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BRIDGING THEORY AND PRACTICE: LEARNING DESIGN FOR AR-BASED CONTINUING PROFESSIONAL DEVELOPMENT IN A PRIMARY CARE SETTING

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Bridging Theory and Practice:
Learning Design for AR-Based Continuing Professional Development in a Primary Care Setting

THESIS FOR DOCTORAL DEGREE (Ph.D.)

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不闻不若闻之，闻之不若见之，见之不若行之。

学至于行之而止矣

荀子《儒效》

公元前 313-238, 中国哲学家

Tell me, I may forget
Show me, I’ll remember
Involve me, I’ll understand

True learning is completed only when action has been put forth

Ru Xiao by Xun Zi

Chinese philosopher, 313-238 B.C.

凡为医道，必先正己，然后正物。

南宋《小儿卫生总微论方•医工论》

Treat the symptoms with reasonable medications,

I need all medical professionals to be proficient.

《Pediatric Overview •Understanding Medical Professional》
Anonymous, South Song dynasty 1156 A.D.

ABSTRACT

Background: General practitioners (GPs) are the gatekeepers of health care in most societies, serving as patients' first point of contact. Continuing professional development (CPD) is needed for GPs to improve their competence and provide successful patient care. Information communication technologies (ICTs) are expected to be used to support effective CPD. Augmented reality (AR), as a new ICT, might have a potential as a learning tool for CPD, but it has not been explored in primary care for GPs' CPD.

Objective: The aim of this study was to determine how to design AR-based CPD to fit the learning needs of primary care physicians in their clinical practice.

Methods: Multiple methods used in design-based research (DBR) were applied in this study. Semi-structured interviews were conducted to understand physicians' CPD needs and attitudes toward AR (Study I). An integrative review was conducted to understand AR in health care education (Study II). A conceptual framework analysis method (CFAM) was used to construct the AR design framework (Study III). Based on the framework, semi-structured interviews were used to identify AR design needs with the physicians in the chosen setting (Study IV).

Results: Most primary care providers accepted the idea of AR-based CPD, but their current CPD model did not help them become qualified GPs. Although the learning needs varied between physicians, they shared a need for integrated clinical competence. Our integrative review showed that AR has been investigated for various research purposes and for all levels of health professionals; however, except for a few reports supported by situation learning theory, 80 percent of the published papers lacked support from learning theories. Driven by situated, experiential, and transformative learning theories, the Mobile AR Education (MARE) framework was proposed, which included identifying learners' personal paradigms, clarifying learning objectives (LOs), and designing AR learning environments and learning activities to develop learners' personal paradigms with respect to domain expectations. The application of MARE has demonstrated physicians' perspectives of AR design needs with the example of rationally using antibiotics. The guidelines, local antibiotics resistance pattern, and physicians' personal paradigms related to diagnosis, treatment, and prescription, including the choice of drug, were the context for the design needs.

Conclusions: To my knowledge, this is the first exploration of learning design for AR-based CPD through practice and theory. The main contribution of this thesis is the design of the MARE framework due to a lack of learning theories supporting the use of AR in medical education. The MARE framework as applied to the Chinese primary care setting shows the usefulness of identifying physicians' personal paradigms in their decision-making process and their expectations for AR-based CPD to improve their personal paradigms. As a future step, AR prototypes and applications might be designed to meet these expectations.

Keywords: Learning design; Augmented reality; General practitioners; Continuing professional development; Personal paradigms

PROLOGUE

This thesis is about learning design utilizing new technology to facilitate continuing professional development (CPD) in health care education.

Realizing my dream of contributing to health care has been a long journey. I missed the opportunity to study medicine more than twenty years ago because I was forced to enroll in a normal university due to priority recruiting. This long journey has allowed me to learn about educational technology but outside the medical context. As an undergraduate student at Central China Normal University, I was first exposed to educational technology. I then had the opportunity to teach and conduct research in the field of educational technology at Hubei University when the use of educational technology was exploding, supported by the educational reform. Meanwhile, I received my master's degree in educational technology from Central China Normal University and entered a doctoral program in distance learning prior to having the opportunity to study at Karolinska Institutet. During this long journey, I have witnessed the rapid development of various technologies in education. I have become increasingly aware of the importance of design over that of technology.

In China, physicians have been held in high regard, but an increasing portion of the population is now questioning this practice. As an educational technology researcher, I am glad I have had the chance to explore the use of new technology for CPD by primary care physicians to potentially help them win back patients' trust. The LIME department provided a great interdisciplinary environment for the exploratory research in my thesis exploration. I have learned a lot in this interdisciplinary and multicultural environment, allowing me to collaborate with health care providers to define CPD learning problems and discover effective pedagogical strategies and uses of technological innovations.

LIST OF SCIENTIFIC PAPERS

I. **Zhu E**, Fors U, Smedberg Å. Exploring the Needs and Possibilities of Physicians’ Continuing Professional Development - A Qualitative Study in a Chinese Primary Care Context. PLoS ONE 2018;13(8): e0202635

II. **Zhu E,** Hadadgar A, Masiello I, Zary N. Augmented Reality in Health Care Education: An Integrative Review. PeerJ 2014;2:e469

III. **Zhu E**, Lilienthal A, Shluzas L. A, Masiello I, Zary N. Design of Mobile Augmented Reality in Health Care Education: A Theory-Driven Framework. JMIR Medical Education 2015; 1(2), e10.

IV. **Zhu E**, Fors U, Smedberg Å. Understanding How to Improve Physicians’ Paradigms for Prescribing Antibiotics by Using a Conceptual Design Framework: A Qualitative Study. Submitted

CONTENTS

LIST OF ABBREVIATIONS

AMR	Antimicrobial Resistance
AR	Augmented Reality
CAI	Computer-Assisted Instruction
CFAM	Conceptual Framework Analysis Method
CHCS	Community Health Center or Community Health Station
CLE	Clinical Learning Environment
CME	Continuing Medical Education
CPD	Continuing Professional Development
DBR	Design-Based Research
ICT	Information and Communication Technology
ID	Instructional Design
GP	General Practitioner
LCD	Learner-Centered Design
LD	Learning Design
MARE	Mobile AR Education
NHS	UK National Health System
PCI	Primary Care Institution
UCD	User-Centered Design
VLE	Virtual Learning Environment
WHO	World Health Organization

1 INTRODUCTION

The thesis explores how we can design for learning with new technology - augmented reality (AR) - to facilitate continuing professional development (CPD) in health care education. In this study, CPD is focused on in-service training of general practitioners (GPs) where the objective is to increase GPs' competence keeping in mind the complexity of the real local context. AR combines computer-generated information with a real physical environment through an interface that can be seen on a computer screen, smartphone, tablet, glasses, or a head-mounted display. AR can provide an authoritative, contextual, and situated experience for learning. It was originally created for workplace learning but has been used in medical education since 2002 (Bajura et al. 1992; Caudell and Mizell 1992; Davis et al. 2002). However, learning design for CPD with AR has not been fully explored. This thesis focuses on learning design with AR for CPD.

