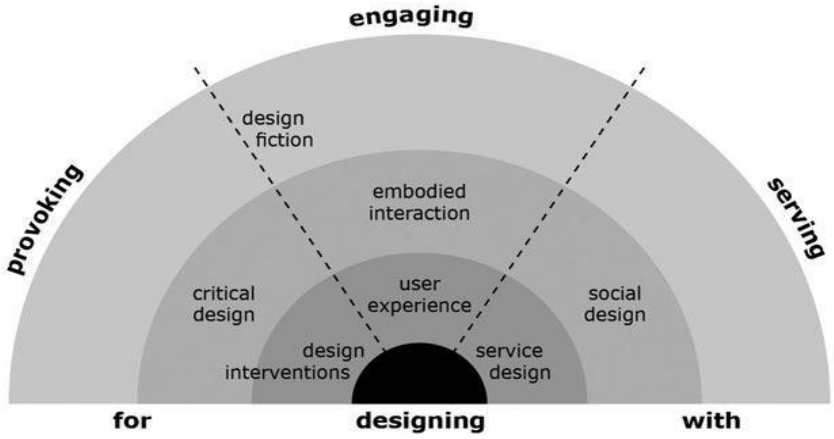


Figure 8: User experience across design approaches (Sanders & Stappers, 2014).

In Sanders & Steppers' diagram in Figure 8, the movements of relative design approaches are shown emerging across different time frames and the center of the diagram shows the core of designing where user experience is positioned with the aim to engage people (Sanders & Stappers, 2014). The rationale for following the participatory design approach came from the central focus of the user experience. Today, the relationship between new technologies and user experience has become very complex and integrated. As research has shown that user experience is the key to the success of a product (Lowgren, 2013), the need of user experience manifests in this research in two aspects. Firstly, designing for this special age group and secondly, designing for collaborative learning experiences.

User experience aims to bring the user to the center of the designer's thinking to ensure products meet the intended users' needs and is usable. As concluded from four user centered studies of three different types of AR applications (Nilsson, 2010), AR applications require the involvement of users both in the design and evaluation processes. However, Sanders argued that designing for experience cannot be really done unless accessing experience through three perspectives, namely, *"what people do, what they say and what they make"* (Sanders, 1999: 4). These three perspectives involved traditional design research methods that focus primarily on observational research (i.e. looking at what people do and use), traditional market research methods that focus on what people say and think (through focus groups, interviews and questionnaires) and new tools that focus on what people make from the toolkits provided for them to express their thoughts, feelings and dreams (Figure 9).

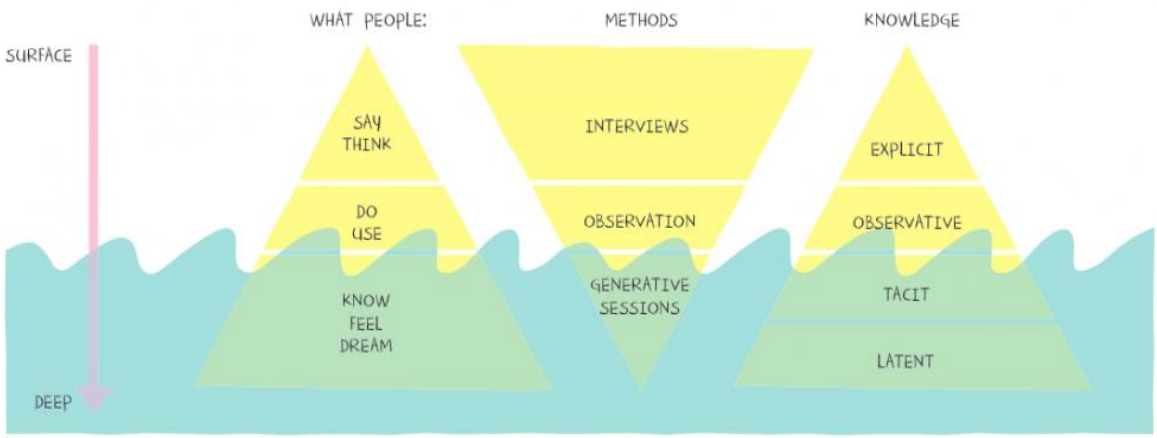


Figure 9: Perspective to design for experience relative to types of knowledge (Sanders, 1999).

> *Listening to what people say tells us what they are able to express in words i.e. explicit knowledge. Watching what people do and seeing what they use provides us with observable information or observed experience. But knowing 'what people say/think, do and use' (Cain, 2010) is not enough. Discovering what people think and know provides us with their perceptions of experience. Understanding how people feel gives us the ability to empathize with them. This way of knowing provides 'tacit knowledge'. Special tools are needed to access the deeper levels of user expression (Sanders, 2002: 7).*

The use of these special tools to access the user experience where *'construction'* is involved in the research is referred to as '*constructive design research',* which is a new term of contemporary design research introduced by Koskinen *et al* (2011), where design and research are integrated. The authors claimed that researchers like Fulton Suri and Liz Sanders have effectively pushed designers into fieldwork where the focus is on co-design as an analytic method and gaining of understanding that is beyond ethnographic observation. The following two quotes can support their claim and support the co-design as the appropriate method:

> *The practice of observing and interviewing people in their natural habitats has become widely established in design…. Certainly ethnographic-style observation can provide inspiration and grounding for innovation and design. It increases our confidence that ideas will be culturally relevant, respond to real needs and hence be*

more likely to have the desired social and market impact. But for design and designers there's much more to observation than that (Suri, 2011: 2).

We put a large number of components together into toolkits, people select from the components to create "artifacts" that express their thoughts, feelings and/or their ideas. The resulting artifacts may be in the form of collages, maps, plans and/or memories. The stuff that dreams are made of is often difficult to express in words but may be imaginable as pictures in your head. Seeing and appreciating what people dream shows us how their future could change for the better. It is another form of the 'tacit knowledge' that can reveal 'latent needs', i.e., needs not recognizable until the future (Sanders, 2000: 5).

Co-design and tacit knowledge

The term *'tacit knowledge'* is the knowledge that can't readily be expressed in words(Polanyi, 1967) and can be described as the phenomenon that, *'we can know more than we can tell'*. Michael Polanyi, who invented this phrase, gave an interesting example for tacit knowledge from the recognition of faces.

If we know a person's face, we can recognize it among a thousand, indeed, among a million, though we usually cannot tell how we recognize a face we know. Similarly, we can recognize the moods of the human face without being able to tell, except vaguely, by what signs we know them (Polanyi, 1967: 4).

Until recently, the term tacit knowledge has gained attention from design researchers as has been cited previously (Sanders, 2000; Cross, 2006; Cain, 2010; Koskinen *et al*. 2011).In addition to Crouch & Pearce, who gave a working definition of the tacit knowledge in which it consists of *"sets of information and practices that we call upon unconsciously but cannot fully articulate, but can simply be demonstrated and imitated"*(Crouch & Pearce, 2012: 38). They argued that *'practice'* is a combination of tacit and explicit knowledge and it is the job of the researcher to try and unravel the two. Melonio & Gennari offer the following observation,

When people are invited to make an opinion, it does not necessarily mean that is taken into account and the level of influence is relatively low; when people are asked

to participate, interact and collaborate in the building of a design process, then there is a high level of influence (Melonio & Gennari, 2013 :24).

Cross also implied that, *"There are 'designerly ways of knowing', distinct from the usually-recognised scientific and scholarly ways of knowing"* (Cross, 2006: 22). This argument about tacit knowledge will be stronger if we are to relate it to children and therefore Sander's perspective of using probes and toolkits became strongly supported for PD research with children.

Using the process which is involved in Druin's cooperative inquiry techniques, make children's knowledge explicit, by involving adults who observe their intuitive behaviours and responses to the experience. The adult research facilitators take notes throughout the session, ask children questions about their thoughts and help them to express their ideas using the toolkit as well as elaborating on their non-verbal impressions. Thematic analysis is central in the cooperative inquiry method because patterns are crucial in conceptualising, not to mention its relation to the cooperative inquiry as a component of its procedure. All these will be discussed in detail in the conceptual framework and research method sections.

III.1.3 **Theoretical Lens and Reflective Model**

After understanding the theoretical position of this research and discussing the adopted approach, the second component of the methodology would be clarifying the theoretical lens through which the research is viewed and conducted. The interpretive tradition of research holds that, *"people are part of and create their own reality, hence the world cannot be understood without us, also understanding the people who create the reality",* (McNiff & Whitehead, 2006: 10). Usher, Bryant and Johnson observe that, *"An interpretive lens focuses on human actions and assumes that all human actions are meaningful and hence to be interested and understood"*(Ian Bryant, Rennie Johnston, 1997: 181).

Interpretive lens and participatory action research

The implication of an interpretive lens is clearly evident when using co-design and thematic analysis more than other methods such as interviews, because the researcher was seeking out and negotiating meaning with the same participants throughout the co-design studies. One

other significant implication is that, *"Interpreting part of something depends on interpreting the whole but interpreting the whole depends on interpreting the parts. It means that knowledge formation always arises from what is already known and is therefore not linear but circular, iterative, spiral"* (Usher, Bryant & Johnston, 1997: 182). This is congruent with action research as *"proceeding in a spiral of steps, each of which is composed of planning, acting, observing and evaluating the result of the action"* (McTaggart, 1991: 170).

One important implication of using this research lens identified in PAR, where both the researcher and the research participants are '*jointly engaged'* in acts of interpretation that reflect their knowledge, is highlighted by Crouch &Pearce.

> *The recognition is that, since the way we know the world is through interpreting it, both the researcher and the research participants are jointly engaged in acts of interpretation and the research process becomes a conversation between the researcher and the participants……. A researcher working within an interpretive lens acknowledges this by providing opportunities for the experiences of others to be given center stage and making the research a vehicle through which these voices can be heard (Crouch & Pearce, 2012: 60-61).*

In this research, it is explicit that these voices are those of the intended user group and the research purpose is to explore, interpret and understand the experiences of them as designers and users as they interact with the AR textbook in the co-design studies. The other point that needs to be disclosed, regardless of whether it will be a research limitation, is that acknowledgment of the pre-understanding of the researcher and other active participants in the co-design studies may shape interpretations in this research. Moreover, choosing the PD approach and its related methods for data collection and analysis in this research, was subjected to the researcher's pre-understanding of the world. The subjectivity of the researcher is acknowledged and built in the research through using the critical lens where the researcher's ideological, and political stance is placed more centrally in the research process as an explicit element.

The final component of the methodology will be the practical framework for planning, data collection and analysis of the research collected. Prior to this explanation, it is important to

conclude this section with an articulation of the process of the research based on what is discussed. The emphasis on the research process comes from the design research knowledge that resides in the methodology, as identified by Cross,

> *Design knowledge secondly resides in process, in the strategies of designing. A major area of design research is methodology, the study of the process of design and the development and application of techniques which aid the designer. Much of this research revolves around the study of modeling for design purposes. Modeling is the language of design (Cross, 2006: 24).*

The powerful aspect in the nature of action research is, *"the possibility for the researcher to own the research process and the research findings and this makes it distinct from other forms of researches where the processes are decided by expert researchers who then impose the findings"*(Ary *et al.*, 2010: 514). The emphasis of reflecting on the process comes also from the PD perspective through focusing on the process of designing and the particular participatory practices that different processes can enable (Simonsen & Robertson, 2013).

Therefore, the following discussion has been constructed on the components of the methodology which have resulted in a model of the reflective process which has been carried in this research. The model is informed by the core principles in each component of the methodology and driven by the key models of reflective practice in design research.

To illustrate this, discussing each component will be in a separate paragraph, showing the methodology component underlines, while the core principles emphasised in the definitions of the methodology components will be in italic and would be underlined. Even though the following section is in the methodology chapter, it should be noted that it has been written at the end of the research when the process has been clarified.

Research process in reflective models

Starting from the theoretical lens used in this research, the interpretive lens emphasised that both the researcher and the research participants are, *'jointly engaged in acts of interpretation'* (Crouch & Pearce, 2012: 60). The other implication was that knowledge formation always

arises from what is already known and is therefore not linear but '*circular', 'iterative'* and '*spiral*' (Usher, Bryant & Johnston, 1997: 182).

The **'***spiral of steps'* is actually used to describe the action research nature and each of these steps is composed of *"planning, acting, observing and evaluating the result of the action"* (McTaggart, 1991: 170). The process is commonly represented as a *'cycle'* or *'spiral of phases'* as in Crouch & Pearce, (2012: 145) model (Figure 10).

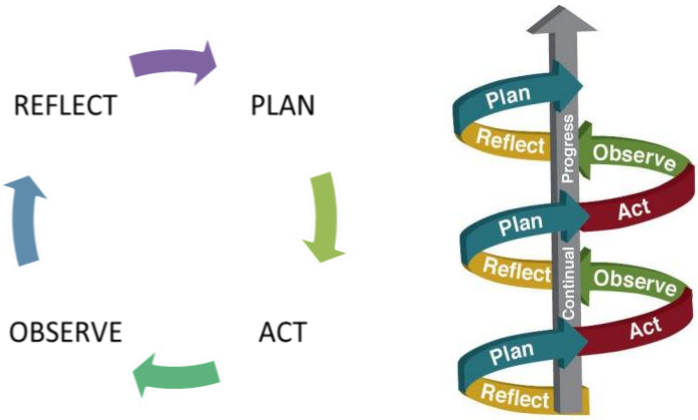


Figure 10: Action research cycle and spiral Crouch & Pearce, (2012: 145).

From the PAR definition, *"the process by which the participants engage in collaborative action-based projects that reflect their knowledge"*(Mclntyre, 2008: 5), we note the same principles of '*participation'*, '*process'* and '*action'* raised again but in a collaborative manner.

Finally, the PD approach, gathers all previous principles in its definition, *"a process of investigating, understanding, reflecting upon, establishing, developing and supporting mutual learning between multiple participants in collective reflection-in-action",* (Simonsen & Robertson, 2013). *Participation*, *practice*, and *design* can be represented as core principles of PD.

While understanding practice is fundamental to PD, Schön(1983) advocated an approach to epistemology of practice which he characterised as *reflective practice*. PD relates significantly to Schön's *'reflection-in-action'* for the individual design practitioner but adds the *'collective'*

aspect for the involvement of multiple participants similar to what was found in PAR and action research (Figure 11).

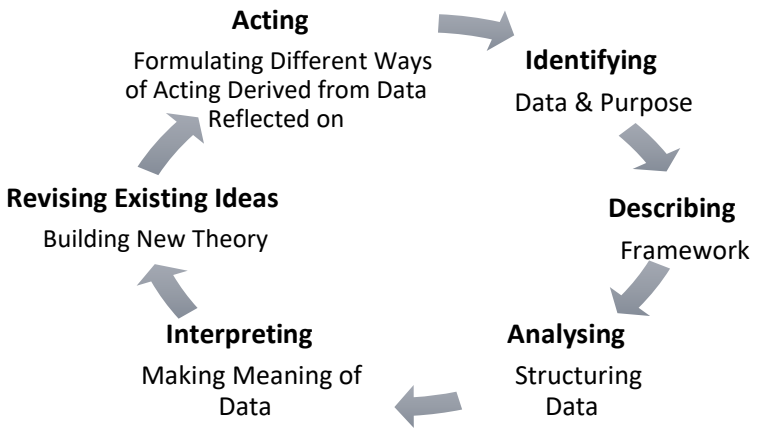


Figure 11: The process of reflection from Shon's Conception.

Similar to Schön's model of conceptualising reflection, a model called the *'experiential learning cycle'* by (Kolb, 1984), can be presented. It is a continuous cycle also of action, observation, reflection and theorising, where action is informed through theorising and new knowledge is created which is a production of learning (Figure 12).

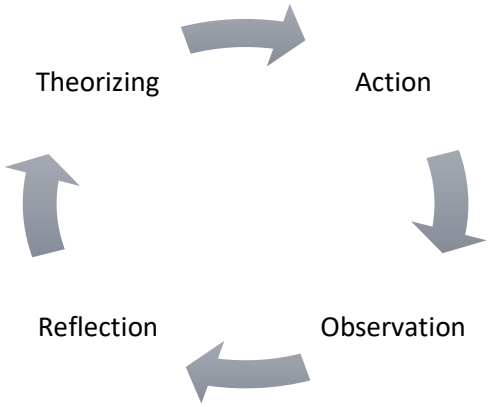


Figure 12: Experiential Learning Cycle from Kolb's Conception.

The focus on practice in PD leads to understanding the context of that practice. Schmidt *et al* noted that, "*PD is driven by a consistent socio-technical approach that appreciates context in which the technology will be used and the processes and practices within that*

context"(Simonsen & Robertson, 2013: 7). This also was one of the reasons of revising the PLU model that will be discussed later in (III.2.3, p.81), since it classifies the contexts of children technologies as *play, learn and use*, which was a substantial consideration to be addressed.

The research indicates that the final principle that can be added in this *context*. Enh's definition can answer what the context should imply, namely, *"Practice is both action and reflection. But practice is also a social activity. It is produced in cooperation with others"* (Ehn 1993: 63). Social interaction and cooperation are central in PD and within its overall context, as described by Simonsen & Robertson,

> *PD recognises that human activities are carried out in cooperation with others and so new technologies need to be designed to support cooperation…. The aim is to design technology not just to support cooperation between those using it but also to enable people to take advantage of the new technologies, to reconfigure and appropriate them and to redesign their practice in positive ways over time (Simonsen & Robertson, 2013: 8).*

In summary, it can be stated that the PD core principles are, *Participation*, *Design*, *Practice*, and *Context*. Their implications in this research are represented accordingly as collective participation, co-design, reflective practice and the context of collaborative learning experience. It can be argued that having the PD as a methodology reflects having the collaborative participation as a mindset of the researcher where the context is chosen to be the collaborative experience, in addition to its potential with AR and its significance to education that are discussed earlier in the thesis.

From a PD perspective, another model can be encountered that repeats the iterative cycle feature, but includes the PD activities as described by Bratteteig *et al.* (2012) (Figure 13).

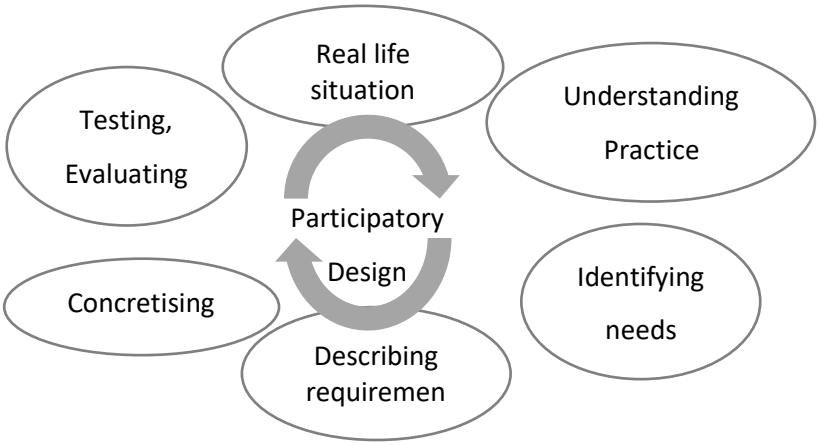


Figure 13: The use-oriented design cycle.

Mackay & Fayard (1997) integrates design and scientific models for HCI work (Figure 14). They argued that HCI creates and revises the interaction of people with artefact, moving from theory and observation to create evolving artefacts and prototypes to influence or revise the models at the theoretical level and observations at the empirical level.

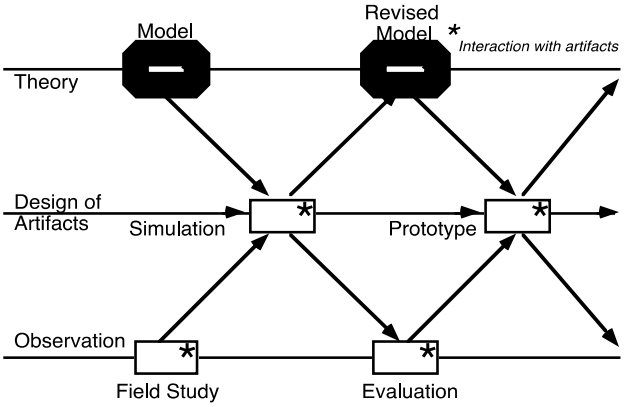


Figure 14: Mackay & Fayards' model for HCI research (1997).

A final model by Sanders & Stappers (2014) can be presented form a PD perspective that is charecterised with the iterative cycle (Figure 15). The characteristics of the phases of '*planning', 'analysis',* and *'conceptualisation'* are shared with the previous models.

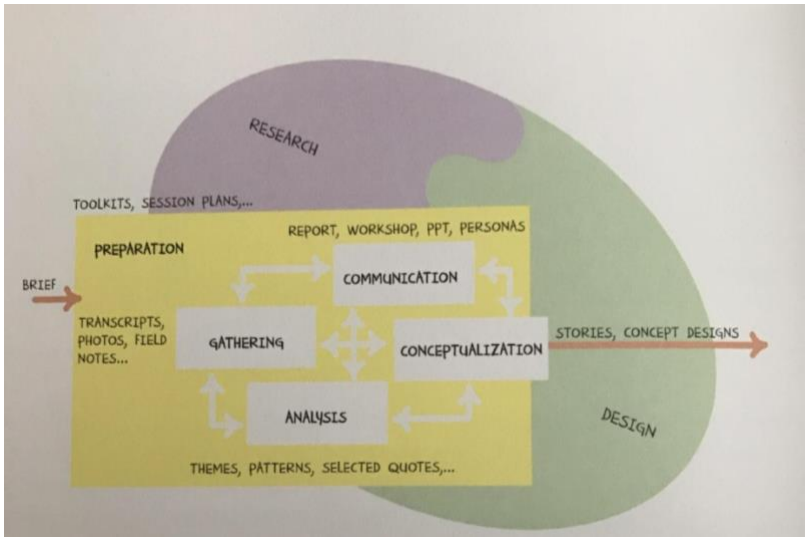


Figure 15: Model of generative design research by Sanders & Stappers (2014: 280).

The research process and the reflective model

Informed by all the previous conceptions, a model can be established based on the concepts defined in the methodological components of this research and informed by the key models introduced. The proposed model in Figure 16 is a cycle of planning, acting, experiencing, interpreting, analysing, comparing and conceptualising, which fundamentally represents the process conducted in this research. This model is a type of a framework that is generalised from the practice of design process. As Koskinen *et al.*described, *"these frameworks are reflections that come after designs. Their ingredients are theories, debates, and the design process",* Koskinen *et al* (2011: 119). The key characteristic of the model is the cyclical and reflective nature, where the concepts are developed as the '*cycle forges on'*, and '*insight is gleaned and integrated'*. It also relies on the participatory design principles where the collective participation is involved throughout the phases.

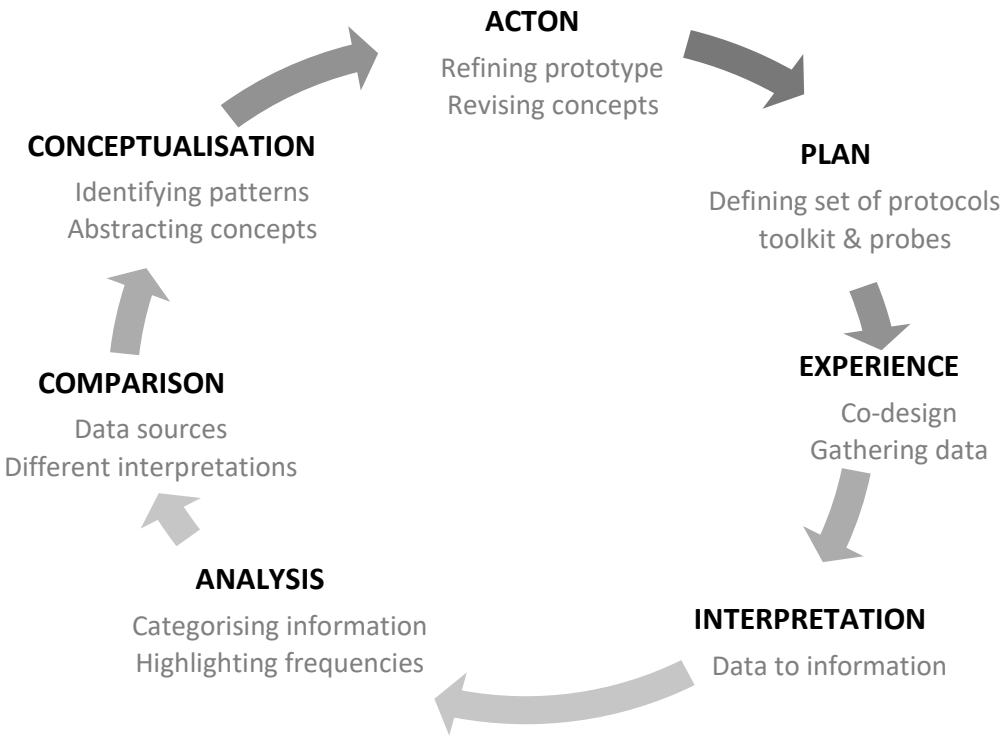


Figure 16: The process conducted in this research proposed as a reflective model.

This model can contribute in building up the working research practice that involves designing a practical outcome or for the '*constructive design research'* where a construction takes the center place (Koskinen *et al.* 2011). The work in this research takes place in a cycle that begins with objectives that informed the initial key concepts and continues to co-design studies. These studies led to concepts creation and development, as well as developing the prototype which is also evaluated before the cycle begins again. **Acting** can be considered as a starting point but it does not represent the final stage, because each design can be further refined and all resulted concepts can be developed further. Acting is the stage where reflection actually happens, because it comes after a new result could be gained and needs to be implemented and acted upon. The researcher here compares the result with the previous study results and even to the raw data, if needed. This process enables identification of the design features related to each concept.

Following this initial stage, the next iteration of the design can be started by implementing the design features in the next prototype. When the implementation stage has been finished and the outcome is ready for evaluation, the planning of the next co-design sessions can be done. The **Planning** involves defining a set of protocols to ensure consistencies and initiate the participants with their roles and informing them with the session objectives and procedure. The planning also involves preparing and organising the toolkits and props as a generative co-design workshop.

The **Experience** then can be conducted using the toolkit and probes to gather the data from the children. Calling this stage 'experience' and not 'data collection' or 'gathering', highlights that the participatory aspect, in which it differs this model from other models that are based on traditional ethnographic methods. This naming came from the idea that, *"Design is supposed to be an exploration people do together and design process should reflect that",* (Koskinen *et al.* 2011: 83). The co-design session includes the data gathering process but also involves the participants in the co-design session experiencing the prototype while giving their inputs.

The session with the adult members comes afterwards, involving **Interpretation** of the raw data into information and commencement of the thematic analysis. The **Analysis** stage involves categorising this information into the low-level themes, highlighting frequencies, reading the interpretations again and re-categorising to higher level themes through a discussion between the researcher and the adult participants. Highlighting the interpretation and analysis stages in the model highlighted that the process relies on understanding by making a systematic description of data and that the research is driven by understanding rather than data alone.

The **Comparison** should be done to compare the different interpretations and the different data sources including the adult notes, the children's transcripts and the children's artefacts. Finally, the **Conceptualisation** focuses on finding patterns and identifying the concepts for each pattern that emerges through a discussion by the researcher and adult participants. As the cycle progresses, the concepts are developed in tandem with the prototype.

The implication in this research

This research undertaking consisted of three studies in which the central purpose was not only to develop the AR textbook prototype, but also to develop the conceptual framework for the design and evaluation of the collaborative AR textbook for children. Although these studies were sequential, finding the generalised concepts was not a linear process. It involved reflecting on the findings and data, at each stage in order to formulate these concepts. This circular process aligns with the relationship between theory and research as Glanville explained, *"First, to combine, co-ordinate and simplify the findings of experiment by developing generalizing concepts. Second, to examine these concepts in order to further clarify and develop them, reflecting back extended understandings into theory",* (Glanville, 1999: 83). He emphasised on the circularity as being the central and crucial aspect of research design, together with creativity.

At each stage of this research, new design features have been implemented in the outcome. These design features cannot be generated without a circular process of reflecting back to the levels of the thematic analysis each time. The creative ideas of the child participants, together with a classification framework of key concepts, have informed the generation of design feature tasks that was implemented in each prototype by the researcher. The process of the thematic analysis relied on moving the data to a higher level of conceptualisation where each level doesn't represent a newly created concept, rather an evolution of the initial concepts which were identified in the earlier stages.

Having clarified the theoretical orientation, the following section will explicate the framework from which the research practical considerations and methods are developed. Later, the final component of the methodology will be presented which is the selected method that has been used in data collection and analysis.

III.2 The Practical Framework of the Research

III.2.1 Sanders and Stappers' Co-Design Framework

There are many aspects to be considered in a co-design process, from recruiting participants, preparing special toolkits and probes, to documentation of the output and reflection on the co-design process(Sanders & Westerlund, 2011). Even though the potential of involving children in co-design is widely agreed, the special issue of co-design sessions is the need for guidelines and directions for designers and researchers to organise and conduct effective participation of children (Scaife *et al.* 1997). In line with that view, Mazzone, Read & Beale(2011) presented a framework to support practitioners in reflecting on the role of elements involved in co-design sessions when making decisions and planning their session. Another framework centered on co-design activities is FACIT PD (Walsh *et al.* 2013) (Figure 17).

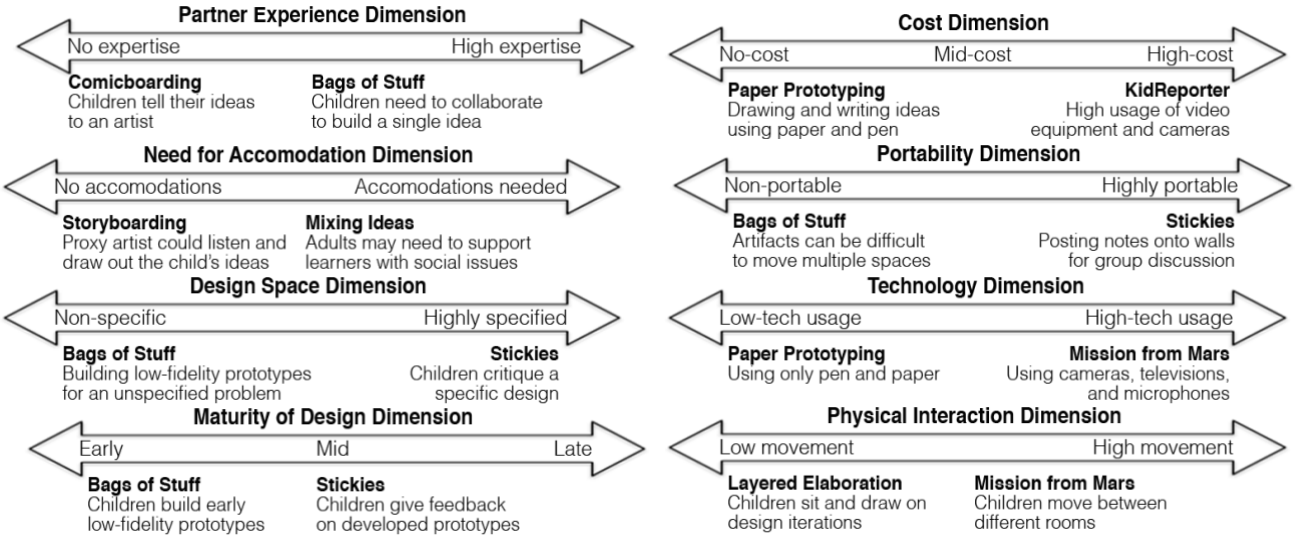


Figure 17: FACITPD (Walsh et al., 2013).

This framework uses eight dimensions that can aid the selection or modification of design techniques for children. It is not designed to be mutually exclusive, or to replace other frameworks, but rather it compliments other frameworks such as Sanders, Brandt & Binder, (2010) framework for classifying the tools and techniques (Walsh *et al.* 2013).

Engaging children in a meaningful experience requires significant effort from gaining participation, ethical clearance, arrangements for the sessions, preparation of toolkits and

probes, running and managing the co-design session, to analysing results and interpreting outputs with different perspectives into design insights (Mazzone, Read & Beale, 2011). Using co-design in this research requires an understanding of the purpose and context of the tools and techniques in each session through the use of a predefined framework. Sanders & Stappers (2014) suggested a co-design framework to help connect academics and practitioners and to help exemplify the co-design sessions. It aims to organise the complexity of co-design with children in such a way that highlights the importance of all elements, including the considerations needed for running co-design sessions with children, by identifying the design objectives, and determining available resources as initial requirements, and expectations of the outputs.

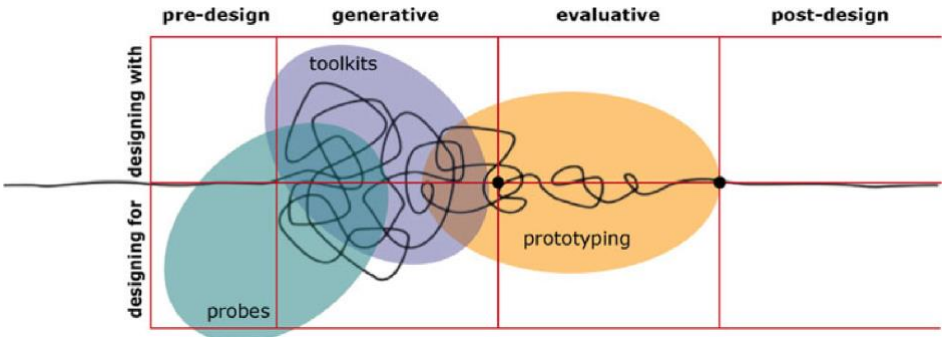


Figure 18: The revised framework of Co-design (Sanders & Stappers 2014).

The revised framework in Figure 18 was developed from Sanders (2007) simple representation of the design process and derived from a participatory action research perspective. The framework lays out the approach to making toolkits, probes and prototypes on a timeline of the four main design phases. It was implicated in the two distinct mindsets from the previous map of designing the expert mindset (designing for) and the participatory mind-set (designing with). This exemplifies what perspectives each approach to making comes from. The comparison of the research design phases, across a number of descriptive dimensions in Table 3, guides positioning each session of this research in the co-design framework. This positioning will consequently lead to clarifying the details of the session and set of protocols by answering the questions proposed in the following table. Whereas the comparison on the approaches in Table 4 is helpful in indicating the requirements of each session and preparing set of protocols.

Table 3: A Comparison of the Research Phases (Sanders & Stappers 2014).

Design research	Pre-design and post-design	Generative	Evaluative
Purpose	To understand people's experiences in the context of their lives and their past, present and future dreams	To produce ideas, insights and concepts that may then be designed and developed upon	To assess, formatively or in a summative manner, the effect or the effectiveness of product, spaces, systems or services
Results	To prepare people to participate in co-designing Empathy with people Creative co-designers	What will be useful? Usable? Desirable? Opportunities for future scenarios of use Exploration of the design space	Is it useful? Usable? Desirable? Identification of problems Measurement of effectiveness
Orientation	Past, present and future	Future	Present and near future

Table 4: A Comparison of The Three Approaches to Making (Sanders & Stappers 2014).

	Probes	Toolkits	Prototypes
What is made?	Probes are materials that have been designed to provoke or elicit response. For example, a postcard without a message.	Toolkits (made up of a variety of components) are specifically confirmed for each project/domain. People use the toolkit components to make artefacts about or for the future.	Prototypes are physical manifestations of ideas or concepts. They range from rough (giving the overall idea only) to finished (resembling the actual end result).
Why?	Designers find inspiration in users' reactions to their suggestions.	To give non-designers a means with which to participate as co-designers in the design process.	To give form to an idea, and to explore technical and social feasibility.

What is made out of?	Probes can take on a wide variety of forms such as diaries, work-books, cameras with instructions, games, etc.	Toolkits are made of 2D or 3D components such as pictures, words, phrases, blocks, shapes, buttons, pipe cleaners, wires, etc.	Prototypes can be made from a very wide array of materials including clay, foam, wood, plastic, simple digital and electronic elements.
Who conceives?	Designers create the probes and send them to end-users and other stakeholders, often with little or no guidance of how the end-users should treat them.	Designers and researchers make the toolkits and give them to others to use to make artefacts. The process is often facilitated or guided.	Co-designers create the prototypes to envision their ideas and to display and to get feedback on these ideas from other stakeholders.
Who uses?	End-users and other stakeholders individually complete the probes, returning them to the person who sent them out.	End-users and other stakeholders use them to make artefacts about or for the future. Toolkits work with both individuals and small groups.	Designers use the prototypes as design tools. End-users may use the Prototypes during evaluative research events.

The nature of the co-design with children and the practical difficulties highlight the need for concepts or dimensions to consider rather than creating a checklist or guidelines to follow (Mazzone, Read & Beale, 2011). This understanding of '*design complexity*' is emphasised by Stolterman (2008). This research adopted Sanders & Stappers (2014) co-design framework since it provides the important concepts and dimensions to consider for each co-design session. It will serve as a useful framework to plan and organise the toolkits and prototypes for conducting the co-design studies.

III.2.2 **Druin's Cooperative Inquiry Techniques**

Cooperative Inquiry offers a set of techniques that can be used by teams of adults and children together throughout the design process. In Cooperative Inquiry, design includes all of the steps necessary to conceive, develop, and produce a technology - essentially all of the work from start to finish in the creation of technology, including

brainstorming, coding, building, iterating, and testing (Fails, Guha & Druin, 2013: 14).

Walsh *et al.*(2013)considered cooperative inquiry as a popular method used in the intergenerational co-design process. They defined a technique as, *"a creative endeavor that is meant to communicate design ideas and system requirements to a larger group"*. The application of a technique can be very brief in one or two design sessions, such as cooperative inquiry techniques, where they defined a method as a *"collection of techniques used in conjunction with a larger design philosophy"*. Thus, a method such as cooperative inquiry unifies multiple techniques such as '*low-tech prototyping'* (Xie *et al.*, 2012) and '*layered elaboration'*(Walsh *et al.* 2010), within a larger design philosophy which is participatory design. In the co-design method, several techniques can be used with children at different stages of the design process depending on the purpose of the research.

Cooperative inquiry is grounded in HCI research and theories of PD, Contextual Inquiry and Activity Theory. It has been specially modified to meet the needs of an intergenerational design team of adults and children(Fails, Guha & Druin, 2013). The work of Yip *et al* (2013) reflected on Nardi's(1996) methodical implications of activity theory in HCI, where aspects of CI reinforces the activity theory premises. Their study suggested that child partners were enabled to more explicitly articulate their design desires that allows for deeper understanding than observations and interview methods. In an exploratory study that aimed to understand the role children can play as leaders in CI sessions (Yip *et al.* 2013). It has shown that children can lead co-design sessions with supports from adults and suggested the consideration of the role of design techniques for child-led sessions for CCI researchers.

Cooperative inquiry has been used in the creation of many innovative technologies such as Tangible Flags, which used tablet computers to enhance learning on field trips (Chipman *et al.* 2006). Another technology that benefited from that method called Mobile Stories (Fails, Druin & Guha, 2010). It used cooperative inquiry brainstorming techniques to design mobile technology that empowered children to collaboratively read and create stories. Others have reported on adaptations to cooperative inquiry and other techniques where children participate as design partners such as (Jones *et al.* 2003).

Based on PD and co-design with children, the critical outcome of cooperative inquiry is grounded in CCI research and HCI theories involving a multi-disciplinary partnership with children, field research and iterative low- and high-tech prototyping (Druin, 1999). Cooperative inquiry was pioneered by Druin (1999) as a design process, to involve children from the beginning to participate in brainstorming, discovering the initial ideas and developing design concepts to refining and evaluating the prototypes.

This research used three selected techniques of cooperative inquiry in the co-design process. The first is '*Low-tech prototyping'* which is a cooperative inquiry technique used for the early stage of designing an interactive technology with children (Xie *et al.* 2012). The second is for formative evaluation of the AR textbook referred to as *'Sticky Noting'* (Xie *et al.* 2012), which is a cooperative inquiry technique for critiquing a prototype with children and will be termed CI Critiquing in this thesis. A *'Layered elaboration'* technique was also used in the formative as a generative method to support CI critiquing (Walsh *et al.* 2010).

III.2.3 **Reads' Play, Learn, Use Model**

Evaluation is a critical part of the overall design process in order to iteratively inform the outcome and redesign it. The need of a formal model in this research was crucial to ensure that important aspects of the AR textbook design are considered. The '*Play, Learn, Use'*(PLU) model is a well-developed model by Janet Read (Figure 19).

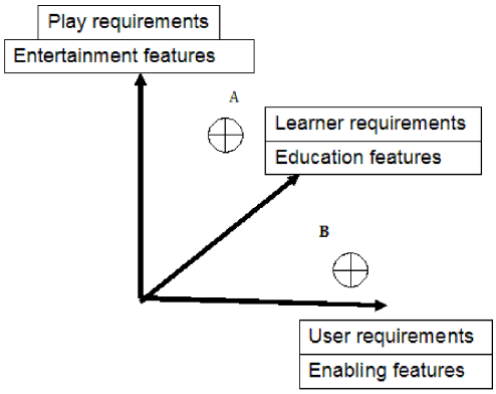


Figure 19: The PLU model (Read, 2004, inMarkopoulos et al., 2008).

This model was proposed as a key tool to assist in understanding and defining children interaction with technology. It was chosen in this research as a tool to think with, because it defines all the relationships between children and the interactive technology. The three relationship dimensions are children as *'Players', 'Learners'* or *'Users'* and the technologies as '*Entertainment', 'Education'* and *'Enabling'*. These dimensions are proposed to be considered in any product for children, but the focus may shift on one more than the other (McKnight & Read, 2011).

The necessity of adopting this model is that it considers the different requirements that children's interactive technology may have, which inform the identification of the design concepts. It can also facilitate the choice of the right method for evaluation. Although the proposed AR textbook's main aim is the collaborative learning experience, the entertainment features should be included since it is an important aspect in children's technologies and the usability concerns also are need to be taken into account as these are inevitable in any interactive design.