1.1 HEALTH PROFESSIONAL EDUCATION

The implementation of effective health systems is, according to the World Health Organization (WHO), dependent on six interdependent building blocks: governance, health care financing, health care workforce, technologies, information, and service delivery (WHO in the Western Pacific 2018). "*No health without a workforce*" was written on the cover of a report by the WHO, which projected a worldwide shortage of 12.9 million health professionals in 2035 (Global Health Workforce Alliance and World Health Organization 2013). Moreover, the health workforce problem might increase because professional education often does not fit the current requirements of the realities of health service delivery to keep up with patients' and populations' needs (World Health Organization 2011). The challenges of health professional education have been identified as *"curricula rigidities, static pedagogy, and insufficient adaptation to local contexts*" (Frenk et al. 2010, p7). Therefore, serious instructional reforms also need to take advantage of modern information and communication technology (ICT) to support competency-driven learning, which can rapidly adapt global resources to local contexts (Frenk et al. 2010). The context or situation around the professional learner is one of many important aspects that affect learning and hence designs for learning.

1.1.1 Learning and CPD

CPD is important for improving health care professionals' ability to provide high-quality care and safeguard patient health (Alahuhta et al. 2007; Newton 1993; Nilsson et al. 2012; Peck et al. 2000; Verma et al. 2016). The UK National Health System (NHS) has defined CPD as "*A process of lifelong learning for all individuals and teams which enables professionals to expand and fulfil their potential and which also meets the needs of patients and delivers the health and health care priorities of the NHS*" (Attwood et al. 2005, p.4). The definition has been broadened to include any follow-up undergraduate education or postgraduate training (Newton 1993). The Dreyfus model describing the continuum between novice and expert status in a certain domain was used to describe the five stages of professional development ranging from among freshman and junior medical students to resident physicians, the early-career and mid-career development points in medical education (Batalden et al. 2002; Hibble 2009). They also suggested different competence development in the five stages. The attending physicians who could be considered in the proficient stage still need continuing improvement of medical competence and other core professional skills, professional attitude, medical ethics and personal qualities after residency training in China (Hou, Horng, and Chen 2016). Benner found that developing the capacity to act fluently in response to a situation is even more important from a competency standpoint for the expert (Benner 2004). The physicians have updated their knowledge and skills to keep up with new findings from clinical and basic medicine research with traditional continuing medical education (CME); however, CPD is expected to improve physicians' competence and their performance in their daily clinical practice (Cervantes 2009). CME and CPD address different educational aspects (Burrows 2003). International comparative studies have also reported a large-scale move from CME toward, CPD, which incorporates CME (Murgatroyd 2011; Peck et al. 2000). However, the CPD evaluation system is not always based on the learning outcomes but on the hours spent on CPD activities within or outside the workplace, including educational meetings, conferences, lectures, and workshops (Alahuhta et al. 2007; Murgatroyd 2011; Peck et al. 2000). It is not surprising that significant knowledge gains and increasing confidence have been found in a systematic review of CPD; however, evidence showed low patient care outcomes and participants' satisfaction with CPD (Phillips, Piza, and Ingham 2012). Simple passive learning, such as only through the use of printed materials or conferences, did not improve professional practices, but the multifaceted strategy, especially practice-reinforcing strategies, showed substantial improvement of professional performance (Oxman et al. 1995).

CPD programs delivering content and didactic practices rather than enhancing learning were found across various professions (Webster-Wright 2009). To exceed the "*common-sense understanding of learning,*" which is achievement and handover of the content pre-specified by experts, CPD needs to grow in the profession and the surrounding environment (Boud & Hager, 2012, p.20). This area has not been explored much. Therefore, further studies are necessary on what this learning is about, how it can be promoted in professional practice, and in which environments it is necessary (Boud and Hager 2012). Benner suggested the experiential learning model in a dynamic environment fraught with uncertainty and complex practice patterns(Benner 2004). This suggestion is similar to the idea of professional development being contextual and embedded in practice patterns. Webster-Wright proposed that situated, authentic, and constructed learning is more important for CPD than trying to find the best deliver programs (Webster-Wright 2009). The suggested essential components of CPD were maintaining competence and developing learning organizations (Bolderston 2007; Davies and Nutley 2000).

1.1.2 Learning Theory and CPD

Learning is a complex process, and no consensus has been reached on the definition of learning because it has an intricate ecology, including numerous interrelated factors such as the relationships between the learner and other people, the learning task, the learning and instruction activity, the learning environment, and materials that interact with and affect the learning (Ringsted, Hodges, and Scherpbier 2011). Learning theories originate from various fields, such as pedagogy, sociology, anthropology, and psychology, to explain how individuals think, act, and learn. Different learning theories suggest different stratagems in medical education (Kaufman and Mann 2010). As mentioned above, the situated learning theory and experiential learning theory could be chosen as foundations of learning design for physicians' CPD. These two theories were also suggested to guide the teaching and learning of medical professionalism (Steinert 2008). In addition, the transformative learning theory, which is an adult-learning theory that shares the influence of individual experiences and their practical environment with situated learning theory, could be used.

Situated learning has been interpreted in a number of ways, depending on whether the perspective is from sociology, anthropology, and cognition psychology (Billett 1996; Langer 2009; Lave and Wenger 1991). It has been interpreted as situated cognition, which emphasized learning in everyday activities (Brown, Colline, and Duguid 1988). Lave and Wenger developed it further through the analysis of cognition in practice, and they called the learning process "legitimate peripheral participation" (Lave 1988; Lave and Wenger 1991). It was further developed as a community of practice. Although agreement on the definition of situated learning is lacking (Langer 2009), most emphasize the idea that much of what is learned is specific to situations in which the learner learns. Situated learning research deals with tacit or relatively unstructured knowledge in complex real-world settings. Billett showed the relationship between cognitive structures and the social setting by describing the cognitive consequences of situated learning during problem resolution (Billett 1996). Situated learning was aroused at all levels of the medical education continuum, including CPD (Kaufman and Mann 2010). Steinert pointed out the key components of situated learning theory, "*cognitive apprenticeship, collaboration, reflection, practice, and articulation of skills within an authentic context,*" as useful for learning medical professionalism (Steinert, 2008, p.48). Situated cognition was used to guide and support simulation-based learning or problem-based learning (Ntyonga-Pono 2006; Paige and Daley 2009; Wyrostok et al. 2014).