There are other frameworks proposed in CCI studies associated with the '*activities, behaviors, concerns and abilities'* of children as they interact with technologies (Read & Bekker, 2011). However, the PLU model was chosen because it intersects with this PhD research in focusing primarily on children's activities and the purpose of the design which is the collaborative experience, while also taking into account the concerns of children in relation to what is important in each aspect.

It is acknowledged that adopting this nuanced model is useful as a tool to think with, yet, it is also important to be clear about the main purpose of the design and not tailoring the research context to fit in the model but instead adapting this model to be applicable for the research context. It would be more precise when making use of this model to identify the ways in which this model might be partial and how it can be applicable for different contexts in CCI studies. The significance and appropriateness of the PLU model are evident, but the reasons of revising it and the need of the new framework will be discussed further in the following sections of this Methodology chapter.

III.3 The Proposed ELU Conceptual Framework

III.3.1 Discussion of the PLU and the need for adaption

McKnight & Read stated that the PLU model was, *"an attempt to open the debate about the need for formal models of the evaluation process"* (McKnight & Read, 2011: 7). The authors suggested the possibility of using this model with other user groups such as old people, through mapping out their specific requirements on the PLU model in the same way. However, it can be argued that, despite the potential to use this model for the same user group the model was proposed for, namely children, but focusing on the purpose of the design, is more important.

It was noted that the original motivation and main reason of proposing the PLU model were the difficulties of evaluating with and for children, in addition to the lack of formal models(McKnight & Read, 2011). Therefore, elaborating on this model while keeping the focus on children as the user group will be of benefit to the CCI community by enriching the debate and contributions of useful models for design and evaluation of children's interactive technologies.

The core principle of the PLU model is the relationship children have with interactive products. The debate on how children interact with technology have been widely researched (Sherman, Druin & Montemayor, 2001;Plowman & Stephen, 2005; Luckin *et al.* 2003; Plowman, McPake & Stephen, 2010;Cassell, 2004). Some of the research made relationships between the concepts, such as Csikszentmihalyi & Csikszentmihalyi (1988) as they viewed '*enjoyment'* as relating to '*engagement'*. Others described the relationship between '*functionality', 'usability'* and *'pleasure'* as a hierarchy of needs(Jordan, 2000).Markopoulos & Bekker (2003) emphasised that enjoyment can relate to social activities and to learning activities.

Similar issues arise when considering how to successfully support less task-oriented activities such as play. The emphasis with such activities is not necessarily on usability but also on having pleasure and fun ((Blythe, 2003; Green & Jordan, 2003). Many researchers have explored the relationship between fun, play and learning, reasoning that fun contributes to being motivated to pursue an activity and as such can also contribute to learning effectively

(Malone & Lepper, 1987; Prensky, 2001). In this regard, Scaife and Rogers discussed the design of technology for supporting playful learning and described five core elements for playful learning, defined as: '*exploration through interaction'; 'engagement'; 'reflection'; 'imagination'; 'creativity';* and *'collaboration'*. Finally, in her book *Design for Kids*, Gelman(2014) argued that most successful children's applications have learning at their core but put play at the front and center.

With reference to the PLU model, the three relationships of play, learn, and use form the three dimensions illustrated in the model in which it based on. When examining where these dimensions came from, the research uncovered alignment with the three genres of children's interactive technology suggested by Markopoulos *et al.* (2008) In their book *Evaluating Children's Interactive Products: Principles & Practices for Interaction Designers,* the authors mixed the different classifications reported in the previous books and came up with the three genres of entertainment, educational and enabling.

They acknowledged that the wide variety of children's interactive technologies do not have to be classified under one genre because some of them are multi-purpose and this is one of the reasons they introduced the PLU model in their book as it considers this variation. Based on this classification, the PLU model similarly assumed that children's interactive technologies will fall into these three aspects.
This suggestion of the main genres is totally agreed with, however, limiting them into these three restricts other features that cannot fall into one of these aspects, such as collaborative features for instance.

> *It is certainly possible that a product could be designed to both entertain and instruct, but in almost all cases it has a main purpose (Markopoulos et al. 2008: 28).*

The PLU supports the different requirements of children in interactive products but acknowledges also that each of them will be designed for a primary purpose. In actuality, a particular aim is to help the project teams to have a shared understanding of the primary aim and avoid the conflicts between these requirements. The emphasis on evaluation to be focused on the primary experience that the product intended to support is definitely contributing to a better and more effective design and evaluation process. However, the classification of play,

learn and use limits other various experiences that children's interactive products are intended to support.

The author would concur with the '*Entertainment', 'Education'* and *'Enabling'* features as main genres of children interactive technologies but limiting them into these three restricts other features that cannot fall into one of these aspects.

In a case of children's technology that aims to support collaborative experience, the designer is obliged to embed the collaborative features into one of these three aspects. This will prejudice against the focus of the collaborative aspect which is the primary aim of the developed technology. As a result, this situation will contradict with the main aim that the model was proposed for, as determined by McKnight & Read,

> *Developing a shared understanding is one of the great challenges of multidisciplinary research and yet the benefits of bringing together influences from a range of fields can be immense and so anything that can be done to make this process easier should be encouraged (McKnight & Read 2011: 1).*

III.3.2 **Proposing the Experience, Learn, Use Framework**

The collaborative experience cannot be substituted with the '*play'* dimension, whereas the *'learn'* dimension is central to the children's technologies and a core aspect of the overall PLU model. Therefore, rather than simply fitting the collaborative features into the '*use'* dimension, it was necessary to propose a broader category that fits the narrower concepts including collaboration and play.

Koskinen *et al* (2011) discussed the limitation of usability-oriented design which was the main focus in the early design research movement and emphasised the importance of usability, but with the focus on the context,

> *The problem with usability was that, while it did help to manage design problems with increasingly complex information technologies, it did little to inform design about the context (Koskinen et al., 2011: 19).*

Experience can be suggested as the third dimension that allows for the incorporation of a wide range of concepts that children's technology is designed to support. These experiences could be entertaining, collaborative, motivational, socially interactive or other concepts that can be classified as experiential, but not as learning or usability. Unlike '*play'*, the Experience dimension is additionally well aligned with the other dimensions of '*learn'* and '*use'* as high-level concepts and major classifications.

A supporting argument was found in Koskinen et al. book, *Design research through practice*, where the authors discussed how '*Experience'* as a comprehensive concept solved the problems of the many types of concepts created by design researchers in the 1990s,

> *The main conceptual innovation came to be user experience, which was open enough and avoided many of these problems. It did not have unwanted connotations like the world pleasure and not contested like aesthetics…. This concept has been so successful that leading universities, corporations and design firms build units to study user experience. Finally, pragmatist philosophy gave this concept credibility, depth and openness (Koskinen, et al., 2011: 27).*

Experience, therefore, can be suggested as a dimension of a relationship between children and technologies, where the child a becomes **Experimenter** and the technology is an **Experience** that can be specified for each project. In the case of this project, for example, the statement will be framed as children operating as **Collaborators** and technology situated as a **Collaborative Experience**.

Technology as experience was suggested by McCarthy & Wright (2004) as a new approach that redefines how we think about users, contexts, technology and experience.

> *Moreover, it is only by seeing technology as participating in felt experience that we understand the fullness of its potential (McCarthy & Wright, 2004: 1).*

A framework, namely **Experience, Learn, Use** (ELU), is proposed by the researcher to be used as a framework for thinking and its implication suggests the following:

1. Specifying the children's experience in which the technology is aimed to support.
2. Indicating the methods for evaluating the prototype from the three aspects of ELU. A method can be selected to evaluate each dimension individually or collectively. In this study, for example, cooperative inquiry critiquing is selected to evaluate the AR textbook prototype from the different aspects of the ELU, in addition to layered elaboration which will be focused on the collaborative experience specifically to collect more data about the primary aspect of the design.
3. Identifying the required design concepts in relation to the three dimensions of the ELU. The importance of clarifying specific concepts is to serve as a classification framework in the analysis process. It also informs the identification of design features to be implemented in the prototype.

III.3.3 **The process of identifying the concepts of the ELU**

Firstly, the definitions of collaboration in the context of students' learning have been reviewed for an attempt to identify the key concepts of students' collaboration. The common definitions are listed in Table 5and the key concepts have been highlighted in green to represent the collaborative aspect.

Table 5: Collaborative concepts extracted from the common definitions of students' collaboration.

	Reference	Definition	Concept
1	Chi(2009)	Collaboration can be a facilitator to learning because it enables students to engage with other learners as well as the educational content at the same time.	Engagement
2	Roschelle & Teasley(1995)	Collaboration is a process by which individuals negotiate and share meanings relevant to the task at hand. It occurs through the interaction and sharing of knowledge	Interaction construction of knowledge

		among group members to construct new knowledge.	
3	Lipponen (2002)	Collaboration involves the mutual engagement of group members in social interaction. The idea of co-construction of knowledge and mutual engagement of participants is stressed for successful collaboration.	Mutual engagement social interaction co-construction of knowledge
4	Makina & Salam(2011)	In face-to-face interaction situations where meanings are mediated through social cues such as faces, gestures, spoken language and intonations of speech, computers can act as a referential anchorand mediate the coordination of attention and collaborative actions.	Communication cues
5	Dillenbourg(1999)	The idea of collaboration as mutual engagement appears to imply synchronous activity or even a situation of face-to-face interaction. CSCL is focused on how collaborative learning is supported by technology can enhance peer interaction and work in groupsand how collaboration and technology facilitate sharing and distributing of knowledge and expertise among community members.	Mutual engagement Peer interaction and group work sharing knowledge
6	Dillenbourg et al. (2009)	Collaborative learning describes a variety of educational practices in which interactions, among peers, constitute the most important factor in learning. Collaboration does not produce learning outcomes; its results depend upon the extent to which groups actually engage in productive interactions.	Peer interaction Group engagement productive interaction

Secondly, the literature of collaborative AR in education has been reviewed focusing on the design concepts recommended by these studies. A summary of that work is presented in Table 6 as a mean of extracting the key concepts from each study. Frequently appearing concepts

were highlighted in the same color, where green represents the collaborative aspect, pink for the learning and blue for usability. It was noted that the identified concepts of collaboration in Table 5 have appeared repeatedly in studies of collaborative AR in education.

Table 6: Concepts identification from the literature of collaborative AR in education.

	Reference	Implementation	Design Concepts
1	Kerawalla *et al* (2006)	Design requirements for AR as an effective learning tool.	• AR systems should be flexible enough for the teacher to adapt to the needs of their students. • The content should be taken from the curriculum and delivered in periods as short as other lessons. • AR system should consider the constraints of the context.
2	Billinghurst, Wagner & Schmalstieg, (2006)	Collaborative AR interface for Art history	• Sharing user views to establish shared understanding. • Enabling users to work in parallel. • Ability to share verbal and non-verbal face to face communication cues.
3	R. Chen & Wang (2008)	Compare the AR system to traditional methods for urban design	A framework developed from learning theories. • Shared communication cues.
4	Aasterud (2010)	AR for Primary Schools	• Non-fragmented reality. • Lightweight interactions. • Configurable material and externalization.
5	Makina & Salam, (2011)	AR interface design for engineering students	• Communication. • Social interdependence and participation. • Students' exploration. • Promoted interaction. • Diversity between groups. • Individual and group assessment.

6	Matcha & Awang Rambli (2012)	Interface design of an AR Book for children	• Social interaction. • Communication. • Engagement.
7	Yuill & Rogers, (2012)	Multi-user interface design	• Mutual awareness of others' actions. • Mutual control of interface. • Mutual availability of background information.
8	Cuendet, Bonnard, Do-Lenh, *et al* (2013)	Design principles for AR in CSCL environment	• Integration. • Awareness. • Empowerment. • Flexibility. • Minimalism.
9	Dunleavy (2013)	AR affordances for education unique to AR	• Enable and challenge. • Curiosity. • See the unseen.
10	Wu, Lee, Chang, *et al* (2013)	AR affordances for education unique to AR	• Learning content in 3D perspectives. • Learners' senses of presence, immediacyand immersion. • Visualizing the invisible. • Bridging formal and informal learning.
11	Lin, Duh, Li, Wang, & Tsai (2013)	Comparison of AR and traditional 2D system for Physics for undergraduate students	• Collaborative knowledge construction. • Behavioural pattern.
12	Boletsis & McCallum (2013)	AR collaborative game for chemistry education	Collaborative game to provide engaging educational experience.
13	Hoda, Henderson, Lee, *et al* (2014)	Educational software design for children	• Children's interest-led learning. • Mutual awareness. • Availability of information. • Shared control. • Collaboration over competition.
14	Javier Barbadillo, Nagore Barrena, V´ıctor Go˜ni, (2014)	AR collaborative activities integrated with e-learning platforms.	• Integration. • Mobile and remote collaboration. • Interaction among students.

15	Ke & Hsu(2015)	Mobile AR for CSCL	Socio-technical interactions aspects: • Habitualness, shared-ness, and intuitiveness.
16	Naseem & Khan (2017)	Modern Learning Method Using Augmented Reality in Education System	• Collaborative Knowledge construction

It has been noted that the frequently appearing concepts of the many authors actually fall into the three aspects of ELU, indicating that the experience aspect represents the collaborative learning experience. When aligning the identified concepts to the related aspects, as in Table 7, it can represent a starting point to develop the ELU conceptual framework.

Table 7: The key Concepts aligned to the related aspect of the ELU conceptual framework.

	Aspect	Key Concepts
1	Collaborative Experience	Mutual Engagement
		Communication
		Interaction
2	Learning	Integration
		Visualising the invisible
		Knowledge sharing
3	Usability	Flexibility
		Mutual control
		Mutual awareness

These key concepts will be serving as an initial classification framework that support the thematic analysis and clustering the data in the co-design studies and will be evolved throughout the three studies as will be illustrated in (V.1, p.102). The outcome of the final study has resulted in eight concepts for the AR textbook design (Table 8). The introduced ELU framework in the final study is suggested as a framework for thinking and will be discussed further in the findings of the third study.

Table 8: The ELU framework suggested for the AR textbook.

ELU Dimensions	Developed Concepts
Collaborative Experience	Joint textbooks
	Personalised collaborative AR
	Interactive AR textbook
Learning	Communication-based learning
	Rewarding AR feedback
Usability	Audio AR textbook
	Intuitive AR markers
	Mutual AR Display

Conclusion

In concluding the methodology chapter, the particular strategic aim of the research in answering the thesis research questions has been demonstrated in terms of the nature of the research as PAR and the particular approach has been adopted as PD, situating the research position within the landscape of a design research perspective. Additionally, the theoretical lens has been outlined for a complete component of a methodology.

The framing of the research methods was then identified to further understand the broader perspectives that underpin the particular set of methods for data collection and analysis. These three perspectives, which have been discussed in (III.2, p.74), are congruent to the methodological orientation and inform about the available choices of the complementary group of methods. They constitute a conceptual framework combined to provide a basis of this research from planning to data gathering, through analysis, to the final outcomes.

The PAR is the theoretical framing of the strategies and the nature of methods used in conducting this research. It has shown also that the PD approach is the broader principle adopted in this research that underpins the selected research methods. The choice of cooperative inquiry, which is a co-design method used with children, is justified as the appropriate method for this research, but it has grown out of these methodological

considerations. This group of complementary methods suits both the research aim and the methodological orientation, whereas the three aforementioned practical frameworks represent a set of well-established principles that inform and influence the whole process of this research. The next chapter will introduce the research methods which can be considered as a final component of the methodology for conducting this research.

IV. Research Methods

Introduction

Adopting the PD approach in this research implied its core principles discussed in the methodology chapter. They represented in the collective participation, co-design, reflective practice and the context of collaborative learning experience. These core principles underpin

the selection of cooperative inquiry as a research method. It is a co-design method specially modified to meet the needs of an intergenerational design team of adults and children. Cooperative inquiry is grounded in HCI research and theories of PD and has been used in CCI studies for the creation of many innovative technologies for children involving a multi-disciplinary team in an iterative co-design process. This research used three selected techniques of cooperative inquiry in the three co-design studies. The first is Low-tech prototyping used for the early stage of research. The second and third studies have used cooperative inquiry critiquing together with the layered elaboration technique for iterative evaluation of the prototype.

IV.1 Low Tech Prototyping

Numerous brainstorming techniques exist in co-design with children. However, there are criteria which make certain techniques more useful than others for the early design process(Sluis-Thiescheffer, 2007). Within cooperative inquiry, low-tech prototyping (sometimes referred to as 'Bags of Stuff') has been proven to be useful as a brainstorming design technique. It has also been proven to be an icebreaking technique when a new partnership or team is established (Fails, Guha & Druin, 2013).

Cooperative inquiry supports the *'Make tools'*, introduced by Sanders as one of the methods developed to amplify creativity and support their ideation in co-design (Figure 20). A proposed framework for supporting the selection of suitable methods for children indicated that children aged 8 - 10 years generate significant options in prototyping sessions (Sluis-Thiescheffer *et al.* 2011). Additionally, it has been found that children aged between 7 - 10 are, *"verbal and self-reflective enough to discuss what they are thinking and understand the abstract ideas of their low-tech prototypes and designs are going to be turned into technologies in the future"*(Bruckman, Bandlow & Forte, 2003: 433).

Figure 20: Low-tech prototyping (Druin, Guha & Fails, 2013).

The research started with low-tech prototyping, which is a brainstorming technique involving groups of children with adults from different academic backgrounds. It aimed to produce models and low-tech prototypes that demonstrate the children ideas and requirements that guide direction for designing the first AR textbook prototype.

The children participants with an average age of 8 - 10 years were placed in three groups of three children, with one adult. The adult in each group initiated discussion with the children and asked questions concerning the activity, while taking notes of the dialogue that emerges. The adults also helped in facilitating the making of the artifacts\low-tech prototypes. The basic idea is to allow children to construct design representations through visual elements as expression of need. The adult group used thematic analysis based on the research questions to form key concepts for the design of the AR textbook. The detailed procedures, and data analysis are discussed in the first study.

IV.2 Cooperative Inquiry Critiquing

After the development of the AR textbook based on the findings of the first co-design study, formative evaluation has been conducted using cooperative inquiry critiquing. It is selected as the suitable data collection method for critiquing technologies with children in order to refine prototype iteratively (Xie *et al.*, 2012). With this technique, each member of a group evaluates

a product or prototype by writing their comments on separate post-it notes to be placed on the wall or white board, where the researchers use thematic analysis to highlight patterns and identify design concepts (Figure 21).

Figure 21: Post-it notes from the children inputs clustered into groups (Druin, Guha & Fails, 2013).

The notes are then grouped in categories, including likes, dislikes and design ideas, as well as sub-categories, which emerge from the transcripts. Adult members not only critique the technology in their notes, but also act as facilitators to help children write or express their ideas, and additionally take notes if the child expresses observations non-verbally when experiencing the prototype. The outcome will be an affinity diagram of the possible themes that can inform directions for the next iteration of the design (Druin, Guha & Fails, 2013).

Many technologies have been created in part using iterative CI critiquing. For example, low-tech prototyping was used with CI critiquing by Colombo & Landoni(2013), who reported that the technique was effective for co-designing with children a more engaging e-book. Another example is '*The International Children's Digital Library*', which is an online library of children's books (Druin *et al.* 2001). This technique has been used by designers in different ways and it can be adapted for younger children aged 4 to 6 as well as older children including teenagers.

It is the appropriate method to evaluate a prototype with both children and adults, and aims to guide future iterations of design (Markopoulos *et al.*, 2008). The inherent features of this technique are brainstorming and reflection represented in empowering the group members for

generating new ideas where each could feel comfortable to offer their ideas, while adult members could easily work with children in small groups, which offers more focused collaboration (Xie *et al.*, 2012).

IV.3 Layered Elaboration

Layered Elaboration is selected to complement the previous methods of data collection in the two evaluation studies. While the CI critiquing will consider all the aspects of ELU, the layered elaboration will be used to proceed with the idea generation focusing on the collaborative experience specifically as the main focus of the AR textbook. Layered elaboration can be considered as a brainstorming technique developed for use with children aged 7 to 11 years, in order to generate ideas through changing, extending, adding to and subtracting from the ideas of others (Fails, Guha & Druin, 2013). It was found effective in co-design with children aged between 7 - 11 years to review prototype interfaces (Yip *et al.*, 2013).

The concept for layered elaboration has its roots in storyboarding for interactive media, paper prototyping, and annotation tools. It is named *'Layered'* because it uses layers of paper and transparent materials, and *'Elaboration'* because it enables design groups to add to ideas presented by others while encouraging design team members to expand on those earlier ideas(Walsh *et al.*, 2010) (Figure 22).