Experiential learning has been considered direct learning from real-life experience (Keeton and Tate 1978). Dale described the experiences as a core from direct to abstract to guide design for learning with various material and learning activities (Dale 1969). Based on works of Lewin on social psychology, Dewey on progressive education and Piaget on cognitive psychology, Kolb developed the experiential learning theory, which referred to learning as spirals process transforming between knowledge and experience (Kolb 1984, 2015). The experiences were considered learning and development resources. Kolb's experiential learning theory includes an experiential learning cycle, learning styles, and learning environments(Kolb 1984; Kolb and Kolb 2005). The experiential learning cycle has widely been used to guide design of instructional strategies and integration of virtual patients with clinical education (Edelbring 2012; Kokotailo et al. 1994; Steinert 2008). Experiential learning theory was used to interpret and diagnose individual learning styles (Kaufman and Mann 2010; Kolb and Kolb 2005). It is also a guide for designing learning environments, especially the virtual learning environment (VLE) (Holzer and Andruet 1995, 2000; Kaufman and Mann 2010).

Although the situated learning theory focuses on helping the participants develop their knowledgeable identity (Wenger 1998), transformative learning theory helps adults develop their ability to change (Mezirow 2003). Influenced by the concepts of paradigm by Kuhn, conscientization by Freire, and domains of learning by Habermas, Mezirow proposed transformative learning theory as an adult learning theory after he studied women's adult education (Mezirow 1978, 1981). He defined transformative learning as a process of changing the problematic paradigm, which could shape and restrict learner's perception, cognition, and feelings, and in the end affect their actions (Mezirow 2009). It adds value for CPD where it was often expected to change physicians' behavior in health care (Lundborg and Tamhankar 2014; White et al. 1985). It was suggested that the third generation of reform in health care education defined by the Commission on Education of Health Professionals for the 21st Century be guided by transformative learning (Frenk et al. 2010). Critical reflection and rational discourse are the two major elements of transformative learning (Mezirow 2009). Three kinds of reflection are content, process, and premise reflection (Kaufman and Mann 2010).

1.1.3 The Learning Environment

Interest in the learning environment has increased in health care education research, leading to the need to further discover how various environments can contribute to health professional development (Koens et al. 2005). In the Dreyfus model's five stages of health professional development, the campus/classroom environment and clinical learning environment (CLE) are the two traditional learning environments for the health professional. The CLE is an important environment for health care professionals improving clinical and professional competence (Chan 2001; Chappell 2016; Papp, Markkanen, and von Bonsdorff 2003). VLEs, which include simulation of the clinical environment and other types of online or offline learning environments have been used to support health care professional development (Półjanowicz et al. 2014).

Medical students in the first two stages of the Dreyfus model mainly learn in a classroom environment. No difference exists in knowledge recall between learning in the classroom and a CLE, but a CLE is helpful in recalling meaningful cases (Koens, Cate, and Custers 2003). Therefore, learning in CLEs is encouraged because students can integrate knowledge and skills into clinical practice (Brown et al. 2011), reduce the shock of practice (Prince et al. 2000), and develop the psychomotor skills for clinical problem-solving ability (Dunn and Hansford 1997). Many research projects have investigated the factors, including physical characteristics, social-cultural characteristics, psychological characteristics, and students' perceptions of CLE (Jessee 2016; Newton et al. 2010; Wray and McCall 2009), but few focus on learning design.

Besides research on CLEs for medical students, CLEs were also considered the foundation of CPD for physicians (Weiss, Bagian, and Nasca 2013). However, the research is scarce and focused mainly on resident training (Byszewski et al. 2017; Roff, Mcaleer, and Skinner 2005) The Accreditation Council for Graduate Medical Education (ACGME) suggests that CLEs should support physicians learning in six areas: "*patient safety; quality improvement; transitions in care; supervision; duty hours oversight, fatigue management and mitigation; and professionalism*" (Weiss, Wagner, & Nasca, 2012, p397). The ACGME found that residents and fellows were aware of patient safety and quality improvement in most CLEs, but many challenges of learning in the six areas remain (Weiss and Bagian 2016). It further suggested that experiential learning could be used to improve the learning quality in CLEs where didactic approaches such as presentations and Web-based modules were not enough. Experiential learning emphasized various types of learning through feeling, thinking, acting, and reflecting in the various learning environments, which was also called learning space (Kolb and Kolb 2005). However, not much is known about how to apply it in CLE design. Situated learning theory was suggested as an applicable theory to guide the design and testing of CLEs for improvement of the clinical reasoning skill (Jessee 2016).

1.1.4 Primary Care and General Practitioners

Primary care is an integral part of most health systems, providing the essential care for all members of the community (Anon 1978) . The quality of primary care is now more important than ever because primary care can quickly and better respond to health challenges in the ever changing world (World Health Organization 2008). Qualified GPs are the cornerstone of primary care for universal health coverage to ensure affordable, appropriate, and effective health services (Maeda et al. 2014). Almost all counties need to undertake an expansion of their numbers of health professionals through the training of GPs (Bhutta et al. 2010; Frenk et al. 2010). Due to the traditional hospital centralism, where a disproportionate portion of health workforce members, technologies, and other resources focus on hospitals and sub-specialization (OECD 2016; World Health Organization 2008), many high-income countries struggle to recruit and retain GPs (NHS GP Taskforce 2014; Royal College of General Practitioners 2014; Teljeur et al. 2010). Various strategies, including CPD focusing on underserved areas, have been used to recruit a GP workforce (Verma et al. 2016). Besides the strategy of recruiting to increase the number of GP trainees (Limb 2014), GPs' education includes CPD as a way to produce qualified GPs. The requirement that GPs gain the competencies needed to integrate the complexity of real practice is also growing (Elwyn et al. 2007; Hibble 2009). This competence requirement of GPs needs to be considered in the design for learning in the clinical context. Values and costs vary depending on the learning design of CPD for GPs (Wilkinson and Walsh 2014). One of the problems mentioned is that teaching is not the only unmet need of GPs; they also face poor and irregular training in some CLEs (Bayley 1994). An appropriate CLE is important for GPs to be equipped with competence that meets patients' and the health system's needs (McNaughton 2006; Pype et al. 2014; Sagasser, Kramer, and Vleuten 2012).

Although primary care health services in most high-income countries focus on providing comprehensive and equitable services, low- and middle-income countries struggle with staffing shortages and capacity gaps together with a lack of integration of services, which even further complicate the situation (Lê et al. 2016). In the UK, GPs assume a leading role of an integrated care for those with multiple health issues (Mathers, Patel, and Thomas 2012; Royal College of General Practitioners 2015). The integration of care is patient-centered requiring multi-professional teams in the community and home settings (Mathers et al. 2012). In contrast, in low-middle income countries like China, due to the focus on hospital-centralism and emphasis on market-driven health care services, primary health care has almost been demolished in the last 20 years. After the introduction of comprehensive reform in 2009 (The State Council of China 2009), primary care has again started to become a cornerstone in Chinese health care. Today, GPs are expected to provide integrated health care service for all patients with common and chronic diseases and provide preventative health care services (Meng et al. 2015).

1.1.4.1 Antibiotic Resistance as an Important Area of CPD in Primary Care

One of the major threats to public health is the increasing frequency of antimicrobial resistance (AMR) (Laxminarayan et al. 2013; World Health Organization 2014). Continuing unabated, in 2050, AMR could potentially result in as many as 10 million people dying every year at a cost of $100 trillion USD (O'Neill 2014). The overuse of and inappropriate production of antibiotics has increased the frequency of AMR and reduced the efficacy of antibiotics on the common bacterial infections, resulting in the emergence of resistant strains of Staphylococcus aureus (Spellberg et al. 2011). The overuse of antimicrobials and increased inappropriate prescription has also led to AMR (Allerberger et al. 2009; Hsu et al. 2008; Klevens et al. 2007). Inappropriate prescription of antibiotics in primary care settings is a major contributor to AMR (Costelloe et al. 2010; Shallcross and Davies 2015). The WHO has suggested that education in the rational use of antibiotics should be a core component of CPD for all physicians, including GPs (World Health Organization 2015). A systematic review found that GPs' perception of extrinsic and intrinsic factors affected their prescribing decisions (Tonkin-Crine, Yardley, and Little 2011). Therefore, to facilitate modifying GPs' prescribing behavior, we need more effective CPD models rather than simply providing correct knowledge (Lundborg and Tamhankar 2014).

1.2 TECHNOLOGY AND LEARNING DESIGN

Information and communication technology (ICT) has been expected to enhance the third generation of medical education reform in the world (Frenk et al. 2010) and provide effective CPD. Educators have used technology to support learning since the 5th century B.C. if we consider soft technology including the strategies, methods, and techniques that were recommend in philosophical, pedagogical, and psychological theories as well as hard technology (Spector et al. 2008). Some technologies became so common in education, for example the blackboard and textbook that we no longer think of them as technologies. Technology also changes the way we interpret learning (Säljö 2010). Thus, technology was thought as a breakthrough in educational reform in many disciplines when education met big challenges or when new technology was introduced. However, the overreliance on technology has been viewed with suspicion as essential learning elements were forgotten in the educational system (Todd 2003), raising the question of how to design learning using new technologies to meet the needs of education reform.

1.2.1 ICT and AR for CPD

The use of ICT to support effective CPD has been expected to improve health care professionals' competence (Ducut and Fontelo 2008; Phillips et al. 2012). However, the use of ICT for effective CPD might be different. Scholars reported that ICT has mainly been used to provide resources for health care professionals' CPD (Glogowska et al. 2011; MacWalter, McKay, and Bowie 2016; Thorley et al. 2007). ICT has also been developed as a VLE to provide a new ways of learning in medical universities (Półjanowicz et al. 2014). The use of ICT simulation from a partial solution to full clinical environment over the past several decades has been remarkable, allowing health care professionals to learn and practice in multiple ways, such as repeating the skill, cognitive exploring, realistic practicing, and team training, to improve their performance (Byrne 2013; Goolsby, Vest, and Goodwin 2014). Technology-enhanced simulations have proven beneficial for health professionals' learning, leading to a good learning outcome regarding knowledge, skills, and behaviors (Cook et al. 2011, 2013; McGaghie et al. 2010). Health care professionals can also use ICT to enhance CPD through "virtual communities of practice" to share experiences and ideas and to be innovative together (Nicolini, Scarbrough, and Gracheva 2016). Based on the experimental comparison, research tradition in medicine, and the eagerness to show the advantage of new technology, for example, the studies compared the learning effectiveness of online learning and non-Internet formats. Due to the different learning contexts and objectives, it is difficult to find significant effects of differences (Cook et al. 2008; George et al. 2014; Wutoh, Boren, and Balas 2004). Cook et al. further suggested directly comparing them using the same technology interventions to avoid bias and determine how and when to effectively implement and this kind of ICT. Effective CPD supported by ICT needs further research not only on its effective implementation (Cook, Erwin, and Triola 2010) but also on how to design and develop ICT to fit CPD needs before rushing to adopt it (Rowe, Frantz, and Bozalek 2012). The CPD can also be of a "blended" nature, with a combination of online and face-to-face learning components (Glogowska et al. 2011).

In contrast to traditional VLEs, AR combines computer-generated information with a real physical environment through an interface to provide a powerful, contextual, and situated learning experience (Carmigniani and Furht 2011; Zhou, Duh, and Billinghurst 2008). AR for learning

- provides learners with an authentic and situated learning experience,

- enhances learners' interactivity with the physical and virtual environments, and
- shows learners their surroundings, including the indirect view, and enhances their senses.

Sutherland's work with early head-mounted displays in the 1960s was considered the beginning of research into AR (Sutherland 1968). The first AR education application was developed for workplace training (Caudell and Mizell 1992). Although exploratory studies have been undertaken in various fields, such as medicine and education, during the past 40 years, technological limitations, the complex user interface, and social acceptance issues, AR did not live up to its promise until the rise of wireless mobile and wearable technology. – Pokémon, an AR game, attracted many people to play it outdoors in 2016. Its influence on physical activity was published and highly tweeted (Althoff, White, and Horvitz 2016).

AR was quickly adopted in the field of medicine because it can provide a physician an internal view into a real patient without incisions (Bajura et al. 1992; Pandya, Siadat, and Auner 2005; Paolis and Aloisio 2012). The AccuVein product is an example of an AR production in which the visualized and augmented veins in the patient's body can help nurses make injections more accurately (AccuVein Inc. 2015). The earliest use of AR in health care education can be traced to 2002, after which the interest in the technology rapidly grew (Davis et al. 2002; Leblanc et al. 2010; Oostema, Abdel, and Gould 2008; Sakellariou et al. 2009). The PlayAR Human Anatomy 4D is another example of AR application in health care education (AR Applications LLC 2014). It can be freely downloaded on either iPhone or iPad and used to visualize a human body's internal organs. Although some reviews have analyzed the potential of AR in education, including medical education (Botden and Jakimowicz 2009; Lee 2012; Sherstyuk et al. 2011; Shuhaiber 2004), we lack a broader perspective on AR in health care education, specifically how to design learnings in AR. Clearly, this matter is of the utmost importance in ensuring that AR provides an appropriate learning design in this field.

1.2.2 Research on Technology Support of Learning

The history of research on educational technology as a field goes back almost one hundred years. Educational technology was defined as "*The study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources"* (the Association for Educational Communications and Technology (AECT), 2013, p1). Research on instructional designs and technology development, utilization, management, and evaluations brought plentiful knowledge about how various technologies could support learning in various educational environments. Meaningful development of standards, frameworks, models, and theories were expected to guide the integration of technology into teaching and learning (Garrison, Anderson, and Arche 2000; International Society for Technology in Education 2016; Merrill 2009). Due to the lack of context and process and despite significant efforts, some of them were easy applied to the practice (Hamilton, Rosenberg, and Akcaoglu 2016; Stoilescu 2015).The top–

down nature of learning design to test the new technology in education was hard to integrate into the learning process (Hsu, Hung, and Ching 2013). Design collaboration is increasing between researchers and practitioners to refine the use of technology in learning in the real-world context (Amiel and Reeves 2008).