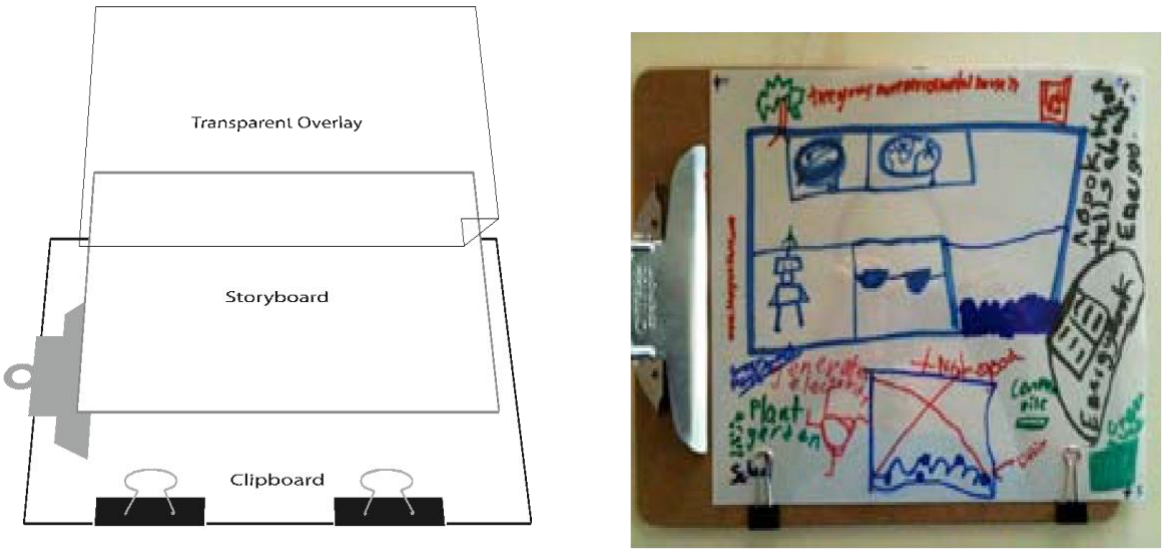


Figure 22: Example of elaborated storyboard (Walsh et al., 2010).

In this technique, each group develops a design idea on a transparency applied over a piece of paper during the session, so each design group is enabled to understand the current design and contribute to their new design. As in the low-tech prototyping, the children need to make a presentation in order for the other groups to understand the generated ideas and therefore to elaborate on it. The groups will present their designs to the larger groups when they could complete their tasks and a transparent sheet is added on the drawing paper and the design is exchanged with another team. The next team adds to the design by drawing on the transparency and the process is repeated to the last group where elaborations are stacked on top of each other to enable understanding of the whole design(Giaccardi *et al.* 2012).

Compared with the other techniques, the participants in layered elaboration generated more open and unconstrained ideas, were more comfortable with design technique, and provided less negative feedback. This technique supports asynchronous co-design and at the same time enables creative expression of the children and several designers can contribute ideas in a non-destructive way through adding and modifying through the utilization of transparent materials (Melonio & Gennari, 2013).

The effectiveness of this technique is represented in the ability both to add to and modify the storyboard without permanently changing it. In addition to this, the portability of the layered sheets on a clipboard deflects the need to have a large physical space, so the process increases the collaborative interaction. The rapid and iterative nature allows a number of design partners to provide input and ideas in a short amount of time. Also, it only requires a clipboard and sheets of paper which are cost effective compared with low-tech prototyping techniques that require more tools. Finally, it offers flexibility in choosing another way of expression for children such as drawing, instead of verbal statements, in which it can support the thematic analysis stage in comparison of the data sources. For these reasons, layered elaboration was selected in conjunction with the cooperative inquiry critiquing in evaluating the AR textbook prototype.

IV.4 Thematic Analysis

There are different definitions of thematic analysis. A broad version defines thematic analysis as a method for identifying and analysing patterns of meaning in a dataset (Braun & Clarke 2006). A more specific example is an analysis that illustrates which themes are important in the description of the phenomenon under study (Daly *et al* 1997). The result of a process of thematic analysis should highlight the most salient constellations of meanings present in the dataset.

The term *'theme'* refers to a specific pattern of meaning found in the data and the concept of thematic analysis was developed to go beyond observable material to more implicit, tacit themes and thematic structures (Merton 1975). According to the founder of thematic analysis, Gerald Horton, such material can be termed *'themata'* and these tacit preferences or commitments to certain kinds of concepts are shared in groups, without necessarily having conscious recognition of them.

The standard procedures of thematic analysis start with a set of text-based data which is defined in this study by the notes collected from the participants. Human-Computer Interaction studies follow a set of well-developed procedures for analysing text content to ensure accuracy and consistency of the thematic analysis. Solid thematic analysis depends on accurately identified concepts which could later serve as categories for which data are sought and in which data are grouped (Blumer 1969). It can be undertaken with only the researcher, but the chance for objective interpretations of the data set will be higher when a team of experts is analysing the theme. It should be noted that this research takes into account these procedures and techniques to ensure systematic analysis in its studies.*Pinto et al* (2017) used co-design with teachers for AR in education and defined a protocol for the thematic analysis that illustrates the previous HCI techniques:

- *Determine a set of categories in which the information obtained from each student will be classified for each evaluation and for the final observations.*
- *Define an analysis template for the categories and the data collected from the evaluations.*

- *Ask evaluators (coders), who read all the information obtained by each student, to classify it in the defined template.*
- *Integrate the evaluations, if there are differences, consensus should be resolved with debate to find agreements.*

There are different sources of qualitative data from the co-design sessions drawn from different traditional methods, such as the discussion between participants during the session as triggered by the artefacts made by the participants using the generative toolkits, which were documented in the form of verbatim transcripts by the adult members as well as the notes and reflections by the adult team members. The variety of data sources feed into the comparison process involved in the *'coding'* process. Coding has been stated by Corbin and Strauss as, *"involves interacting with data, making comparisons between data and so on, and in doing so, deriving concepts to stand for those data, then developing those concepts in terms of their properties and dimensions",* (Corbin and Strauss, 2008: 66).The coding categories come from the '*researcher-denoted concepts'* as high-level themes and in-vivo codes as low-level themes, which are the terms identified by the researcher to describe the interesting and pertinent instances that emerge from the data.

These concepts are represented in the ELU framework identified by the researcher and are used in the data analysis process. Corbin and Strauss (2008) refer to this process as '*open coding'*, since the coder is open to all possibilities that reside in the data. This is why the key of the open coding is being creative and drawing a linkage between the concept and the data(Lazar, Feng & Hochheiser, 2010).

The nature of the co-design studies requires being creative and open to all possibilities, since the main aim is brainstorming ideas for the design. It also requires the analysis of the data at the same time that it is collected. Thematic analysis is suitable for co-design sessions for these reasons and is thus widely used in the selected co-design methods with children. It is a common data analysis method in qualitative studies with open-ended data. It is a recommended method in generative design research, where it usually relies on visualisation on the form of placing the data on the wall or whiteboard (Sanders & Stappers, 2014). It is also best used with a few numbers of participants during the co-design sessions where small amount of data generally is

analysed. It is best suited to elucidate the specific nature of a given group's conceptualisation of the phenomenon under study.

This type of analysis is best suited for this research because it suites the data collection methods; in this instance, it is cooperative inquiry which requires the dataset to be placed on the whiteboard. Other reasons are that the dataset is text-based, the amount of data is relatively modest and the sample size is small. This method permits all the team members from the different backgrounds to visualise, reflect on and contribute to the analysis process. Utilisation of this method is effective since initial findings can be easily collected, moved and rearranged. Placing the ideas on the wall helps the team to follow the progress and contribute to the discussion and decisions. It also supports the conceptualisation process where the team can refer back and further reflect on the analysis with the initial data as well.

The model in Figure 23, illustrates the process of the analysis based on the DIKW scheme which stands for Data, Information, Knowledge and Wisdom (Ackoff, 1989). It explains the process of the data analysis in layers where the data has many aspects and no meaning until it is interpreted into information which is symbolic (Sanders & Stappers 2014).

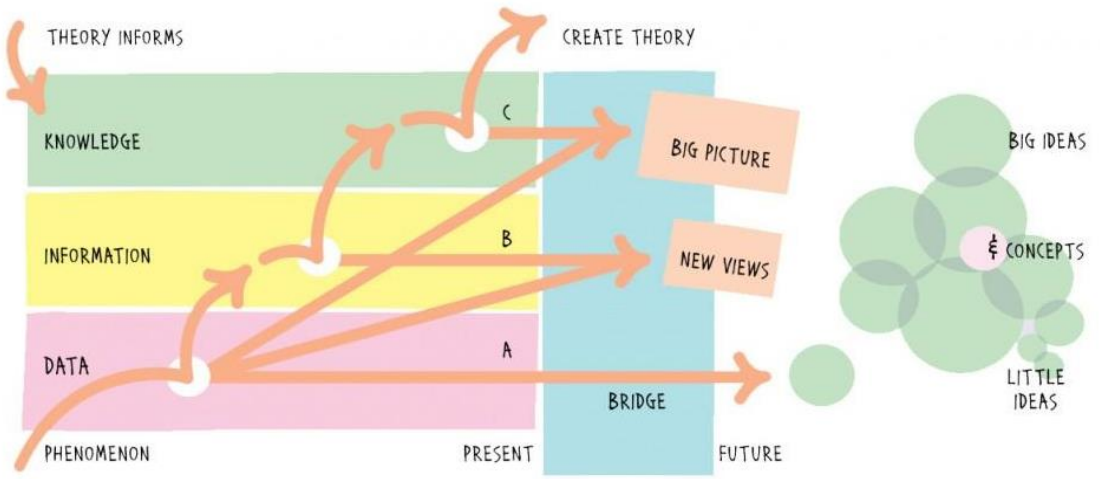


Figure 23: The analysis process in based on Ackoff's DIKW scheme (Sanders & Stappers 2014).

These different levels of symbolic interpretations are chosen within a classification framework, in which patterns can be sought, whereas *'Knowledge'* is the generalised and abstracted level

of the patterns. This abstraction hierarchy shows how the raw data is taken to a higher level of abstraction through the process of analysis that involves interpretation of the data, relating the information into categories, making comparisons to other data sources, searching frequencies and patterns and determining how well they fit are the process of analysis. This procedure is easily recognisable in the illustration. However, they are not just sequential steps from gathering to conceptualisation. Moving through these levels involves intensive insights that require a deep understanding in order to make these insights explicit.

Conclusion

An overviewed the set of methods selected for this research has been illustrated. The justification of selecting these particular set of methods is critically discussed in the methodology chapter, which clarifies the methodological orientation that informs the choices of the complementary group of methods. The cooperative inquiry technique used in the studies of this research has been discussed and their implications in practice in the context of co-designing the AR textbook prototype will be reported in the three studies in chapter (VI, p. 113). The background of the thematic analysis has been discussed and the procedure followed in each co-design study using the ELU framework will be presented as the implication in practice for this research context.

V. PRACTICAL COMPONENT OF THE THESIS

Introduction

The aim of this chapter is to elaborate on the practical components of the thesis as a contribution in this practice-based research. The first section gives a description of the stages of the prototype through the three studies. Then a brief overview of some of the educational, technical and ethical issues related to the practical component. The chapter ends with a discussion of the linkages between practice and research, to understand the relationship of the practical component of the thesis with the knowledge creation.

V.1 The Evolving Versions of the Prototype

This section describes the evolving versions of the AR textbook prototype, in which V1 is the outcome of the first study, V2 is the outcome of the second study and V3 is the outcome of the third study. (Figure24) illustrates the prototype as it goes into and out of the three studies.

Version 1

The first study was low-tech prototyping which has resulted in three models of the prototypes created by the children in the low-tech prototyping session. The thematic analysis has resulted in three themes that are related to a number of low-level themes and the first version of the AR text prototype was then developed guided by these themes and informed by the ELU concepts identified through the literature. Three key design features, which had been described in the first study, have been implemented in V1 which has been built into a high-fidelity prototype to be evaluated in the next study.

Version 2

The next iteration of the design was implemented after conducting the formative evaluation of the previous AR textbook. V2 represents the design features found from using the CI and layered elaboration and thematic analysis with the ELU framework. The second study has brought V1 as the prototype in this formative evaluation and has resulted in identifying specific aspects of ELU and new design features related to these aspects. The refinement in this prototype is represented in the AR joint marker feature through adding the interactivity feature.

Figure 24: The evolving versions of the prototype.

Version 3

The formative evaluation has been conducted again for the outcome of the second study. V2 has been brought to the third study as the prototype to be evaluated with the same methods of CI critiquing and layered elaboration. This study has resulted in the overarching design concepts of the AR textbook as well as further improvements to the prototype. The outcome of this final study has featured new enhancements in each aspect of the ELU dimension which were implemented in V3. For the collaborative learning experience aspect, further elaboration on the joint markers and AR card features were applied to support the rewarding feedback. The joint marker feature was extended to enable the interaction of more than two students. Also, changing the image markers to a unified theme and the feature of interactivity was enhanced in V3 as students can interact with 3D content using the touch screen. Finally, the feature of enhanced sound effects and voices which appeared with the 3D models has been implemented in V3 as well.

V.2 Educational, Technical and Ethical Issues

Educational issue

The Apple iPad was chosen as the AR display, for being reliable and integrated with AR since it includes a built-in video camera, GPS, wireless receiver, faster processor and large hard-drive memory (Dunleavy, Dede & Mitchell, 2009). It was elected as it emerged as the best portable system for young children, because it supports natural freehand input, without the need of a mouse or a stylus that can be too small for children (Chipman *et al* 2006). Moreover, the relative lightweight nature of the product and the screen size of a tablet allow one child to hold it, while others share the same view which support the collaborative design features. A study by Abdulaziz (2013) found that children aged between 7-12 years enjoy and appreciate iPad applications and have no issues using a lot of gestures on one interface or interacting with 2D/3D objects on the touch screen.

The other important motivation that takes educational issues into consideration is that a growing number of schools in Saudi Arabia have introduced the iPad in their classrooms and are looking for applications that actively support the learning environment. In addition to this,

the percentage of students having their own mobile devices is growing at every year, regardless of the student's socio-economic status (Burton *et al.*, 2011).

Many educational innovations, such as AR in classrooms, could encounter constraints from schools and resistances from teachers. However, the intuitiveness of the AR tablet application does not require specific training for teachers or students, whereas many other AR applications in the classroom require the teachers to be skilled or formally trained, for the educational AR to work effectively. In addition, the usual learning activities associated with AR involve different instructional approaches from the teacher-centered, delivery-based focus in conventional teaching methods (Kerawalla *et al.*, 2006).

As illustrated in this research, the AR textbook was designed based on the English school textbook of the Saudi Arabian primary schools. It would not be possible to design the AR textbook for the whole textbook, since developing an AR application requires a vast amount of time due to the various elements which are needed to be encountered, such as the 3D animations, trigger markers, redesigning of the textbook and application building. It should be noted that the collaborative experience was the aim of this research, which should be encountered for each lesson. Therefore, the proposed outcome demonstrates the key features through some lessons of the textbook for the purpose of the experience. The pages of the lesson were redesigned to include the AR trigger markers.

The integration concept was also represented in the audio feature, where the sounds in the AR textbook were taken from the CD of the textbook, which includes the audio content of all the textbook activities. The selected sound tracks which were imported in the AR, were seen and connected to the 3D characters through the use of scripts in Unity software. These sound effects would be played once the related image marker of the 3D model was tracked. Some other voices have been recorded with a child's voice for the character voices and feedbacks.

Technical issues

There are multiple requirements which are needed to build the AR application. First of all, Autodesk Maya was used for modeling and animating the 3D objects to be imported into Unity

which was used to set the AR scene (Figure 25). Vuforia SDK for unity extension was used to install the AR camera and trigger markers in the Unity scene.

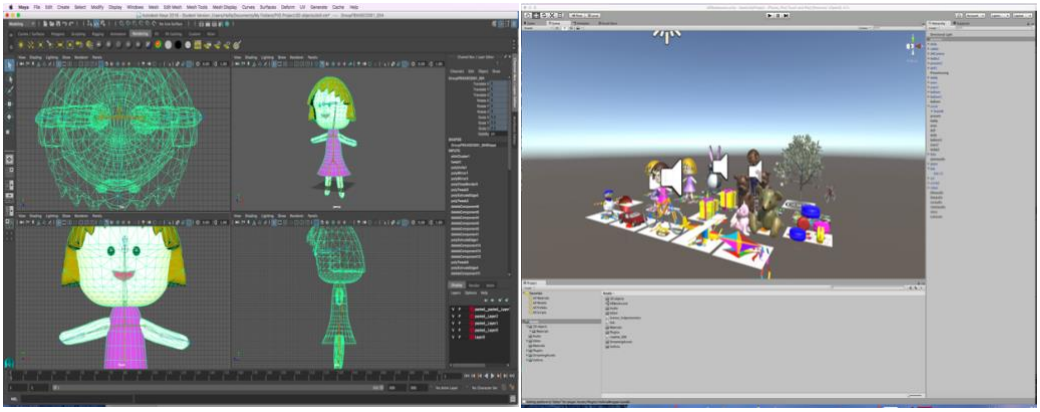


Figure 25: Modeling the 3D characters in Maya, and the AR scene in Unity.

Xcode was needed to build and run the AR application to the iOS device, in this case, the Apple iPad. The application definitely needed to be available for the students to be installed onto their own tablets. Therefore, an Apple developer account was created to get the final application into the App store to be available on the iPad as an application. Finally, designing the printed material so the pages of the lesson were redesigned to include the AR trigger markers needed to be completed so full integration between the book and the tablet technology was possible.

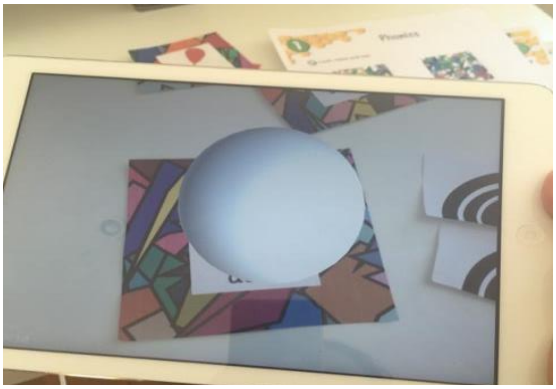


Figure 26: Designing, and testing the AR markers.

One of the challenges encountered in this practical work was dealing with number of software applications required to work together in order to develop the AR textbook. Having to manage the workflow between the several sets of software raises many technical issues which need to

be handled appropriately, such as updates in one application are not fully compatible with all versions of the other applications. The other challenge was the lack of resources to guide the development process of the AR Books. Since AR as a usable technology is a relatively recent development, it was occasionally challenging to find primary references throughout the practical component of this research. On frequent occasions, there was not enough guidance to support the prototyping process and solve the obstacles encountered.

A technical issue is related to the applications workflow, in which each feature is needed to be tested a number of times in order to work effectively, which required going over the same steps frequently for each testing. The process of testing the feature of Joint Markers for example requires designing the marker, printing it, uploading it to the Vuforia database, importing and adjusting it in the Unity scene and then building and running the application on Xcode in order to test the result. If the result was not successful, it needed to be fixed accordingly, thereby repeating that process until finding a solution for the feature to be applied efficiently.

Ethical issue

A full ethics application that looks into all aspects of ethical conduct has been approved for this research from Ethics Approvals Sub-Committee whose remit is to guide and assist investigators and ensure that full consideration is given to the health and safety of the participants who could be taking part and that the rights of the participants are protected. It has involved a full research proposal, assents from child participants and consents from their parents. Consent from adult participants has included fully completed information sheets for each study. A generic risk assessment form has been filled and submitted as well. The Code of Practice was approved by the Loughborough University Ethics Committee on 18 June 2012 (University Committees, 2015). The researcher worked within these relevant guidelines to ensure the research is conducted ethically.

V.3 Linkage between Practice and Research

This section falls into the debate of design research that discusses the traditional perspective of separating design practice from research. Many have begun with a research definition in

their attempt to introduce a new definition of design research. Friedman used the definition of research as *"a methodical search of knowledge",* stating,

> *Because design knowledge grows from practice, design knowledge and design research overlap. The practice of design is one foundation of design knowledge. Even though design knowledge arises in part from practice, however, it is not practice but systematic and methodical inquiry into practice- and other issues- that constitute design research as distinct from practice itself (Friedman, 2003).*

Another contribution to this perspective is made by Archer, where he defined research as, *"a systematic inquiry whose goal is communicable knowledge"*, going on to define action research as a, *"systematic investigation through practical action calculated to devise or test new information, ideas, forms or procedures and to produce communicable knowledge"* (Archer, 1995: 7). More definitions about action research and discussion about this research approach can be found in the methodology chapter. However, this section would further provide a clarification of the link or relationship between the practice and the research, deriving from Archer's argument that creative practitioner activity is synonymous with research activity. However, Archer argued that practitioner activity can be counted as research if it is "*knowledge directed, systematically conducted, unambiguously expressed",* Archer (1995: 6). Here is an argument that these criteria of systematic investigation, knowledge based and clear expression throughout the research conduction, are evident.

Schön (1983) provides a link between action research and practice-based research through the reflective practice which the researcher does on his work, which is emphasised by Sartre(2003), *"Reflection is knowledge; of that there is no doubt".* This concept of the *'reflective practice'* is represented after each study where the findings are implemented in the practical component of the research. It is also represented throughout the research process, where each study is influenced by the result of the previous study.

As shown in this overview of the research, the first co-design study has led to finding the design features that was mapped into the ELU concepts identified from the literature. The first prototype was developed accordingly, then evaluated to find new design features which in turn reflecting the next iteration of the design. The study has resulted in specific aspects of the

construction of the ELU model, which in turn are used as classification frameworks for the next evaluation study. The final study has resulted in the key concepts of the ELU framework that is proposed for designing and evaluating AR Books for children's experiences. This process can demonstrate that the reflection on what have been learnt from others' practices and those of our own, in order to develop and apply that knowledge further is an essential part of this research practice.