Although the new technology, such as animations, overall had advantage over static pictures (Höffler and Leutner 2007), media comparison research has been viewed suspiciously in educational technology research because it often produced results with no significant differences (Bernard et al. 2004; Clark 1983; Kulik, Kulik, and Cohen 1979; Reeves 2006). However, the desire for new technology to replace old technology in learning continued what Thomas Edison predicted a one hundred years ago: "*I believe the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks*" (The quotation is from Cuban, 1986, p.9). Evidence showed that eLearning systems, when designed to mimic face-to-face classroom settings (Glancy and Isenberg 2011), cannot change the way we teach and learn (Amiel and Reeves 2008; Garrison and Zehra 2009; Reigeluth and Joseph 2002; Salomon 2002). Moreover, numerous sites use "*enervative, endless, or empty*" eLearning designs (Merrill, 2016, P359). The technology cannot support learning by itself. Well-designed learning is much more important for the effective use of technology to support learning.

As we discussed, learning is inherently a complex process and depends on the interaction between multiple aspects of the learning ecology (Ringsted et al. 2011). Various technologies, such as conventional computer-assisted instruction (CAI) or computer-based learning, social media, and virtual learning communities, are suitable for various learning requirements. Because most CAI is designed for learning through a prearranged path with various media and provides learners immediate feedback, CAI is much more appropriate for shallow learning (Graesser 2013). Because social media is more open and based on users' interests, it is better suited for informal and conversational learning (Baiyun and Thomas 2012). The virtual learning community, especially the user, requests information in the community of inquiry, that includes a social, teaching, and cognitive presence and can support collaborative learning and deep learning (Garrison and Arbaugh 2007; Kreijns, Kirschner, and Jochems 2003). Moreover, varying instructional designs even with the same technology can produce different learning outcomes (Cook 2005). Learning is also affected by the various approaches to technology by stakeholders, especially the learner and teacher (or facilitator) (Edelbring 2012). It is therefore important to have a clear understanding of the learner, learning method, and technology's capabilities when determining how to most effectively use new technology.

1.2.3 Learning Design

During the last decade, learning design (LD), specifically three aspects on how to bridge the gap between the prospective ways technologies can enhance learning and actual practice, has gained attention.

The first aspect is technological, using a computer-oriented semantic notation to describe the units of learning for reuse and interoperability in eLearning (Koper and Manderveld 2004). This research started by the Open University of the Netherlands in the field of integrated management systems (IMS) considers LD *a description of a method* of the teaching-learning process for enabling learning in the units of learning (IMS 2003). Based on the IMS learning design, editing tools such as RELOAD and COLLAGE were developed (Beauvoir and Sharples n.d.; Hernández-Leo et al. 2006). However, because these tools focus on the computer language description, it is hard for teachers to apply them in their practice (Conole 2013).

The second aspect concerns the educators, especially teachers facing the challenges of effective teaching in technology-rich environments. LD was considered a scientific inquiry by teachers for sharing their innovations in practice (Mor, Ferguson, and Wasson 2015; Persico and Pozzi 2015). From this perspective, Mor and Craft defined LD as *'the act of devising new practices, plans of activity, resources and tools aimed at achieving particular educational aims in a given situation'*(Mor & Craft, 2012, p.86). Although Mor et al. believed teachers have the capacity to design because they understanding the context of learning and learner (Mor et al. 2015), most teachers still need effective training on integrating technology and adapting appropriate pedagogy (Adams and Petty 2003; Clarke and Zagarell 2012).

The last but not least important aspect comes from research on instructional design (ID), a core research area in educational technology. This historical heredity of LD can be traced to Ralph Winfred Tyler's curriculum development. In the 1950s, Tyler published the *"basic principles of curriculum and instruction,"* which focused on the learning objective, learning experience, and learning outcome. He added two important issues, the learner's active role and no-school environment, in 1970s (Tyler 1976). Meanwhile, educational technologists, including Skinner (1954), Bloom (1956), and Gagné (1965), developed other meaningful theories for ID, and many ID models provide guidelines for designing effective learning (Sharif and Cho 2015). Dick and Carey used a systematic approach for their ID model to systematically analyze the instructional aspects. In their fifth edition of *The Systematic Design of Instruction,* they put a greater emphasis on the analysis of the learner, the context of learning, and the context of working (Dick, Carey, and Carey 2001). Conole defined learning design as "*a methodology for enabling teachers/designers to make more informed decisions in how they go about designing, which is pedagogically informed and makes effective use of appropriate resources and technologies*" (Conole, 2013, p.7). The term's evolution from "ID" to "LD" showed the practice turning from an emphasis on instruction to an emphasis on learning.

1.2.4 Learner-Centered Design

Learner-centered design (LCD) is the traditional Chinese education recommendation, which we call "*因材施教-we teach students in accordance with their individual differences,"* which include aptitude, ability, personality, and learning style. The learner-centered movement started during the education reform in the early 1980s in the United States (U.S. Department of Education 1983). Learner-centered courses were considered effective in promoting motivation and learning in medical students (Cheang 2009; Harpe and Phipps 2008). LCD is a principle of instructional design that has been transformed from teacher-centered to learner-centered (Brown 2003). Dolence suggested an LCD for all types of curriculum design and development (Dolence 2003). It was found the differences between user-central design (UCD) and LCD to develop computer software for various purposes (Quintana, Krajcik, and Soloway 2000). The further proposed that LCD needs to be developed in a team consisting of designers collaborating with domain experts and educational experts to create a system that helps the learner acquire expertise in the work domain. Meanwhile UCD is developed to build a system for the user's benefit. UCD has been used for health informatics technology development in health management, clinical information management, and clinical decision support, etc. (Davoody 2016; Lerouge, Wickramasinghe, and Affiliations 2013; Schnall et al. 2016; Teixeira, Ferreira, and Santos 2010; Wannheden 2014). LCD has been used in continuing education and in ICT-based medical education (Boyd 2012; Henry et al. 2013; Michea, Phelps, and Johnson 2003). Design frameworks are used to guide the developer in determining how the software can be developed as a scaffold for learners to become experts (Quintana et al. 2006). LCD should follow the rule of learning, which is supported by multiple learning theories. Based on behaviorism learning theory, Skinner (1958) developed teaching machines(Skinner 1958). Behaviorism learning theory was also used to support CAI design. Cognitive theory has been used to design multimedia learning (Mayer 2005). Computer-supported collaborative learning (CSCL) was supported by the constructivism learning theory (Koschmann 1996). AR could be the new technology learning support in the complex real-world settings and could be supported by the situated-learning theory, experiential learning theory and transformative learning theory.

1.3 CONTEXT AND SETTING

In the previous sections, I have presented the study's theoretical background. In this section, I will focus on the empirical work, its context, and its setting. This empirical work has been conducted in primary health care settings in China.