It can be suggested that the practical relationship between designing and researching is the reflective process which aligns with the common iterative design cycle, while the theoretical relationship is building on the theoretical foundation to develop an evaluation framework which could be used in the analysis and to inform the generated outcomes. Bonsiepe (2007) argued for the indispensability of research in contemporary designs. Additionally, Crouch & Pearce argued that researching and designing are fundamentally linked activities in our new contemporary circumstances,

> *Designing and researching are not new partners. Designers have always thought about what they do and have always researched information to help them tackle the tasks they are faced with…… There is an increasing dialogue between design and research in the contemporary design field. New practices in both fields inform the other (Crouch &Pearce, 2012: 17).*

The practical work was not created in opposition to the research questions and findings; rather, the research process is incorporated in the practice. The investigation carried out in this research was based on practice by means of an understood and recognised co-design method. This research has offered advances in knowledge in the research context as a result of both the process of the practice and the practical outcomes of it. Thus, it should be considered practice-based research, since it relies fundamentally on the nature of the practice as a central focus of its methodology and results.

The practice was underpinned by a theoretical foundation of the participatory action research, and the theoretical findings of the developed conceptual framework gained by the practice. Although it has undertaken a designer's practice of co-design, the research does not simply apply this method to gather information. Rather, it involves consideration of the ways in which

this method is applied to the '*circumstances'* and '*purpose'* of the research. It has also justified the rationale for the method selection and has applied a structured framework and systematic analysis in the design, development and conclusiveness of the research.

Having clarified the significant connection between the research and practice in the iterative and reflective nature, it was important to point out also the distinction between this participatory action research and the practitioners design process. A key distinguishing feature is that this research is methodologically systematic, as supported by Archer, *"research is systematic enquiry"*(Archer, 1981). It is deliberately planned and documented (Crouch & Pearce, 2012: 147).

The researchers and the participants involved in the participatory action research learn from the changes they make during their practice(Kemmis, McTaggart & Nixon, 2014). While the designer may engage in reflection on-day-to-day experiences, these are often short term and reactive. It may be argued that this improves their efficiency; however, it is also worth noting that their practices will not be changed at a deeper level. In contrast, this research, which takes place over a period of time and is deliberately planned and in so doing assumes proactivity on the part of the researcher, has the opportunity to suggest changes in practice and the potential that the documented process adds to the knowledge base, unlike the designers' reflection which remains private (Crouch & Pearce, 2012). This research included a practical outcome as an integral component of the research process, but it is accompanied with a complete documentation of this process with the underpinning theoretical perspectives. Therefore, the value of these research outcomes can be of benefit for researchers in CCI and co-design as well as designer practitioners of AR Books and children technologies in a broader context.

Finally, the notion of '*tacit knowledge'* has been discussed earlier in the methodology justification of the thesis (p.58). It represents a small justification for the contribution of the practical outcomes of this research in which the AR textbook, as a creative practitioner's output, constitutes new knowledge. The practical outcome constitutes, *"a kind of knowing that is not separated, or is separable, from the perception, judgment or skill which the knowledge informs",* as Archer defined tacit knowledge. He then went on to state,

> *There will be some of that in all creative practitioner activity. Undoubtedly some knowledge can be transmitted by some works to other practitioners and possibly to the population in general, when the work is published. Undoubtedly, in some circumstances, a striking art work or radically new product or other innovation can itself constitute new knowledge, tacit or otherwise, that can be highly significant in leading to major changes in people's perception, circumstances and values (Archer, 1995: 11).*

This body of research has identified the concepts underpinning the design outcome, which move this tacit knowledge to an explicit expression for a shared communication necessary for reflection and analysis, as has been identified by Grand(2012):

> *Explicit and articulate statements are the basis of all theorizing and all theory construction……only explicit articulation allows us to test, consider or reflect on the theories we develop…. for design profession to be prepared to meet the challenges that face designers in today's complex world (Grand, 2012: 141).*

Conclusion

The practical outcome of this practice-based research represents a collaborative AR text book, which represents a co-design output. The prototype has been evolved through the iterative co-design process and the evolving versions have been demonstrated in this chapter. The integration of the practice and research in the development of the ELU framework and the practical outcome has been clarified. The next illustration in Figure 27 can provide a visualisation of what has been discussed in that section. Finally, the next chapter will present the co-design studies conducted for this research, the procedure in each session and the key findings.

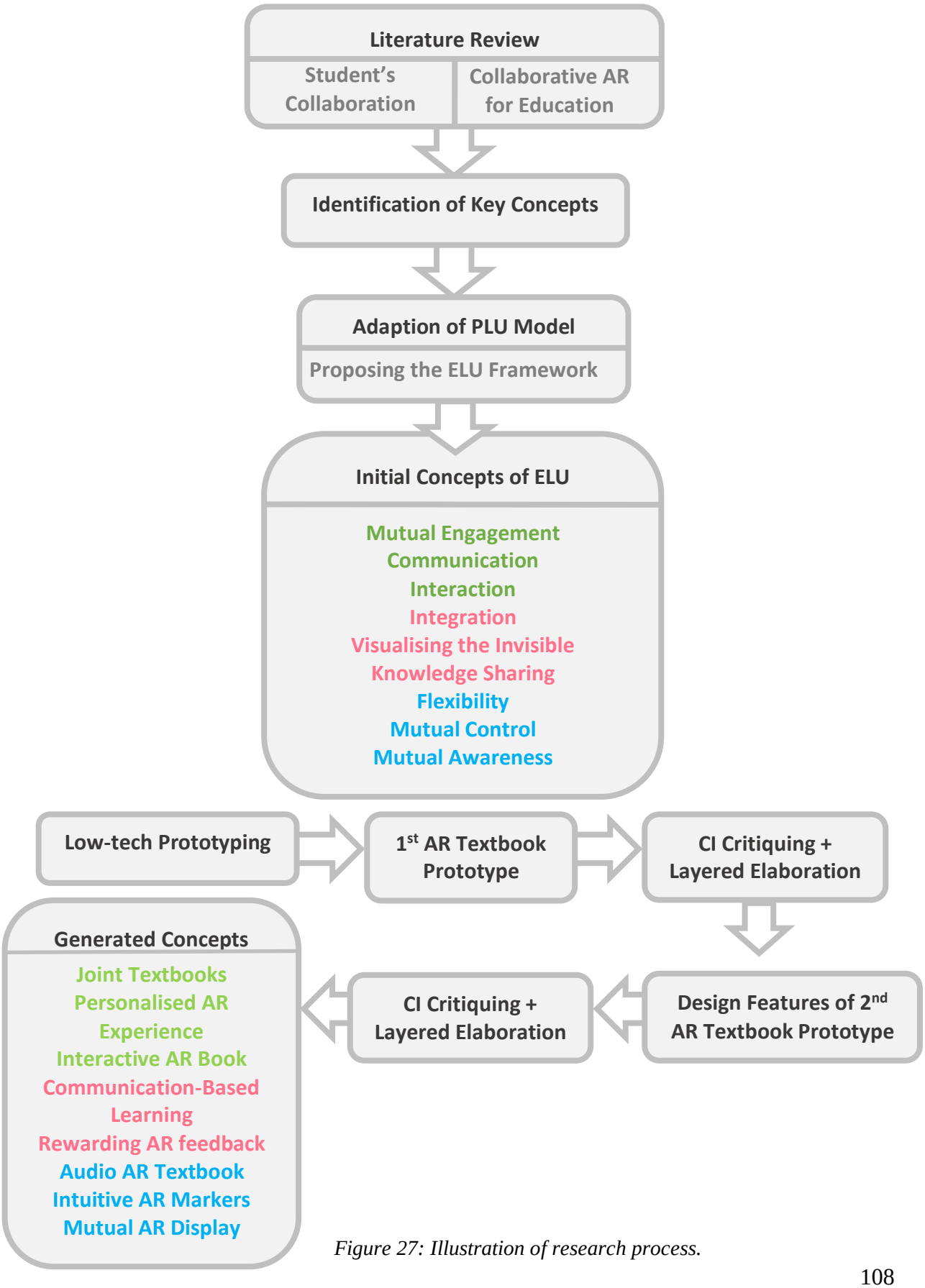


Figure 27: Illustration of research process.

VI. IMPLEMENTATION & FINDINGS

Introduction

This chapter presents the three co-design studies that have been undertaken through the three years of this PhD research. It reports the procedures of planning, data collection and analysis using the set of methods discussed earlier in the research methods chapter. It should be noted that the same participants of children and adults including the researcher are involved in each of the three co-design studies of this research. The children who participated in the research were four males and five females of the age group 8–10 years who were approached and selected from different primary schools in Saudi Arabia. They all study the same textbook used in the study and are familiar with tablets and with the children's tablet applications. The three adult participants have different academic backgrounds. They include one teacher of a Saudi primary school, an HCI expert and a university lecturer qualified in children's psychology. Each study concludes with its key findings and limitations.

VI.1 First Study

VI.1.1 **Planning**

The aim of this study is to brainstorm design ideas of the interactive AR textbook interface that support students' collaboration. The generated outcomes aim to envision the co-designers' ideas and to get feedback on these ideas.

At this initial stage, it was important that criterion sampling was used to select the nine children and the three adults. Qualitative research typically involves purposeful sampling to enhance understanding of the information-rich case(Patton, 1990). Purposeful sampling is oriented towards the development of idiographic knowledge from generalisations from and about individual cases and criterion sampling is a kind of purposeful sampling of cases on preconceived criteria (Sandelowski, 2000).

The criteria for children participants are stated as:

- Fourth grade children (aged 9-10 years) of Saudi Arabian primary schools who are familiar with tablet applications.

The criteria for the adult participants are stated as follows:

- A Saudi Arabian primary school grade English teacher, with a postgraduate degree in teaching methods of English language.
- An individual with an HCI qualification and relevant experience.
- A person with a psychology qualification and relevant experience.

The children participants and the teachers were approached through contacting the schools. After obtaining the head teacher's permission, the information sheets were given to children of the fourth-grade classes. The children who participated in the research were comprised of four males and five females of the age group of 9 - 10 years. The adult participants were comprised of an English teacher from a different school, an HCI expert and a psychology qualified, both from King Saud University in Saudi Arabia.

Although co-design doesn't have special criteria for the location and space, these research studies were conducted in the primary school classroom to reflect the actual setting for the AR textbook. As Robertson, Macvean & Howland (2013: 3) stated, *"The freedom of the setting can be a disadvantage because it doesn't reflect a real classroom environment".* The issue of where to experiment with the technology takes place has been critical in the HCI studies (Lew *et al.*, 2011). Also, CCI, *"has a strong focus on natural setting environments. This is pursued primarily through different kinds of field studies and secondarily through action research and case studies"*(Jensen & Skov, 2005: 83). Therefore, the naturalistic settings of the primary schools' classroom were chosen to conduct the AR textbook studies.

As illustrated in section (III.2.1, p. 67), the co-design framework was used for the studies of this research and it can be inferred that the first co-design session (low-tech prototyping) is mainly positioned in the generative phase of the framework. This is because the first co-design session's purpose is to produce ideas and concepts for the AR textbook design to serve as a direction of the design. Therefore, this session can be situated in the highlighted zone of the framework which is the toolkits approach to making (Figure 28).

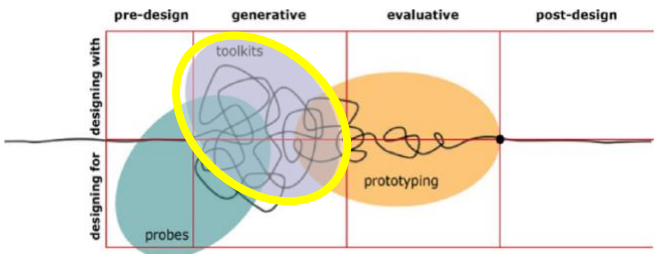


Figure 28: First study in the highlighted zone of the co-design framework Sanders & Stappers 2014).

This approach is positioned mainly in the generative research phase with a small part in the pre-design research phase. In terms of the research mind-set, the larger portion of the toolkits approach is in the participatory mind-set (designing with) which sees users as partners and active co-creators, whereas the smaller portion is in the expert mind-set (designing for), which sees the users as subjects. Since this approach of making overlaps with the probes and prototyping approaches, looking at the comparison of these three approaches provides a distinction of this toolkit's approach (Table 9). Therefore, situating the co-design sessions in this framework gives a clear understanding of the low-tech prototyping session through answering the same questions proposed by Sanders and Stappers.

Table 9: Sanders and Stappers (2014) questions for co-design sessions.

	Probes	Toolkits	Prototypes
What is made?	Probes are materials that have been designed to provoke or elicit response. For example, a postcard without a message.	Toolkits (made up of a variety of components) are specifically confirmed for each of the projects/domains. People use the toolkit components to make artefacts about or for the future.	Prototypes are physical manifestations of ideas or concepts. They range from the rough (giving the overall idea only) to the finished (resembling the actual end result).
Why?	Designers find inspiration in users' reactions to their suggestions.	To give non-designers a means with which to participate as co-designers in the design process.	To give form to an idea, and to explore technical and social feasibility.

What is made out of?	Probes can take on a wide variety of forms such as diaries, work-books, cameras with instructions, games, etc.	Toolkits are made of 2D or 3D components such as pictures, words, phrases, blocks, shapes, buttons, pipe cleaners, wires, etc.	Prototypes can be made from a very wide array of materials including clay, foam, wood, plastic, simple digital and electronic elements.
Who conceives?	Designers create the probes and send them to end-users and other stakeholders, often with little or no guidance of how the end-users should treat them.	Designers and researchers make the toolkits and give them to others to use to make artifacts. The process is often facilitated or guided.	Co-designers create the prototypes to envision their ideas and to display and to get feedback on these ideas from other stakeholders.
Who uses?	End-users and other stakeholders individually complete the probes, returning them to the person who sent them out.	End-users and other stakeholders use them to make artefacts about or for the future. Toolkits work with both individuals and small groups.	Designers use the prototypes as design tools. End-users may use the Prototypes during evaluative research events.

Table 10clarifies the toolkits and prototype for this study based on Sanders and Stappers's framework. It helps defining the design tools for engaging non-designers in this specific co-design activity, and shows the purposes of these tools and the roles of co-designers related to these tools. Figure 29 shows the actual tool being used in this study.

Table 10: Planning the first co-design session based on Sanders & Stappers (2014) questions.

Questions	Toolkit & Prototype
What is made?	A tablet template for AR interface made of transparent thick plastic material with a tablet frame. The interface elements are printed on pieces of paper to let users build their ideal interface out of these initial parts.
Why?	The tablet serves as the main elements for the co-design activity, to give the participants the sense of the tablet to build on and to help imagine the

	AR interface, which will turn on the camera directly to show the real world behind.
What is it made out of?	Pieces of UI elements, different sizes of sticky notes, tracing papers, pipe cleaners, clay, strings, scissors, glue, erasable coloured markers and pencils.
Who conceives?	The researcher makes the initial template of the tablet, and provides the toolkits to the participants to make artifacts. The process is facilitated and guided by the researcher and adult members.
Who uses?	The primary school children and adult participants use them to make artifacts for the future direction of the design.

Figure 29: The toolkits (bags of stuff) and the tablet template for the AR interface.

Based on review of the related co-design studies of new technologies for children and grounded in the previous co-design framework, a set of protocols was indicated and had been provided to the adult participants before the session to ensure a level of consistency in the outcome (Table 11).

Table 11: The first co-design session's set of protocols.

The aim of the co-design session	The expected outcome
The aim is to brainstorm design ideas of the interactive AR textbook interface that supports students' collaboration. The generated outcomes	3 models of low-tech prototypes of the AR textbook interface. The models are made up of a variety of components using the toolkits provided. The prototypes are physical

aim to envision the co-designers' ideas and to get feedback on these ideas.		manifestations of the groups' ideas or concepts.
The role of the participants		
Adults	Facilitator: Facilitating the collaborative work in creating the prototypes.	Note takers: Guidelines are listed below.
Children	Creator: Creating the prototypes from the provided toolkit.	Presenter: Present the group idea and prototype to the whole team.
The researcher	Observer: Floating from group to group to get an overall feel of the directions that the groups are headed to.	Note taker: Listening to the groups' presentations and writing the big ideas. Reviewing the big ideas with the groups and checking that no important ideas were missed.

The AR textbook guidelines	
Collaborative	The AR textbook should be designed in ways that support collaboration between students in the classroom.
Interactive	It has to be interactive with the students through feedback for different navigations.
Easy to use	It has to be easy to learn to use for the first time for 8-10 years old children.
Textbook-based	It should be based on an English school textbook and should be useful.
Fun	It has to be desirable, interesting and fun through the use of different media.

The Note taking guidelines	
In addition to activity facilitating, adult members will contribute in the data collection process. While the final prototype is important, the building of the model and the discussion and elaboration that occur around the prototype are as important.	Writing short text descriptions of conversations that occur during the brainstorming process.
	Notes of the dialogues that occur during the activity (making process) as the resulting prototype may not represent all of the ideas expressed in the verbal discussion.
	Notes concerning children's impressions can also be written.
	There are no right or wrong in note taking, the aim is to provide rich content for the directions of the research.

VI.1.2 **Data Collection**

The procedure of this session started with dividing the participants into three groups of three children and one adult. The researcher proposed the idea of the AR textbook and explained the aim of the intended project. An example of AR books was presented by video to the whole group in order to familiarise them with the idea of this new technology. Each of the groups was given three bags of the toolkit and the prototype which is considered in this session as a transparent thick plastic material with a frame to give the sense of the AR interface, to make a model for the AR textbook prototype (Figure 29). The children in each group started to create the artefact using the toolkit and the prototype provided (Figure 30).

Figure 30: The three groups creating low-tech prototypes.

The adult members were facilitating the collaborative work in creating the prototypes as well as taking notes of the dialogue between children throughout this process (Figure 31).

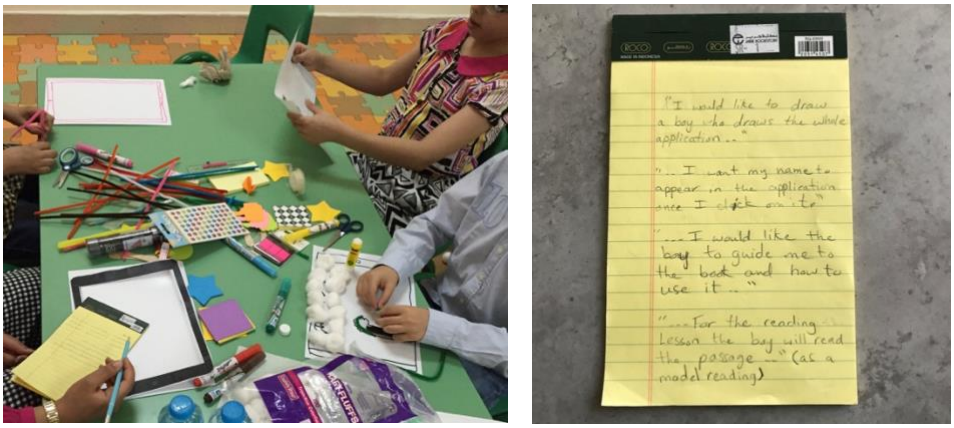


Figure 31: Adults taking noted of children dialogue, and example of the notes as a source of data.

At the end of the session each group presented their model and discussed it with the whole team, while the researcher took notes of the key ideas on the whiteboard (Figure 32). The notes on the whiteboard then were checked with the groups to ensure there were no important ideas which could have been missed.

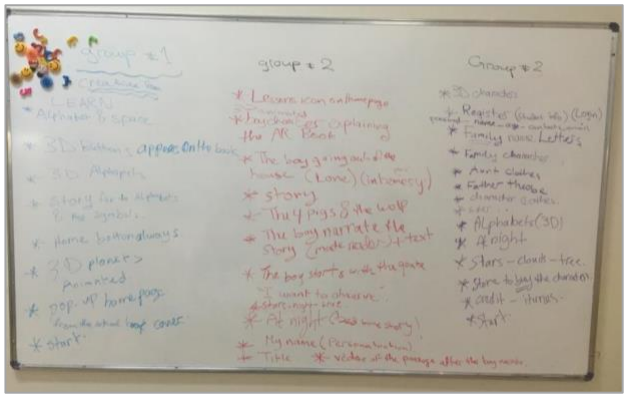


Figure 32: Data set on the white board.

The data gathered from this session are the three generated models of the AR textbook prototype (Figure 33), the adult members' notes of the children dialogue through the process, and the notes taken on the white board form the children's verbal presentations.

Figure 33: The artefacts generated by the three groups of children.

VI.1.3 **Data analysis**

After reading the data set from the white board and getting an overall impression, the adult participants tried to identify patterns that emerged in the first procedure of coding. The researcher has defined set of coding statements as indicated in Table 12.

Table 12: Defining a set of coding statements.

Statement	Definition
Interface	The user interface elements and application screen.
Content	The augmented objects on the school textbook.
Features	The actions and functions of the application.
Style	The items that defines the theme of the AR textbook.

The data set on the whiteboard was grouped under the relative statements (Table 13).

Table 13: Data set categorised to the coding statements.

Statement	Data
Interface	3D buttons appear on the textbook Home button appears all the time Start button after the pop-up Icons of the lessons titles appears on the homepage My name appears on the screen Start button appears on the screen
Content	Story about the alphabets Animated boy character explaining the AR textbook 3D characters of the family 3D alphabets of the first letters of the family member's names
Features	Pop-up home page when the school cover detected. The 4 pig and the wolf story narrated by the boy with written text Video of the passage after the boy reads it Register my name and password in the app The app let us buy the characters by credits
Style	Learn alphabets and space Animated 3D planets The boy character comes out from his house at the beginning The boy starts with the quote: "I want to observe!" The boy comes out from his house at night looking at the stars and trees The alphabets appear at night. Stars, clouds and trees appearing around the 3D letter

The second level of coding was about highlighting the frequencies in the data where patterns started to emerge as low-level themes. The researcher, with the adult members, then categorised the low-level themes to generate the high-level themes for determination of an overall direction of the task of designing the first AR textbook prototype (Table 14).

Table 14: Data set categorised to the coding statements.

Low-Level Themes	High-Level Themes
Collect and exchange Ability to customise Credits and rewards	Personalisation
Animated characters Game Story Pop-up objects	Fun
Family Home Nature Night time	Intimacy

Finally, as can be noted the analysis process followed three techniques recommended by Lazar, Feng & Hochheiser (2010) for the quality of the analysis. First, defining a group of specific items in order to look for while coding, asking questions constantly about the data and making comparisons at various levels. The second technique involved asking questions about the data. This was done during the presentations, where the adult members asked questions to the children so that they could better explain their statements and to help the coders make connections between data and the involved categories. Examples of questions asked about the data are listed in Table 15 with the responses of the children and photos from the presentation session.

Table 15: Examples of questions about the data and responses.

Question	Photo	Response

Is this the boy's house behind him?		Yes, he comes out of the house when we start the application.
What is the boy saying?		He is explaining the AR textbook.
How do you buy the characters? What is the register button for?		By collecting credits from winning the game. It lets us create account with our names and password.

The last technique involved was making constant comparisons between data sources which was done at two stages of the session. After each presentation, the researcher checked the data with the notes of adult member of the group to ensure no important ideas were missed. The other stage was during the coding process between the three adult members and the researcher.

VI.1.4 **Key Findings**

Findings for the AR textbook prototype

A principal issue identified at this stage shows that the children have similar views of the AR textbook. However, some different patterns did emerge from the data using thematic analysis with the three adult members. What is clear is that the emerging themes are Personalisation, Fun and Intimacy. These aspects define the overall direction of the design and represent the

design features which could be implemented in the AR textbook prototype.

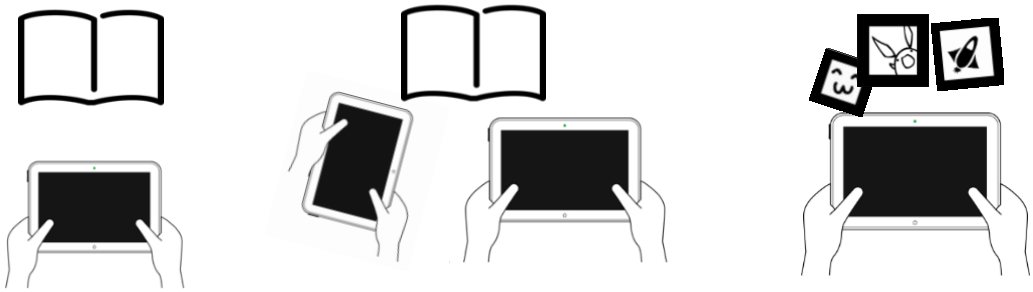
In this stage of the research, the work on the ELU framework in chapter (III.3.3.) had been started and the concepts of the ELU have been defined in (Table 7). The researcher then reflected on the study result together with the definition of the ELU concepts to identify the design features that can be implemented in the first AR textbook prototype. Three key features have been indicated that supports the collaborative experience, learning and usability. These are related with the resulted themes considering the low-level themes to inform the content to design the prototype. Table 16 illustrates the description of these three features, aligned to the related ELU and the resulted themes.

Table 16: Alignment of the design features informed by the resulted themes and the ELU concepts.

	Concept	Design Feature of The Prototype	Theme
E	Mutual Engagement Communication Interaction	The end of the textbook activity will result in a reward card which is an AR marker that can be displayed by the tablet (figure 35). The reward card will play the animation of the selected object but if more than one student could share their cards, an enhanced version of the animation will play. This feature represents a unique AR collaborative experience which supports the diversity between the classroom students and provides each student with a chance to participate. It was informed by the resulted theme of personalisation in which it can be exchanged by the students to display different 3D scenes and can be joined together to complete the 3D objects of	Personalisation: Collect and exchange Ability to customise Credits and rewards
L	Integration Visualizing the invisible Knowledge Sharing	Using the textbook as the main interface, with the only change being made is adding the AR markers into the textbook to be tracked by the AR application. This feature allows for the integration of AR in the regular curriculum not being concerned with the educational content since the printed textbook is designed by the curriculum experts. In the textbook, students see the pictures. But with the AR textbook, they will visualise the object in an animated	Fun: Animated characters Game Story Pop-up objects Intimacy:

		form as the characters could come to life. This feature considers the learning aspect since it provides immediate digital content related to the printed content of the textbook and integration in the curriculum (figure 36). The digital content is informed by the resulted themes of fun and intimacy, using an animated boy explaining the AR activities and using the printed images of the textbook to model and animate fun 3D characters.	Family Home Nature Night time
U	Mutual awareness Mutual control Flexibility	The AR textbook can be applied in three settings where students can share the control or use the AR textbook by their own to learn individually. Using the template of the tablet interface in the low-tech prototyping session allowed students to see each other while also interacting with the environment. This principle informed the design of the AR book to be applied in three settings illustrated in figure 34 to allow flexibility and share control. This feature reflects the theme of personalisation in the ability to customise the reward cards and the ability to learn either individually or in groups.	Personalisation: Collect and exchange Ability to customise Credits and rewards

The initial prototype of the AR textbook was completely developed by the researcher as the first version (V1) considering the findings of the first study and can be seen in the following figures that demonstrate the key features in Table 16. V1 has considered children inputs from the low-tech prototyping and has been informed by the concepts of the ELU and was built as high-fidelity prototype to be evaluated in the next study.



a) Individual AR textbook experience.

b) More than one student share the same textbook and display the same AR scene.

c) Collaborative experience using the reward cards

Figure 34: AR textbook can be used in different settings.

Figure 35: The AR markers for individuals and the cut-outs as AR reward cards for collaboration.

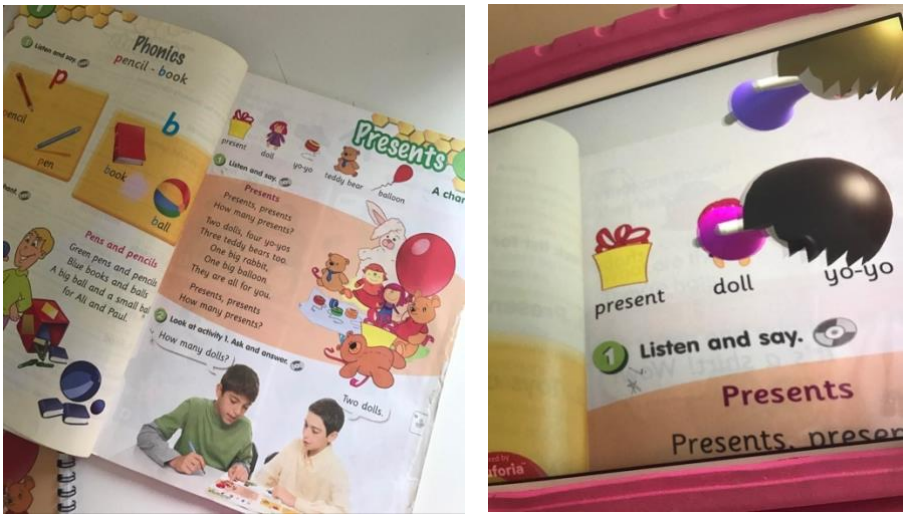


Figure 36: The regular textbook and the AR textbook showing same content with added AR markers.

Findings for the CCI Community

Regarding the participation of the children, it was noted that the child members were surprisingly interactive and information active. The argument that children are natural partners for co-design is evident by this process. The child members had participated with interesting design ideas. Moreover, there were significant connections between each group's ideas, which show that children had similar views of the AR textbook in which it was easy to find patterns using the thematic analysis. It is important to note that adult participants were also effective in their different roles of facilitator, note-takers, and coders respectively. Having three coders, with three different theoretical backgrounds, had increased the quality of the analysis when comparisons were made with different data sources.

Limitations

Although there was sufficient time to conduct the co-design study appropriately against the frameworks which have been identified, experience showed that it would be better to separate the sessions in different days. As has stated earlier, the children were interactive and enthusiastic to express their ideas and each child member was expressing the idea once it came into his/her mind. This occasionally interrupted statements from the other children or the note takers, because they were speaking at the same time. The adult members therefore were trying to have conversations with each child and asked questions to ensure all children about the ideas which have been explained and documented. Giving sufficient time for the data collection session ensures that no idea has been missed, and child participants had the time to think, express, and elaborate on their ideas. This is a critical factor of the next evaluation study when even a greater amount of time would need to be allocated. This study has been done at the early stage of the research but it has indicated the starting point to answer the research questions. The first question of the key concepts of children's AR textbooks for collaborative learning experience remains open, however the question of the design features has a preliminary answer which will be completed in the next two studies. Finally, this study has shown helpful guidelines for the low-tech prototyping session for an AR textbook. It can start answering the last research question of using co-design methods with children for AR textbooks for children.

VI.2 Second Study

VI.2.1 **Planning**

This study is considered as a formative evaluation for refining the outcome of the first study. It aims to improve the collaborative experience, usability and learning aspects of V1 and the generated results of this study are aimed to feed in the next iteration of designing V2. This co-design session is situated in the highlighted zone of the co-design framework (Figure 37). This approach is positioned mainly in the generative research phase leaning towards the evaluative research phase.

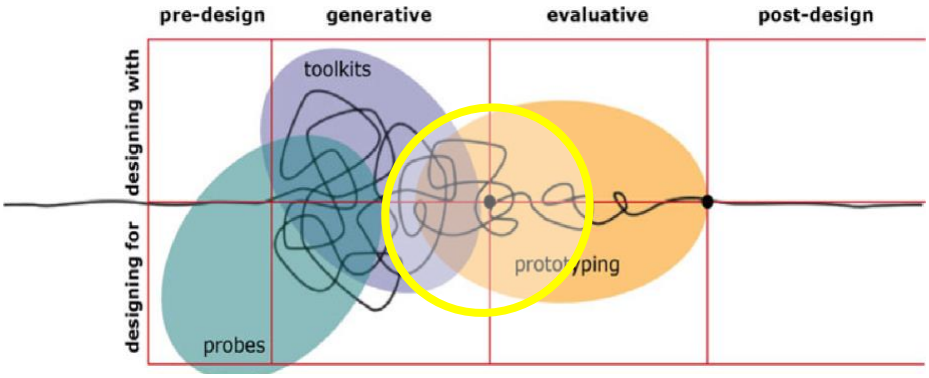


Figure 37: Co-design Framework (Sanders & Stappers 2014).

While this co-design session overlaps between the generative and evaluative approaches to making, using the comparison of these three approaches provided by Sanders and Stappers clarifies the important elements of this study (Table 17).

Table 17: Toolkits and Prototype evaluation sessions based on Sanders and Stappers's comparison.

	Toolkits	Prototype
What is made?	Clip- boards, binder clips. write-on clear transparency film Coloured Sticky notes. Pens and markers.	A completed prototype of AR textbook.

Why?	The hanger and the trans are used for layered elaboration. While the sticky notes are used to write their likes, dislikes and suggested design ideas in separate colours.	To evaluate the current prototype which is based on the concepts of the ELU framework.
What is it made out of?	Pieces of UI elements, different sizes of sticky notes, tracing papers, pipe cleaners, clay, strings, scissors, glue, erasable coloured markers and pencils.	The AR textbook prototype includes the tablet application and the redesigned school textbook, with the image marker cards.
Who conceives?	The researcher provides the toolkits to the participant groups. The process is facilitated and guided by the researcher and adult members.	The researcher developed the prototype based on the co-designers' ideas and the result of the low-tech prototyping session in the first study of this research.
Who uses?	The children with the adult members use them for the formative evaluation.	The groups of children experience the AR textbook for the purpose of evaluation.

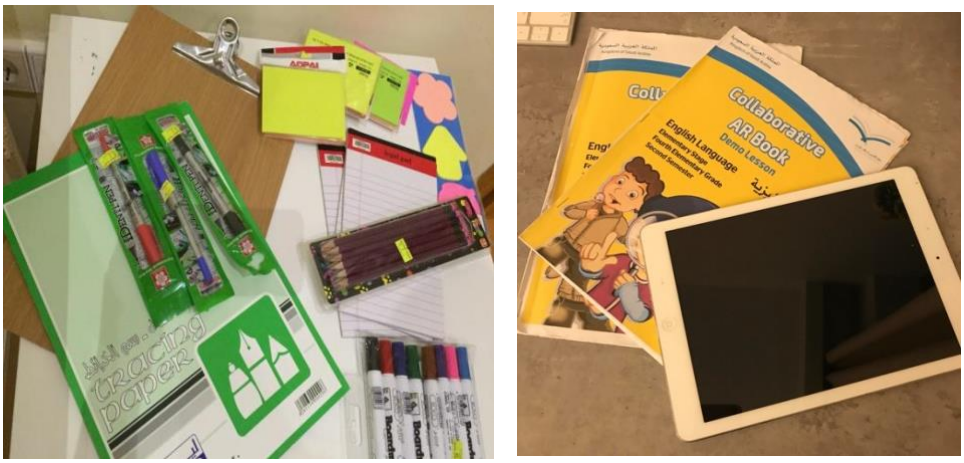


Figure 38: The toolkits and the prototype v1.

Cooperative inquiry critiquing, in addition to layered elaboration, was employed for data collection. The CI critiquing was used to evaluate the different aspects of the ELU, whereas the layered elaboration focused on the collaborative experience, to collect more data about the primary aspect. Children were asked open-ended questions by adult members to collect data

about the E, L and U dimensions during the CI critiquing. In the layered elaboration session, the children were asked questions about how to improve the collaborative experience for the AR textbook. As in low-tech prototyping the participants were divided into three groups of three children and one adult. The set of protocols were given to the adult participants before the session.

Table 18: The set of protocols for the second study.

<table>
<tr><th colspan="2">The objective of this co-design session</th><th colspan="2">The expected outcome</th></tr>
<tr><td colspan="2">Formative evaluation of the AR textbook prototype to improve the collaborative experience, usability and learning aspects. The generated results aim to feed in the next iteration of the design.</td><td colspan="2">Categorised ideas on the whiteboard of the collaborative experience, usability and learning that will be analysed for improving the next AR textbook prototype.</td></tr>
<tr><th colspan="4">The role of the participants</th></tr>
<tr><td>Children</td><td>Creator:
Creating the layered prototype based on the current AR textbook.</td><td colspan="2">Evaluator:
Stating their likes, dislikes, and suggested design ideas to the adult member to write.</td></tr>
<tr><td>Adults</td><td>Facilitator:
Facilitating the layered elaboration process.</td><td>Note taker:
Writing children's statements in separate colored post-it notes. Also, taking notes about the discussions which occur around the prototype and during the layered elaboration. Guidelines are listed below.</td><td>Coder:
Participate in the thematic analysis of the data gathered on the whiteboard in order to make sure no idea is missed and to compare the data with notes taken during the session.</td></tr>
<tr><td>The researcher</td><td>Observer:
Getting an overall feel of the directions that the groups are headed.</td><td>Note taker:
Taking notes about the layered elaboration.</td><td>Coder:
Guides the coding process with the adult members, based on ELU.</td></tr>
</table>

The Note taking guidelines
Writing the exact statements of the children without any interpretation in separate sticky notes.
Writing short text descriptions of conversations that occur during the layered elaboration process and during the phase when children are experiencing the prototype.
Notes concerning children's impressions can also be written.
There are no rights or wrongs in note taking and the aim is to provide rich content for evaluation.

VI.2.2 **Data Collection**

As has been stated in the first of this chapter, the same participants of children and adults including the researcher are involved in each session of the three co-design studies of this research. There were two sessions of the data collection which are cooperative inquiry critiquing and the layered elaboration session, whereas the data thematic analysis session has been carried out on the following day with only the adult participants.

The procedure started with dividing the participants into three groups of three children and one adult child and given the AR textbook prototype for experimentation. The first spontaneous impression when the 3D object popped up from the book was surprising to them, while they reacted with appreciative expressions. After a short experiment of exploring the design features of the prototype, the CI critiquing started as the researcher asked the groups to write their likes, dislikes and suggested design ideas on the colored post-it notes while continuing to experiment with the AR textbook. These notes were collected by the adult members and placed on the whiteboard.

The researcher then asked the groups to do the same process again focusing on the aspects of collaborative experience, learning and usability. The adult members in each group asked the children questions of how the prototype could be improved, related to these aspects. This stimulated the child member's thinking to generate more ideas, in order to collect as much data as possible about these specific concepts.

Figure 39: Data set of CI critiquing on the white board.

The second session applied the layered elaboration technique focusing on the collaborative experience. The session started by giving one group a clipboard with white paper and a marker and asked them to draw their final idea on how to improve upon the collaborative experience of the AR textbook prototype. The group members already had some idea to elaborate on, so the adult member guided the discussion and facilitated the process to develop a shared design idea to be drawn on the clipboard paper. The group then presented a brief overview of their design idea to the whole team and then passed the clipboard to the next group. The process was repeated for the third group, in which each group overlaid a transparency sheet on the clipboard and the adult member read a description of the current storyboard and then started, to elaborate on it.

Figure 40: Group members in the layered elaboration session.

Once all of the groups had a chance to design a presentation of their ideas, the final elaborated idea was discussed with the whole group to gather the important ideas on the post-it notes to be placed on the whiteboard with the category of suggested design ideas.

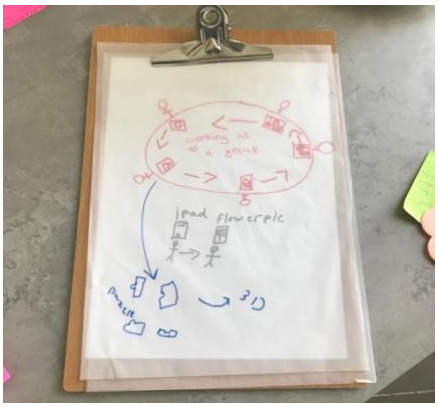


Figure 41: Layered elaboration outcome.

VI.2.3 **Data analysis**

From the lessons learnt of previous study, the data analysis session was planned to take place on the following day with the adult members only. Thematic analysis was used to elucidate the groups elaborated result on the prototype, in addition to the data collected from CI critiquing. The analysis started with the set of text-based data gathered on the white board from the previous data collection sessions. These notes contained raw data which were verbatim transcripts from the children co-designers. The initial data set was categorised initially by colored post-it notes into like, dislikes, and suggested design ideas. The coding process started with categorising the data based on the ELU regardless of the post-it note color.

Figure 42: The open coding process.

Each of the adult participants read the transcripts and interpreted the interesting quotes taken from the children's own words. The researcher discussed these interpretations with the three adult participants to indicate the shared interpretations based on the comparisons of these different interpretations and on the notes taken by the adult member in each group. The data then has been re-categorised again under each dimension into the related concepts of the ELU identified in Table 7. The group then joined up to discuss their insights about the categorisation where specific themes started to emerge. The researcher, with the help of the three coders, compared the emerged themes based on the definition of the ELU framework concepts as well as the different data sources of the adult's notes, the layered elaboration and the transcripts taken from children's verbal views.

VI.2.4 **Key Findings**

Findings for the AR textbook prototype

The data from the child members led to ideas and insights in low level themes which can feed into the next iteration to improve the current AR textbook prototype, whereas the wider concepts emerged after the data interpretation into a more conceptual level. These concepts represent the important aspects for each dimension of the ELU in which each aspect is related to a design feature that can be implemented in the next iteration of the prototype. The key findings of this study for improving V1 have been illustrated in Table 19 which define the design features to be implemented in V2 (Figure 43).

Table 19: ELU aspects with the new design features related to each aspect.

Dimension	Aspect	Design Feature
Collaborative Experience	AR Markers	Extending this feature into more than one textbook.
	AR Reward Cards	Extending this feature for a variety of the textbook activities.
	3D Content	Enhancing animation and visual effects.
Learning	Printed Content	Adding more lessons to the AR textbook.
	Feedback	Using the AR cards as a rewarding feedback.
Usability	Audio	Adding sound effects to the 3D content.
	AR Markers	Re-designing of the AR markers to be tracked effectively.
	AR Display	Fixing the point of view angle of the 3D models.