1.3.1 The Chinese Health System and Primary Health Care

The Chinese health system is a very complicated one and has undergone radical changes along with the economic development (Wagstaff et al. 2009). The Chinese health system has improved the health of the world's largest population (Meng et al. 2015) but faces formidable challenges such as inefficiency as well as inequities between regions and within the health delivery system (Hougaard, Østerdal, and Yu 2011; Long et al. 2013; Meng et al. 2015; Wang et al. 2015). Following the introduction of a market-oriented reform, in 1989, Chinese hospitals were divided into three classes (Tier1, Tier 2 and Tier 3) and ten levels according to certain criteria, including the number of health professionals, hospital beds, and functions. However, the hospitals tiers' functions were not defined clearly, and patients are free to visit any hospital. Therefore, Tier 3 hospitals are overcrowded while Tier 1 and lower-level hospitals have few visiting patients. To resolve the imbalance in the health care system, an effective primary health care system needs to be built in China.

The primary health care system currently consists of staff members and facilities working in Tier 1 hospitals and the clinics do not meet to the criteria for hospitals (Bhattacharyya et al. 2011). Primary health care services are provided through community health service centers or stations (CHCSs) in urban areas and township hospitals or village clinics in rural areas (Meng et al. 2015). The primary health care system has played various roles and has had various preferences in the multiple China health system reforms over the past 60 years. The reforms can be divided into four phases:

Phase 1 **-** Between 1949 and 1978, primary care was the keystone of the health system and achieved outstanding improvements in health outcomes (Wagstaff et al. 2009). The central principle was prevention. Three health insurance systems covered most Chinese citizens (Anon 2012). The health care system was divided into three levels and organized around the workplace, corresponding to the first and second hospital classification if we use the current classification system (Wagstaff et al. 2009). The medical students had to work in the township health centers when they graduated during the Cultural Revolution, beginning in 1965 (Salaff 1971).

Phase 2 - The primary care system broke down during the market-oriented phase between 1979 and 1998. Financial criteria were used to manage the health system after 1979, and a series of reforms expanded hospital autonomy beginning in 1985. Health professionals who used to work in the countryside gradually began returning to cities. Limited resources and the siphoning of health professionals to the higher-level hospitals in the hospitals' classified management system led to a series of crises with poor efficiency, inequality in access, and unnecessary care with overuse of drugs and high-tech care (Eggleston et al. 2008).

Phase 3 - In 1999, the primary care system was rebuilt based on the continuing economic reform and comprehensive reform up until 2008. Rebuilding the primary care system was of paramount importance to resolve the challenges of access to and the cost of health services (Bhattacharyya et al. 2011; Liu et al. 2011; Wang et al. 2015). To make health care more affordable, a new three-insurance scheme, including a new rural cooperative medical scheme and basic medical insurance for urban employees and residents was established (Long et al. 2013). Although the number of CHCSs has grown and some GPs training programs were launched, with a market orientation and hospital property reform footsteps growing louder, a large number of hospital were sold (Anon 2012). The financial burden of health care still increased (Eggleston et al. 2008; Long et al. 2013), and the performance remained poor (Bhattacharyya et al. 2011).

Phase 4 - Improving primary care was one of the primary goals in the recent comprehensive reform of the health system beginning in 2009 (The State Council of China 2009). Among the many reform issues were accelerating the basic medical insurance system, defining a national essential drug system, improving the primary care health service system, addressing the inequalities of basic public health services, and boosting the reform of public hospitals. A CNY 850 billion (US$ 127 billion) plan was created to develop infrastructure and improve human resources for primary care.

Due to the chaotic reforms, China is well-known for its high AMR and the spread of new microbial threats (Yezli and Li 2012; Yu et al. 2012). Overuse of antibiotics is spread across various hospital levels in China (Yin et al. 2013). More serious, widely shared incorrect knowledge and misconceptions about antibiotic use was leading to the misuse of antibiotics (Reynolds and McKee 2009). To improve antibiotic use by primary care physicians, there is a need to further explore the gaps between knowledge and prescribing behaviors in China (Sun et al. 2015).

1.3.2 Health Professionals and General Practitioners in China

In China, health professionals are defined "*as staff members who work in hospitals, primary health care institutions, specialized public health institutions and other health-care institutions*" and are categorized as physicians, nurses, pharmacists, technicians, and other health professionals (Meng et al., 2015, p116). Before 2014, without standardized resident training, medical students became physicians immediately after they graduated from medical school and started to work in a health care institution. The qualification required for registered practicing physicians and health care professional positions was published in 1998, after which physicians need to pass a qualification exam to receive their license; then they can work as medical practitioners. Physician licenses are classified as clinical, traditional Chinese medicine, stomatology, and public health (Meng et al. 2015). Licenses have two ranks according the practitioner's education level and the qualification exam. The rank of licensed physician can be accorded to a person who has received a bachelor's of medicine or above and passed the qualification exam. The rank of assistant licensed physicians is awarded to someone who has a medical vocational degree or who did not get bachelor's degree but graduated from a medical college or university if they have passed the qualification exam.

The GP specialty was created as an effort to strengthen primary health care in 1997 (P.R. China: State Council 1997). It was thought that GPs providing basic primary care could help China improve overall health and achieve the aims of health reforms (Parry 2010). In 2010, the Chinese Ministry of Health (CMH) and five other authorities, focused on GPs, passed a bill creating primary health care professional teams, with a goal of training 300,000 GPs by 2020 through a variety of ways. GPs mainly working in primary care institutions (PCIs) "*provide integrated services, including prevention and health care; diagnosis, treatment and referral of common diseases; rehabilitation and management of chronic diseases; and health management*" (Meng et al., 2015, p119). The concept of GPs is new, and there is a substantial shortage of them in China, partly as a result of education. Most GPs are physicians who work at PCIs and received in-service training, which is a kind of CPD (Chen et al. 2007; Kong and Yang 2014). GPs receive a training certification if they have taken part in CPD consisting of in-service training. GPs are certified if they received GP training, but licensed GPs must have passed the qualification exam for GPs (Chen et al. 2007). Among the 172,597 GPs in 2014, only 64,156 were licensed GPs and the others had the training certification. Table 1 shows the distribution of PCIs and physicians (data summarized from a Chinese Health and Family Planning Statistical Bulletin 2015).