Figure 43: Version 2

Concerning the issue of usability, the collected data related to such issues contained important points that will be fixed in the next prototype. For example, the 3D content point of view needs to be more flexible for the group of children to display. The AR marker needs to be fixed to a more accurate image for the AR camera to track easily from far distance. Also, having realistic 3D models reflects the children's sense of wide imagination. On the other hand, regarding the learning dimensions, the children raised the need of activities without the help of the teacher, and suggested adding more learning content from the school textbook, with using the AR content for motivational tasks and activities. Finally, the collaborative experience dimension was provided with interesting feature which is cutting the AR marker in the edges of the two textbooks in order to encourage students to join each other to display the AR content . In addition, the concept of personalisation was suggested where children can create and modify

the AR content. Also, the need of enhancement and promotion of feedback using the AR, which will be valuable for the children collaborative experience.

Findings for the CCI community

In these co-design sessions, it was found that all team members were highly involved throughout the process. It was noted that the child male participants were more information active and enthusiastic to participate in the co-design session than the child female participants. There was evidence that the child members who happened to know each other before were more productive compared to others who did not. However, the nature of co-design sessions as well as the collaborative AR textbook activities helped the group members to build a team relationship which facilitated every child's active involvement.

Important aspects have emerged from this second study, and will feed into the next AR textbook prototype. Posting all the notes on the whiteboard was a form of visualisation in which every member could follow, reflect on, and contribute to the analysis process. The post-it notes were helpful in collecting both CI critiquing and Layered Elaboration data, since they could be easily rearranged and were useful in organising the data set. At the beginning of each round in the layered elaboration session, each group selected one unique colour with which to make their modifications. Selecting one color for each group helped to identify similarities and differences in the groups' modifications. It was recognised that applying layered elaboration techniques after the CI session enabled the participants to generate further ideas which lead to the identification of several areas to improve the prototype. It was evident from this stage of study that the value of the ELU framework and the connection between its concepts and the ideas of the identified design features emerged from the study. The framework helped structuring and organising the data and searching for patterns, as well as guiding the direction of the thematic analysis.

Limitations

The analysis has been carried out for the data collected from the two sessions of CI critiquing and layered elaboration. However, the thematic analysis followed systematic procedures, which had commenced from the data collection sessions, where the adult members asked questions about the data, allowing children to better explain their elaborated ideas or their

statements to be written on the notes. In addition to this, the adult facilitators asked children to further explain their impressions or statements, before writing them on post-it notes to ensure clear quotes were written and no important idea was missed. Having three coders, in addition to the researcher, increased the quality of the analysis which helped to control the risk of subjective interpretations of the data. The other technique was the making of comparisons of the data at various levels. This was achieved by comparing the notes from the whiteboard to the adult members' notes and insights during the experiencing of the AR textbook prototype and after each presentation of layered elaboration where the researcher checked the data with the notes of the adult member of each group to ensure it was correctly expressed and to create another layer of rigor to the research process.

The design features identified from this study are mostly extending and enhancing of the previous prototype, however, the data analysis has resulted in important aspects regarding the ELU framework which will be useful in the thematic analysis for the next study. It has been shown that the findings of this study can complete the initial answers of the research questions indicated in the first study. The question of the key concepts is still open; however, the aspects of ELU framework has started to emerge. The design features of the AR textbook are improved and were classified under related aspects of the ELU framework. Finally, this study can answer the question of how co-design with children can be applied in the context of AR textbooks in terms of using the CI critiquing, and layered elaboration. This can add to the previous guidelines found by the low-tech prototyping technique, to demonstrate the application of these methods in practice for the AR textbook design.

VI.3 Third Study

VI.3.1 **Planning**

The aim of this study is to further improve the prototype V2 considering the ELU aspects. It represents an iteration of the formative evaluation of the AR textbook prototype in which the generated results can feed in the next iteration of designing V3. The same participants of the previous studies were recruited for this final study as well. The toolkits also are similar to the previous study because CI critiquing and layered elaboration techniques will be used again in this study, whereas, the prototype which has been used, is V2 which is the outcome of the second study. The set of protocols of this third co-design study are indicated in Table 20.

Table 20: The third co-design study set of protocols.

<table>
<tr><th colspan="2">The objective of this co-design session</th><th colspan="2">The expected outcome</th></tr>
<tr><td colspan="2">Formative evaluation of the AR textbook prototype to improve the collaborative experience, usability and learning aspects. The generated results aim to feed in the next iteration of the design.</td><td colspan="2">Categorised ideas on the whiteboard of the collaborative experience, usability and learning that will be analysed for improving the next AR textbook prototype.</td></tr>
<tr><th colspan="4">The role of the participants</th></tr>
<tr><td>Children</td><td>Creator:
Creating the layered prototype based on the current AR textbook.</td><td colspan="2">Evaluator:
Stating their likes, dislikes and suggested design ideas to the adult members to write down.</td></tr>
<tr><td>Adults</td><td>Facilitator:
Facilitating the layered elaboration process.</td><td>Note taker:
Writing children's statements in separate colored post-it notes. Also, taking notes about the discussion that occurs around the prototype and during the layered elaboration. Guidelines are listed below.</td><td>Coder:
Participate in the thematic analysis of the data gathered on the whiteboard in order to make sure no idea is missed and to compare the data with notes.</td></tr>
</table>

The researcher	**Observer:** Floating from one group to another to get an overall feel of the directions that the groups are headed.	**Note taker:** Placing the written notes on the whiteboard and taking notes about the layered elaboration process.	**Coder:** Guide the coding process with the adult members, based on the ELU framework.
The Note taking guidelines			
Writing the exact children statements without any interpretation in separate post-it notes.			
Writing short text descriptions of conversations that occur during the layered elaboration process and during the phase when children are experiencing the prototype.			
Notes concerning children's impressions can also be written.			
There are no rights or wrongs in note taking. The aim is to provide rich content for evaluation.			

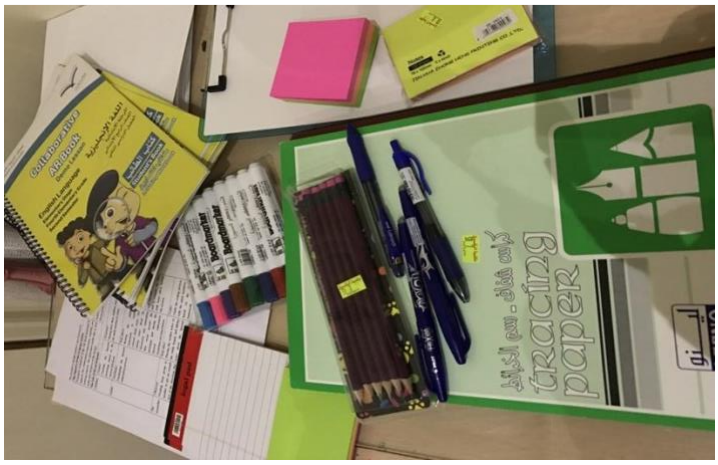


Figure 44: Third co-design Session Toolkits and Prototype.

VI.3.2 **Data Collection**

Most of these co-design study procedures are similar to the previous evaluation study and can be considered as the next iteration of evaluating the AR textbook prototype. The difference in this third study is that child participants will experience the AR textbook in the classroom in a regular school day at the English subject lesson, because it is crucial to experience the prototype in the naturalistic context (Howland, Good & Robertson, 2007).

After the class had finished, the nine child participants were taken to join the co-design study with the researcher and the three adult participants. The layered elaboration session was completed the following day. The workshop classroom location was reserved for this research study, so the whiteboard with data collected, were placed in the same way on the following day. The analysis was done afterwards during two sessions with the adult participants, noting that the reason why the researcher and the adult participants did not attend the lesson in the classroom was to limit the factors that detract the realistic settings. As Kelleher, Pausch and Kiesler (2007) explained that despite their best efforts to avoid bias, some researchers still feel that their presence at evaluative studies is a potential limitation to the work as it may influence the participants' experience.

Figure 45: Cooperative inquiry critiquing session.

The procedure of the data collection started with the CI critiquing session with the same procedure of the CI critiquing in previous study in which each group wrote the children's statements on colored post-it notes. The children were experiencing the AR textbook prototype giving their comments, while the adult member were taking notes. The same process has conducted again focusing on the aspects of collaborative experience, learning and usability. This is done by an adult member in each group asking children questions about how can each concepts of the ELU be improved.

Figure 46: Placing the post-it notes on the white board.

The layered elaboration session also conducted the same procedure in which the groups discussed their ideas and children took turns with the marker and expressed their ideas by drawing on the clip board. As has been with the second study, this session was aimed to collect further data but focused specifically on the collaborative experience.

Figure 47: Layered Elaboration session, and outcome.

Figure 48: Children presenting their elaborated idea to the whole group.

After the group had completed this task, they did a presentation for the other groups explaining their ideas for the whole group. The elaborated ideas were identified and written on the post-it notes to be added to the whiteboard with different colours.

Figure 49: Data set on the whiteboard from the CI critiquing and Layered Elaboration sessions.

VI.3.3 **Data analysis**

The adult members started the coding process by reading the transcripts on the whiteboard taken from children's own words and writing their interpretations on each one. This interpretation is useful to turn the raw data into information, and to compare the data and discovering patterns, because the transcripts were paraphrased with the coders languages. The interpreted transcripts were re-categorised under the relative dimension of E, L, and U relying on the definitions of the concepts (Figure 50).

Figure 50: Data set categorisation.

The next level of coding was categorising the data set in each dimension based on the aspects that emerged from the previous study. After reading the transcripts in the new classifications, frequencies and specific patterns started to emerge for each aspect (Figure 51).

Figure 51: The data set categorised based on the identified aspects.

The next session of the data analysis started with the conceptualisation process, where the coders referred back to the analysis and further reflected on the results with the initial data as well. The group discussed their overall impression about the categorisation and their insights about emerged patterns. The researcher, then with the three coders, identified the design features for each group of data based on the interpretations, the connections between the data sources and the related aspect, which represented the design features of the final AR textbook prototype (Table 21). The result of the analysis gave insights of future design features that could improve the current AR textbook prototype V2 into the final version (V3).

Table 21: ELU concepts with overall visualisation form previous studies.

Initial Concepts of ELU (from the literature)	Design Features of 1st Study	Aspects of ELU (from the 2nd study)	Design Features of 2nd Study	Developed Concepts of ELU
Mutual Engagement Communication Interaction	Using the textbook cut-outs as AR markers.	AR Markers	Dividing the marker into more than one textbook.	Joint textbooks
		AR Reward Cards	Using the AR reward cards in different sections of the book and not only in the cut-outs.	Personalised collaborative AR
		3D Content	Enhancing animation and visual effects.	Interactive AR textbook
Integration Visualizing the Invisible Knowledge Sharing	The printed and the digital content based on the regular textbook content.	Printed Content	Adding more lessons to the AR textbook.	Communication-based learning
		Feedback	Using the AR cards as a rewarding feedback.	Rewarding AR feedback
Mutual Awareness Mutual control Flexibility	AR textbook can be applied in 3 settings by sharing, or learning individually.	Audio	Adding sound effects to the 3D content.	Audio AR textbook
		AR Markers	Re-designing the AR markers to be visible and consistent.	Intuitive AR markers
		AR Display	Fixing the point of view angle of the 3D models.	Mutual AR Display

In the conceptualisation process the team referred back to the previous studies and summarised the results on the whiteboard as an integral visual summary. This visual representation connects to the raw data to of each study and was used in the reflections as a way to provoke the creation of new concepts. By this means the team, led by the researcher, analysed the previous studies findings into a higher level of concepts that are indicated in Table 21. The initial concepts identified at the early stage of the research have been developed to eight fundamental concepts specific to AR for collaborative learning experience (Table 22).

Table 22: Key concepts and definitions of the AR Book aligned to the ELU.

	Developed Concepts	Definition
E	Joint textbooks	This concept relies on the joint AR markers which are found by the researcher, where the AR markers are separated in the textbooks in order for the AR scene to be played only when the students join their textbooks to connect the markers.
	Personalised collaborative AR	AR content can be displayed in different settings by individual student books or by joining and exchanging the AR markers.
	Interactive AR textbook	Students can interact with the AR content through the touch-based interface.
L	Communication-based learning	Learning new information is a result of the use of communication cues by the students to do the textbook activities.
	Rewarding AR feedback	Using AR as a feedback for the textbook activities that provide an enhanced experience as a reward.
U	Audio AR textbook	Integrating the audio content of the CD provided with the textbook into the AR application as type of interaction between the 3D content and the students.
	Intuitive AR markers	The AR markers should be added to the actual textbook in a way students can recognise them intuitively.
	Mutual AR Display	The 3D models and animation should be displayed effectively from any perspective, taking into account multiple students positions.

Figure 52: Version 3 (the final outcome).

VI.3.4 **Key Findings**

Findings for the AR textbook prototype

In the context of this thesis, it is significant that the eight fundamental concepts can be generalisable to a broader scope of the ELU framework. The researcher defined these original design principles to provide an original contribution to knowledge and experiential implications for future research. Importantly:

- Starting with the Joint Textbooks, this research introduces an original concept for the collaborative learning experience using the affordances of AR and the idea of separating the AR marker into two part placed at the edges of the textbooks which hasn't been done before. This concept can relate to the *'joint action'* theory, which is a form of social interaction where two individuals do an action with shared intentions to produce a joint outcome (Knoblich, Butterfill & Sebanz, 2011).

- The second key concept identified Personalised AR Experience, where the collaborative experience can be encountered by different scenarios of the students' choices. This can be represented in children sharing and exchanging the cut-outs of AR cards or joining their textbooks for different AR contents.

- The third concept, identified as Interactive AR Book, demonstrates the interactivity between the students and the textbook using AR. The application interface is

interactive, allowing the children to interact with the AR content benefiting from the touch screen affordance of the tablet.

- The Fourth concept was shared between the E and L dimensions and was called Communication-Based Learning. It suggests that the learning process should depend on communication between students, as using communication cues is a fundamental concept of the collaborative learning. Applying this concept assures all students encounter the collaborative experience.

- The concept of the learning dimension could be identified as Rewarding AR Feedback, whereas the feedback is an essential aspect in learning, this concept introduces a specific type of motivational and interesting feedback using the AR reward cards. Each reward card collected completes a series of the textbook content to be displayed.

- The shared concept between learning and usability referred to as Audio AR Textbook, which is an enhanced version of the audio textbooks using AR. Most of textbooks come with CD's, and by using AR the audio is enhanced and merged with the related digital content.

- The other concept of usability dimension is Intuitive AR Markers. Whereas AR marker is a substantial element in any AR Book, this concept emphasis the intuitiveness of this element especially if it is designed for children.

- Finally, Mutual AR Display, which is important for the prototype to be usable. It demonstrates the flexibility of the displaying the AR content in multi-user setting. This concept ensures the 3D content is successfully displayed and tracked by the AR marker from different angles of view.

It is noteworthy to reiterate the concepts overlaps between the collaborative experience dimension and the learning dimension in the concept of Communication-Based Learning. This is because it was intrinsically related to, the E and L dimensions, and represents the design features pertaining to the aspects of E and L. This also can be noted from the overlaps between

the L and the U dimensions in the concept of Audio AR Book. These overlaps indicate that each dimension of the ELU is an integral part of the overall framework. Although each study has resulted in new design features, they were closely related to the identified concepts of ELU. The second study resulted in specific aspects related to the ELU, and it was apparent in the data analysis that the data set of this study was fit exactly for these specific aspects. This confirmed that the identified aspects from the previous study were comprehensive where no new aspect has emerged in the following study.

Findings for the CCI Community

The study offered an example of how the ELU framework can be used in practice to support the thematic analysis in co-design studies. Using the proposed ELU framework in this study has resulted in identifying eight design principles of the AR textbook related to the aspects of ELU. It can be applicable in similar contexts of CCI studies as a framework for thinking about tangible textbook design. This study has used the CI critiquing and layered elaboration techniques as a formative evaluation of the AR textbook prototype. These techniques are based on the cooperative inquiry which is considered as a common method in CCI studies, and applying them in the context of AR for children offers a practical framework for CCI community.

Limitations

Using the ELU framework has shown its usefulness in the thematic analysis and clustering the data as done in the three studies, but as with other frameworks it has some limitations. Even when using the suggested ELU framework to support the thematic analysis the coding method has a limitation of relying on the participants' interpretations. Therefore, the outcomes of the studies including the resulted ELU framework are only part of the many possible outcomes that could have been derived, since this research has a reflective and qualitative nature. However, the methodological evidence and theoretical foundation have been underpinning the different approaches in the studies have been indicated throughout this research.

The nature of the co-design practice and the endless variety of the possible approaches for conducting the co-design studies makes it neither feasible nor sensible to create a generalisable framework that can be applicable for supporting all the instances of co-design sessions with

children. Therefore, this framework is suggested as a means to think about tangible textbook designing. The introduced concepts are suggested for this research context that can be appropriate to AR textbook for collaborative learning experiences. Relating these concepts to the major concepts of E, L and U aims to underline the important factors which are to be considered in the design requirements but, without limiting or prescribing specific situations for the design. It rather allows for personalisation and adaptation to different situations and design purposes. The limitation of using the three concepts of ELU can also be seen as a possibility for further elaboration and evaluation of the framework in other contexts of CCI studies. The use of it in the CCI community could provide an additional investigation of its effectiveness in practice and its possible improvements.

Conclusion

As can be seen, the last study has tied the previous findings of the research together and generated the key concepts for the design of children's AR textbooks for collaborative learning experience, which answers the first research question. The second research question was answered in each study in which new design features are identified and applied in the evolving prototypes. Whereas, the final outcome of the prototypes demonstrates the specific design features that can be integrated in the school textbook and are related to the concepts which have been identified in the first research question. The first study has resulted in the overall direction of the design at the early stage. The design themes aligned with the concepts identified from the literature have resulted in the initial design features to be implemented in the first prototype. The second study has indicated the important aspects required for an AR textbook for children in relation to collaborative experience, learning, and usability. Finally, Answering the question of how co-design methods can be applied in the context of AR textbooks for children, is represented in reporting the procedure of each session, and the key findings regarding co-design with children in schools for each study. The documentation of the studies, showing in detail the methods, techniques, and frameworks used for planning, data collection and analysis can provide useful guidelines for other researcher seeking to co-design with children an AR textbook in schools.

VII. CONCLUSIONS

VII.1 Answering the Research Questions

In this section, the researcher will conclude by revisiting the original research questions posed in the introduction chapter and summarising the findings in direct response to these questions through the collection, analysis and presentation of collated research data, practically designed outcomes and usable methods for other researchers to employ when designing AR textbooks for primary age children in educational environments.

RQ1: What are the key concepts that inform the design features and evaluation of children's AR textbooks for collaborative learning experience?

Through the research studies, it has been found that the key concepts of the children's AR textbook for collaborative learning experience can be concluded as follows:

1. **Joint Textbooks.**
2. **Personalised AR Experience.**
3. **Interactive AR Book.**
4. **Communication-Based Learning.**
5. **Rewarding AR feedback.**
6. **Audio AR Textbook.**
7. **Intuitive AR Markers.**
8. **Mutual AR Display.**

These concepts are falling into the three major concepts of the ELU framework as shown in Table 22. The first three concepts involving Joint textbooks, Personalised AR experience and interactive AR Book are related to the collaborative experience, whereas the Communication-based learning is shared between the collaborative experience and the learning dimension. The Rewarding AR feedback is related to the learning dimension, whereas the Audio AR Book is shared between the learning and the usability dimensions. Finally, the Intuitive AR markers and Mutual AR display are related to the usability dimension.

RQ2: How co-design methods can be applied in the context of AR Books for children?

The research has identified three perspectives to inform the co-design process which has been documented in a way that can be useful for any researcher seeking for a practical application of co-designing a children's AR Book. Each of the three studies consisted of documenting the procedures of planning, data collection and analysis. The three perspectives inform each of these stages and are methodologically oriented from PD and CCI.

1. Sanders and Stappers's co-design framework which informs the planning stage(Sanders & Stappers, 2014). The research has used this framework to plan the co-design sessions and organise the toolkits and probes specific for the AR Books.
2. Druin's cooperative inquiry which informs the data collection methods(Druin, 1999). The research has used low-tech prototyping for the early stage of the design and for the evaluative stage, the cooperative inquiry critiquing with layered elaboration has been selected.
3. Read's PLU model which has been adapted to the proposed ELU framework to inform the analysis process(McKnight & Read, 2011). The researcher has developed a conceptual framework called ELU based on the PLU model, which can serve as a classification framework in the thematic analysis process.

   Within PD, what could be designed includes both the technological product or artefact and the process that enables different participants to engage in designing this product. Indeed, PD has a strong focus on the how of designing i.e. a focus on the process of designing and the particular participatory practices which different processes can enable. (Simonsen & Robertson, 2013: 9)

This research reached a new understanding about co-design practice, concerned with the nature of practice and led to new knowledge that has operational significance for that practice. This research included co-design practice as an integral part of its method that falls within the area of participatory action research. The documentations of this research study can *"come to stand as their own theories of practice, from which others can learn"*(Whitehead & McNiff, 2006: 7). These research studies were explicitly reported and the process was clearly documented and justified, with the objective of allowing another investigator to replicate the procedures in a verifiable fashion.