Table 1.1 Health professionals and GPs in PCIs in China

Area	PCIs		2014	2013	2012
Urban	Community health centers	Numbers	8,669	8,488	8182
		LPAs	134,258	130,907	124,634
		Daily work load per LPA	16.1	15.7	14.8
	Community health stations	Numbers	25,569	25,477	25,380
		LPAs	42,740	42,931	42,780
		Daily work load per LPA	14.4	14.3	14.0
Rural	Township hospitals	Numbers	36,902	37,015	37,097
		LPAs*	433,000	434,000	423,00
		Daily work load per LPA	9.5	9.3	9.1
	Village clinics	Numbers	645,470	648,619	653,419
		LPAs**	304,000	291,000	233,000
		VPs	986,000	1,005,000	1,023,000
Total in Primary Care		LPAs	609,998-913,998	> 607,838	>551,912
		GPs	172,597	145,511	109,794
All physicians in China		LPAs	2,892,518	2,794,754	2,616,064

LPAs: licensed physicians and licensed assistant physicians; VPs: village physicians

* The number of LPAs is approximate ** includes those who work in village clinics set up by a township hospital

1.3.3 General Practitioners' Education in China

Medical education in China can take different paths. Clinical medical students can become physicians after they get their degree or diploma after studying medicine for three years, after studying five or six years for a bachelor's in medicine, after studying seven years for a master's in medicine, or after studying eight years for an MD or PhD (Xu et al. 2010). Even medical students who entered secondary vocational medical school before January 1991 can be physicians. Although the three-year diploma program is phasing out after 2009, in 2014, the educational background percentages of licensed physicians and licensed assistant physicians (LPAs) are 9.5 percent for an MA and above, 38.0 percent for a BA, 31.3 percent for a diploma, 19.1 percent for those who graduated from secondary vocational medical school, and 2.1 percent for high school education (National Health and Family Planning Commission 2015). There is no difference between specialized subjects except stomatology and ophthalmology under a bachelor's degree (Lixin Education and Research Center 2004). Since 1998, clinical medical students have needed to pass a qualification exam to receive their license after graduating and have needed to work one year in a hospital to be a medical practitioner. They can become specialists depending on what specialty they worked in at the hospital. The standardized resident training to be a specialist was suggested to improve the quality of physicians' education but was compulsory for clinical medical students until 2014.

Although the Chinese Medical Association formed a general medical Education Committee in 1989, which was tasked with developing an education system for GPs (Lixin Education and Research Center 2004), it still falls short of the needs of the health gatekeepers and the basic aim of the health reform (Bhattacharyya et al. 2011; Chen et al. 2007; Kong and Yang 2014; Meng et al. 2015; Wang et al. 2015). Three education models are used to train GPs (Kong and Yang 2014).

Medical students who aimed at being a GP upon initial admission into a program or in the third year of their clinical medicine program can choose to be GPs after they graduate and are granted a bachelor's degree (Kong and Yang 2014; Wang et al. 2013). This five-year undergraduate GP education system, which lets students become GPs, was introduced to universities in 1997 (Lixin Education and Research Center 2004; Wang et al. 2013), but as of 2016, only 13 out of 76 medical colleges or universities offered five-year GP-based clinical medicine education. For six of the 13 colleges, focused training GP students are recruited from rural areas, while the other seven run GP education under the subject of clinical medicine but have problems recruiting students (Chen 2016).

The second education model is the three-year standardized GP training program, which requires three years of clinical practice after students graduate from a five-year clinical medicine program (Meng et al. 2015). This model was required to be set up gradually (The State Council of China 2011). Medical students can choose between different three-year standardized resident GP training programs or being a specialist after graduating (Meng et al. 2015). However, non-GP-based specialties are more popular (Liang and Tang 2016). Thus, few GPs have received the standardized training, except in a few pilot studies (Chen et al. 2007; Kong and Yang 2014). Moreover students can also enter other careers, such as being a manager or working in the health care industry, upon finishing the standardized training (Chen 2016).

The third model is the in-service training, which is a way of CPD for current physicians at PCIs to become GPs. While the credit-based CME determines which physician should earn annual credit though a CME course, self-study is or academic activities are mandatory for physicians. In-service training mainly helps physicians get a higher degree or a certification from health authorities and health care institutions (Meng et al. 2015). GP in-service training is currently the most important part of GP training in China for fixing the yawning gap between GPs, and current physicians at PCIs are encouraged to join (Chen et al. 2007; Lixin Education and Research Center 2004; The State Council of China 2011). GP in-service training began in 2001, and, as of 2014, more than 108,441physicians participated in this type of training (Chen et al. 2007; Division of Planning and Information 2015). The specialty students, who were interested in being GPs at the early stage in China and who benefited from the in-service training, became the core teachers and key researchers of GP training (Chen et al. 2007). Although the current physicians, especially those who are LPAs, are expected to be the main force of GP in PCIs (The State Council of China 2011), the lack of opportunities for professional development reduced their job satisfaction at CHCSs in China

(Zhang et al. 2016). As of 2014, more than 609,998 LPAs working in PCIs still have not received any GP in-service training. Moreover, the quality of GP in-service training has been inconsistent because most of the training has been delivered by public health lecturers who lack the background to teach practical skills (Bhattacharyya et al. 2011; Chen et al. 2007; Kong and Yang 2014).

1.3.4 Wuhan

This thesis focuses on the Wuhan district in China, where 540 CHCSs are located. Wuhan is the capital of Hubei province, located in central China, and it provides economic, cultural, educational, and transportation centers in this area. In 2015, it had 10,607,700 people. The ratio of medical personnel to the population in central areas is less than in the east and west: 4.65 per 1,000 people, compared to 5.33 per 1,000 in the east and 4.71 per 1,000 in the west (Meng et al. 2015). Expectations for the health care industry's expansion between 2011 and 2020 led the municipal public health and family planning commission, in addition to the city land planning bureau, in Wuhan to set aside space for health care facilities (2011-2020). The intent was to make Wuhan a national health service center, a national demonstration center of public health service, a national demonstration center of basic medical and health services, and an international health city (The Municipal Public Health and Family Planning Commission and City Land Planning Bureau 2011). According to the plan, in 2020, there will be 749 CHCSs, 86 townships hospitals, and up to 1845 village clinics in the greater Wuhan area. Wuhan could be important for improving the quantity and quality of medical personnel in China's central areas.

Wuhan was the one of 10 pilot cities for the introduction of the national GP service mode reform in 2012. GP in-service training began in 2009 in Wuhan when 27 physicians received their certification, and 200 GPs were registered in 2012 (Jiang, Peng, and Tu 2012). Through 2015, 707 GP teams, each comprising one GP, one public-health physician, and one nurse, were formed. The number of GPs is still far behind the population's needs, estimated at 3 to 5 GPs per 10,000 residents.

2 RESEARCH AIMS

The aim of this thesis is to explore a way to improve physicians' CPD and to study how AR can play an important part in the design. The specific objectives were

- To explore the needs of CPD for physicians becoming primary care GPs in Wuhan, China, with a special focus on identifying reasons, opportunities, and challenges for participating in this kind of CPD and the possibilities of employing AR-based learning methods in such CPD.
- To find a suitable learning design with AR that can be used in CPD for primary care physicians from current research on AR in medical education.
- To develop a design framework that can guide the development of AR-based CPD applications for primary care physicians.
- To apply the design framework to identify AR design needs for the development of educational applications for primary care physicians in Wuhan, China, with a special focus on identifying their personal paradigms of prescribing antibiotics and expectations of AR function.