RQ3: What is the outcome of co-designing an AR textbook with children for collaborative learning experience?

The practical component of the thesis presents a co-design outcome of an AR textbook for Saudi Arabian primary schools that is integrated in the actual textbook and has included the design features informed by the concepts of the ELU. These design features have been informed and developed through the three co-design studies and the proposed features of this research outcome can be indicated as follows:

1. **Joint AR markers:** The idea of separating the AR marker into the edges of two textbooks, where the student needs to join another student to complete the AR marker in order to be tracked by the camera and display the AR scene.

Figure 53: The joint AR markers.

2. **Textbook images as AR markers:** Using the pictures and images in the actual textbook as AR image markers to completely integrate AR in the school curriculum.

Figure 54: The images in the textbook as AR markers.

3. **AR reward cards:** This feature uses the textbook cut-outs to play an enhanced AR scene as a rewarding feedback. It encouraged collaboration where the student needs to join others to do the activity and collect the cards. It also supports personalisation where students can exchange their cards to display the enhanced AR content.

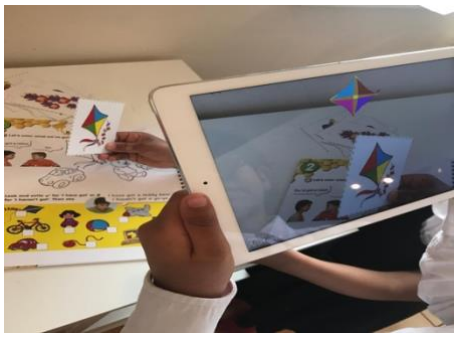


Figure 55: The AR Reward Cards.

4. **Textbook content as AR scenes:** Designing the 3D models based on the printed content of the textbook and using the activities that are already in the textbook to design a collaborative AR experience.

Figure 56: The AR scene based on the printed content of the textbook.

5. **Interactive AR display:** This feature allows the students to interact with the 3D model through the tablet touch-screen enabling different sound and visual effects.

Figure 57: The interactive AR display.

VII.2 Contributions and Discussions

VII.2.1 **ELU Framework for AR textbook design and CCI work**

AR textbook design requires additional frameworks and guidelines that consider children's requirements as well as AR requirements. Several authors proposed to use traditional usability testing and HCI methods for evaluating the prototypes of the technology, while other researchers have used existing models and guidelines to address the needs and challenges of interactive AR systems. Several reported guidelines and frameworks have been reviewed in the literature to identify specific concepts and themes that can be applied for this AR textbook.

Reviewing the literature of collaboration in the context of students' learning, as well as the collaborative AR in education, it was found that the frequently appeared concepts fall into the three aspects of Collaborative Experience, Learning and Usability. It has been noted that these three aspects intersect with the PLU model by Janet Read. In this respect, the researcher proposes an adaption of the PLU model that defines the relationships between children and the interactive technology, as a tool to think with. It was an attempt to make use of this model by identifying the ways in which it might be partial and how it can be applicable for different contexts in CCI studies. The Experience aspects were suggested to allow for the incorporation of a wide range of concepts that children's technology designed for. These experiences could be entertaining, collaborative, motivational or other concepts which can be classified as an experience but not as learning or usability. It was suggested as a dimension of a relationship between children and technologies, where the child is the experimenter and technology is an experience that can be specified for each project.

The research has introduced the ELU as a framework for thinking in terms of the AR textbook design. The studies presented an implication in practice, through a formative evaluation of children's AR textbook for collaborative learning experience. The reported studies offered an example of how this framework can be used in similar contexts, and showed its usefulness in the co-design sessions for supporting the process of thematic analysis and clustering the data. The suggested framework includes eight design principles that might be appropriate to the AR textbooks. These concepts are falling into the three major concepts of the ELU framework. Whereas the broader ELU dimensions can be applicable in other contexts of children's

technologies that focuses on specific experiences, while taking into account learning, and usability. This opens the possibility for personalisation and adaptation to different situations and design purposes.

The concepts of the collaborative experience are Joint textbooks, Personalised AR experience, and interactive AR Book. The Rewarding AR feedback is related to the learning dimension whereas the Communication-based learning is shared between the collaborative experience and the learning dimension. Finally, the Intuitive AR markers and Mutual AR display are related to the usability dimension, whereas the Audio AR Book is also shared between the learning and the usability dimensions. It is noteworthy to reiterate that the concepts overlap between the collaborative experience dimension and the learning dimension in the concept of Communication-Based Learning because it represents the design features pertaining to the aspects of E and L. This also can be noted from the overlaps between the L and the U dimensions in the concept of Audio AR Book. These overlaps indicate that each dimension of the ELU is an integral part of the overall framework. Moreover, each study has resulted in new design features. They were intrinsically related to the identified concepts of ELU. The concepts of the ELU will be articulated in the next section to be helpful to other researchers in CCI seeking to design collaborative AR textbook for children.

In conclusion, although many researchers and practitioners have proposed guidelines and models of AR in schools, most of them required further adaptation to the context of children learning for specific experiences in schools. The framework in this research aimed to refine and extend the existing work in both CCI and AR for children learning to provide appropriate guidelines and specific requirements for researchers seeking to design AR textbooks for children collaborative learning experiences.

VII.2.2 **Collaborative AR Textbook for children**

> *The world of doing and making is usually ahead of the world of understanding. A significant branch of designerly ways of knowing, then, is the knowledge that resides in objects (Cross, 2006: 26).*

In his book, The Designerly Ways of Knowing (2006), Cross tried to identify the intrinsic values of design, as it relates to both the design process and the designed object. From this perspective, it can be argued that the intrinsic value of this research stems from the comprehensive documentation of the co-design process in the three reported studies, as well as from the novel design outcomes represented in the evolving prototype of the AR textbook. The contributed knowledge of the collaborative AR textbook is immersed in this designed outcome, in which other designers can draw upon as a primary source of cognition. This practice-based doctoral submission includes a contextualisation of the practical work which is represented by a sample of an AR textbook that uses the affordances of AR to provide a collaborative learning experience. This practical outcome demonstrates original design features unique to AR which are related to the concepts of collaborative experience, learning and usability. These design requirements are informed by co-design with children and are built in a practical outcome of an AR textbook, based on an actual textbook. One of the aspects of originality in this research is in showing how AR can be integrated in the school's curriculum for a collaborative AR experience. The proposed outcome demonstrated a sample of how these features can be integrated in a school textbook for different curricula.

The contribution is made towards facilitating collaboration which could be helpful to other researchers seeking to design collaborative AR textbooks for children.

Joint Textbooks: This concept supports the collaborative experience between students because it relies on the joint AR markers where the AR markers are separated in the textbooks in order to make the AR scene to be played only when the students join their textbooks to connect the markers. Using the affordances of AR and the idea of separating the AR markers into the textbook which, could not have been done before, were demonstrably effective when applied for this research prototype and can be applied in any AR book to support collaboration between the children.

Personalised AR Experience: This concept demonstrates that AR content can be displayed in different settings by individual student book or by joining and exchanging the AR markers. The collaborative experience can be encountered by different scenarios of the students' choices. This can be represented in children sharing and exchanging the cut-out AR cards or joining their textbooks for different AR contents. This concept has to be considered by other researchers by using the content of the printed material. For example, in the school textbook used for this research, there had been pages of cut-outs at the end of the book and they were used as AR markers to allow children to personalise the content of the AR which they wanted to display. It encourages collaboration at the same time because children want to exchange their cards to display different contents which have been seen.

Rewarding AR feedback: Using AR as a feedback for the textbook activities that provide an enhanced experience as a reward. This concept relates to the learning dimension, whereas the feedback is essentials aspect in learning. It introduces a specific type of motivational and interesting feedback using the AR reward cards, in which each reward card collected complete a series of the textbook content to be displayed. While the feedback is essential in learning, this concept is important to be considered by other researcher designing AR in schools to benefit from the use of AR in learning to be used as the feedback which is more engaging and motivational for children than other traditional feedback.

Communication-Based Learning: Learning new information is a result of student's use of communication cues to do the textbook activities. This concept was shared between the E and L dimensions and it suggests that the learning process should depend on communication between students, as using communication cues is a fundamental concept of the collaborative learning. Applying this concept in designing the AR textbook assures that all students encounter the collaborative experience.

Interactive AR Book: Students can interact with the AR content through the touch-based interface in tablet. This demonstrates the interactivity between the students and the textbook using AR. The application interface is interactive, allowing the children to interact with the AR content benefiting from the touch screen affordance of the tablet. Although, enabling the

feature of interactive interface is offered when using a table such as the iPad. However, there are different features that can be added for the AR Book to be interactive. This concept is proposed in this context because it was found from the studies that interactivity was important for children and can be considered as a requirement when designing the collaborative AR textbook.

Intuitive AR Markers: The AR markers should be added to the actual textbook in a way students can recognise them intuitively. It relates to the usability dimension since AR markers is a substantial element in any AR Book. This concept emphasises on the intuitiveness of this element especially if it is designed for children. One of the challenges in developing AR books is that the AR markers work effectively and therefore it is common that designers of AR books focus on designing the AR content that could be displayed by the marker and that the marker displays the 3D models and works well. By focusing on that they might miss this concept which is found as an important requirement for children in terms of the AR book to be usable.

Audio AR Textbook: Integrating the audio content of the CD provided with the textbook into the AR application as type of interaction between the 3D content and the students. It is shared between learning and usability dimensions. It is an enhanced version of the audio textbooks using AR. Most of textbooks come with CD's and by using AR the audio is enhanced and merged with the related digital content.

Mutual AR Display: The 3D models and animation should be displayed effectively from any perspective, taking into account multiple students positions. It is the other concepts of usability dimension which demonstrates the flexibility of displaying the AR content in multi-user setting. It was important to include with this list of requirements because designers of AR textbooks should ensure the 3D content is successfully tracked by the AR marker from different angles of view allowing children to use one tablet for the collaborative activities.

VII.2.3**Co-design with children in Saudi Arabia in schools**

This research aims to contribute to the body of research that considers the PD approach for the involvement of children as co-designers from the early stage of designing the AR textbook. It explores the impact of children on the design of a technology by presenting the outcomes of

co-designing a collaborative AR textbook. The emphasis of PD and co-design and their relationships on the contexts of CCI was clear from the literature review and this practice-based research uses the benefit of these perspectives to exploit the potentials of AR for collaborative learning experiences for children.

This research included a practical outcome as an integral component of the research process, however, it is accompanied with a complete documentation of this process and theoretical critical reflection. Therefore, the value of this research outcome can be of benefit for researchers in CCI and co-design, as well as designer practitioners of AR Books and children technologies in a broader context. The practice was underpinned by a theoretical foundation of the participatory action research and the theoretical findings of the developed conceptual framework gained by the practice. Although, it has undertaken a designer's practice of co-design, the research does not simply apply this method to gather information. Rather, it involves consideration of the ways in which this method is applied to the 'circumstances' and 'purpose' of the research. It has also justified the rationale for the method selection and has applied a structured framework and systematic analysis in the design, development and conclusiveness of the research. The researchers and the participants involved in the co-design studies learn from the changes they make during their practice. The three co-design studies took place over a period of time and were deliberately planned, allowing for changes in practice and the potential that the documented process adds to the knowledge base.

> *The more practitioners engage in action research and identify and document processes and practices, the more the field of design as a whole is enriched by their contributions (Crouch & Pearce, 2012: 157).*

Several researchers around the world have co-designed with children in varying ways to best meet their needs. Some use the overall model of the cooperative inquiry techniques, and others adapt it to a different context such as a university lab, a museum, a field trips or schools. The co-design studies in this research used the low- tech prototyping which children and adults use bags filled with art supplies such as string, markers, colored papers, foam balls, glue and scissors to create artefacts of the technology. This is based on one of the oldest cooperative design methods used in Scandinavian countries (Druin, 2010). However, it has been used for

this research in Saudi Arabia to create low- tech prototypes of AR textbook using the art supplies with an iPad template created by the researcher. It doesn't differ from the original method but it adds to the procedure commonly used in CCI for this method by considering Sanders & Stappers (2014) approach in organising the toolkits and probes, which informs the planning stage of this co-design study. The planning stage in our co-design studies considers indicating a set of protocols which can support bringing children and adults into an effective design process. A set of protocols is suggested for co-designing AR textbook with children for each co-design study in this research that can be helpful for other researchers.

The other cooperative inquiry techniques have been also refined to be used for formative evaluation of the AR textbook prototype. The cooperative inquiry critiquing has been used together with the layered elaboration techniques in one co-design study in which each technique was used in a separate session. Then, the thematic analysis has been done for the data collected from all the sessions. The new way which has been suggested in this approach is in selecting different techniques of cooperative inquiry as one data collection method and anlayse the data of the different sources together in a thematic analysis session. This was best suited for the context of the study, in which more data was collected for one prototype evaluation.

The co-design sessions in this research have been carried out in a classroom of a primary school in Saudi Arabia, in which there are round tables, and a white board. Putting the children in their familiar classroom environment has been a bridge between child members and the adults in the same table to become comfortable with each other. As reported in the findings of the study, the children have been effective as design partners and have participated with interesting ideas. The adult's involvement was found crucial in the role of facilitating the generative collaboration, to enhance children's creative thinking and to support dialogue between group members. The co-design sessions were successful in terms of going as planned and achieving the objectives. Each of the three studies has reported the key findings in term of co-design with children for this context of this research.

Many studies on how children have been engaged in co-design of wearable and non-desktop systems have been discussed in the literature(eg. Williams, Jones & Fleuriot, 2003; Williams *et al.* 2005; Khaled & Vasalou 2014; Norooz *et al*. 2015; Kazemitabaar *et al*. 2015;

Kazemitabaar *et al*. 2017). However, this work has added to what was done before, by suggesting a practical framework for planning, data collection and analysis for co-design with children in schools, demonstrating a process of action and reflection to develop an evolving prototype of the AR textbook. For example, in Gennari, Melonio & Rizvi(2017) study, they followed a similar approach of co-design with children in terms of planning, actions in the field and reflections over their results which advanced the design features in the prototype. However, the data collection has focused on usability and the user experience only and using the ELU framework could be of benefit to include the learning aspects which were lacked in the data collection since the design is intended to support an aspect of learning.

On the other hand, many studies reported in the literature highlighted guidelines for organizing co-design sessions(eg: Vaajakallio, Mattelmäki & Lee, 2010; Mazzone, Read & Beale, 2011; Mazzone, 2012), and the procedure of the selected methods, whereas this research contributes to these guidelines by focusing on the process as well as introducing the outcomes of the co-design process. It is believed that the reported findings will be useful lessons for many co-design situations taking into account that every case is unique, depending on changing or refining specific elements to suite each context. There is still a need of studies that contribute a framework for co-designing of specific technologies for children.

In terms of AR for learning, for example, there is a lack of studies that used co-design with children in schools. One study that considered co-design for prototyping AR for classroom, have used this method with adults without involving children in the process of prototyping and testing (Cuendet *et al.* 2013). However, the design principles which have been found by this study have been highlighted in the literature of this research and for the identification of the themes of the AR textbook prototypes. The other study using co-design methods in the context of AR for learning also relied on the contributions of the teachers and experts, while involving children in a usability testing of the final outcome (Pinto *et al.* 2017). Using co-design with adults differs as a method from co-design with children because it doesn't apply the cooperative inquiry that is related to CCI studies which will be of benefit to this community. Studies of co-designing AR with children for schools such as (Alhumaidan, Lo & Selby, 2017) are still needed to advance the knowledge in this field in such a context.

This research applied the common methods of CCI in the context of AR for children. It has considered the perspective of CCI in the design process of AR textbook for children. This consideration has been represented from two angles of involving children using cooperative inquiry as a research method and in building on the PLU model in the evaluation process. Even though PD is considered as a common approach in the CCI community, when looking at practical implications as a method, a little work has considered the fundamentals of participation, namely how children can be involved, and how their ideas are included and represented (Read, Fitton & Horton, 2014). Until recently, studies of AR for children have only involved children when the final outcome has been developed by the researchers, without their involvement to actually inform the design prototypes. It is hoped that the documentation of the three studies conducted for this research in it's' completeness will bridge the gap between AR and CCI communities by considering the methods of CCI in developing AR applications for children.

VII.3 Limitations, and Recommendations

> *No one can actually establish for sure what social reality is and how it connects to knowledge and experience (Ramazanogulu & Holland, 2002:57).*
>
> *The questions we see, the answers we seek, the way we go about seeking those answers and the interpretation we make (Walter, 2010:13).*
>
> *Knowingly or unknowingly, underpins all our research…… Time, place and culture all affect what we can know and how we know it and in this sense all knowledge is contextual (Pearce & Crouch, 2012: 57).*

The philosophical terms of Epistemology and Ontology are connected to each piece of research, but considering these perspectives is vital for the CCI researchers to understand how their world views shape the nature of the research and how their subjective cultural perspectives influence the way they understand new information. It is recommended that being more explicit about the context of the co-design studies that involve children, in order for other researchers to take into account the underpinning factors when building on that work, is a necessary consideration of moving forward.

Research outcome context

The findings of this research are informed by reflective practices. Although the research involved participants from different academic backgrounds, they all share the same ideological background that might affect their worldview, which in turn might affect their interpretation and analysis of the data. Acknowledging that point means that the outcome of this research will be specific to similar communities that share the same geographical location and ideological background. This could, theoretically, bind up the acquired knowledge to a narrower context. However, being mindful of that consideration allows other researchers in the field to understand where particularly these outcomes might be influenced and how to embed these outcomes in different added locational contexts.

Co-design participants

Conversely, having a small sample is expressed partly in terms of the need for greater social accountability but it also means that individuals themselves cannot function effectively without reflecting about all the actors involved. Following the PD approach and using the co-design method require only a small number of participants, besides having the same participants throughout the design process because they are actively involved as design partners. This makes all participants more reflexive and deepening the understanding that it brings, which in turn "*has an effect on what is considered worthwhile doing and hence, on the structure of the research itself"* (Grand, 2012: 193).

Co-design with children

As has been reported in the studies, the co-design method has its' own limitation when involving children in the research, which has raised lots of challenges in managing the time and efforts in each session. It also costs more than the traditional methods since it requires toolkits and prototypes. Also, the qualitative data and especially the data gathered from such co-design sessions, is messy and one example of how to overcome this issue is having a specific set of protocols for all the participants to follow. This ensures consistency in how data is collected and documented which helped in managing the analysis, noting there are no fixed procedures or step-by-step processes to deal with management issues, as with quantitative data.

However, the process in this research followed a systematic pattern borrowed from previous studies of CCI and HCI. For example, the comparison technique between the different types of data sources and using the ELU conceptual framework for the data analysis could be mentioned.

The content of AR textbook

Another aspect that could be considered a limitation is the limited content of the AR textbook prototype designed in this research study. However, the development process of any AR Book is time consuming due to technological issues and since the research has a time constraint, the researcher was concerned in providing protocols for the design of material in accordance with findings from the literature review and the conducted research. Although the proposed AR textbook could not include the whole content of the actual textbook, it has exemplars of different lessons and activities which showcase the important features and concepts which are required. Importantly, the implications of this study are specified to make analytical generalisations and theoretical propositions, as opposed to statistical generalisations. In other words, the findings of the studies are not meant to directly design an AR textbook for primary schools, instead are explicitly designed to explore the practical implications of designing AR textbook with children and adults who have different types of expertise. This aspect could be covered in future work, as will be illustrated in the next section.

VII.4 Future Work

The AR textbook prototype combined with this thesis should not be viewed as a final outcome that cannot be improved. In addition to this, the concepts proposed in this thesis are not, in themselves, the final goal to satisfy the design process. As has been suggested in the methodology chapter, the final concluding point of this research is actually placed in a circle where the researcher can determine future work, as well as drawing interest from other interested researchers, who may examine, utilise and collaborate a circular model of *'knowledge-using and knowledge-building'*(Owen, 1998). The final proposed concepts of ELU were actually generalised from the evolution of the initial concepts, identified from the literature, and then finally mapped to the ELU. This also relates to notion of, *'designing the evolving artifact'* that Herbert considered in (Grand, 2012),

> *Each step of implementation created a new situation; whether the later stages were consistent with initial one or not, the new situation provided a starting point for fresh design activity (Grand, 2012: 76).*

It can be stated that the final result of this thesis can be a starting point for further developing the conceptual framework, as well as refining the AR textbook prototype. The formative evaluation will be continued for the intermediate prototype sand a summative evaluation will be conducted for the final outcome. Throughout these evaluations, the ELU framework will be used and the result will be reflected on the concepts, which in turn will inform new design features that can be implemented in the prototype. Finally, the effectiveness of the AR textbook on collaborative learning experience will be evaluated in the classroom to provide an evidence of its greater educational impact, which can contribute in raising the awareness of AR effectiveness on education in general, to be embedded it in future academic settings.

VIII. APPENDIX

Below are google drive links to videos that demonstrate the practical component of the thesis:

https://drive.google.com/open?id=0B7gwEqwZsArnOFQ5d0drekJ0UlU

https://drive.google.com/open?id=0B7gwEqwZsArnSFZ3c21TeF85QTQ

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