3 OVERVIEW OF EACH STUDY IN THE THESIS

This thesis is composed of four studies with a design-based research (DBR) focus on a design for learning using AR technology in CPD for primary care physicians. The aim of the design is to provide CPD focus on in-service training for primary care physicians who are becoming GPs. This training should meet the learning needs of the primary care physicians based on their own experiences and those of their managers in addition to the health care reform priorities of China's health care system while focusing on new learning environments in the clinical context. Figure 3.1 shows the overview and sequence of the four studies in this thesis. Study III takes the practical needs from Study I and the applicable knowledge from Study II to produce new design knowledge, adding to the existing knowledge base and being applied in Study IV. Study IV produces new practical needs for further development.

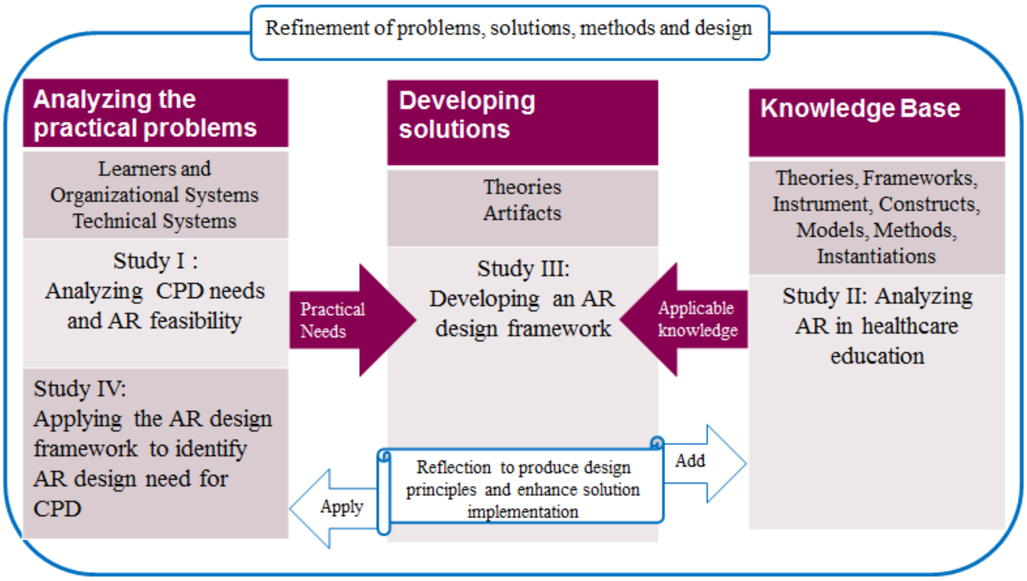

Figure 3.1 Overview of the studies and the relationships between them

Study I provides understanding for CPD needs among physicians and managers, with a focus on exploring the acceptance of AR and the challenges of the current CPD used by GPs in in-service training at CHCSs in Wuhan, China. Study II describes the current use of AR in health care education and identifies the strengths and weaknesses that could inform AR design. Based on the findings in studies I and II, and driven by the learning theories, Study III focuses on designing a framework to guide the design, development, and application of AR in health care education. An example of learning the rational use of antibiotics by GPs is used to explain the framework in Study III. Based on the AR design framework in Study III, Study IV is a renewed analysis of the practical problem at CHCSs in Wuhan, China. This renewed analysis uses the AR design framework to understand physicians' personal paradigms of prescribing antibiotic and their expectations of AR at CHCSs in Wuhan, China. Identifying problematic areas in their decision making and their expectations of AR could be used to design AR prototypes in the future.

4 METHODOLOGY

Health care systems in most countries face challenges that need to be met by medical education. My doctoral research seeks to explore the characteristics of CPD in the workplace and the possible impact of the development of a certain technology—AR—to try to enhance GPs' learning in their workplace. The aim of this study is to explore how to design a learning experience using AR to fit the needs of primary health care physicians' CPD in the clinical context. To achieve this aim, design-based research (DBR) is used in my study.

4.1 PHILOSOPHY AND RESEARCH PARADIGM

"*Reality is the fruit of an interaction of the given cosmos and the way mind engages with it*" (Heron & Reason, 1997, p.279). I am not verifying or falsifying hypotheses to find the law of nature but admit existence of natural reality. The cosmos or the universe is a true reality that is a primordial ontological datum: it is objective. However, objectivity is relative to how knowledge is shaped by the knower and how it is inter-subjectively shaped because knowledge is constructed through our mind and is subjective.

My research paradigm differs from the true reality of positivism/post-positivism and the relative reality of critical theory/constructivism (Guba and Lincoln 1997). It is based on participatory inquiry (Heron and Reason 1997). The participatory inquiry is an iterative process. It requires researchers and practitioners to work together to identify the problem and to discover the effect of positive change (Lingard, Albert, and Levinson 2008). This participatory inquiry also needs to be guided by the current relative theory. As a researcher and designer, collaborating with health care workers to define the learning question in the workplace to discover the effective pedagogical strategies and technologic innovations is important. The participatory inquiry is not only the inquiry paradigm but a kind of way to understand learning in which such learning is specific to the situation. It could be modified during the inquiry process. I realized that the meaning for an individual depends on that individual's historical and local context, but I want to find a way that we can understand each other. According to the research paradigm and the question I aim to resolve, DBR will be used in this project. We will cooperatively investigate using health care workers, such as physicians and managers who understand CPD for GPs, to find the practical problems, the methods of resolving them, and in the most effective way to do so.

4.2 DBR

According to Simon's *the sciences of the artificial*, medicine, computer science, and education are viewed as belonging to sciences of the artificial that are centrally slanted toward the design process (Simon 1996). DBR has been used as design sciences, design research, or design experiments in these different disciplines (Collins 1992; Collins, Joseph, and Bielaczyc 2004; Hevner et al. 2004). Design sciences explore how to design artifacts under different conditions, while analytical sciences explain the phenomena in the world (Collins et al. 2004). DBR is different from traditional educational research methods that focus "*more on establishing the legitimacy of one educational research tradition over another rather than on improving education per se*" (Reeves, 2006, p.104). The DBR approach is used to build bridges between theory and practice (Dolmans and Tigelaar 2012), and it could be used for learning design at the macro, meso, and micro level (Cole and Packer 2016).

Different DBR cycles have been suggested in medical education, educational technology, and information systems based on their research paradigm. When using DBR in medical education, redesign is integrated into three main steps: analysis, evaluation, and reanalysis (Dolmans and Tigelaar 2012). Framework and prototype development is the first step. The following step is to investigate the effectiveness from different aspects based on the framework and the prototype. A literature study is used as the last step to produce principles. From an information systems perspective, there are three different cycles: relevance, design, and rigor (Hevner 2007; Hevner et al. 2004). The relevance cycle is used to analyze the application context and design input while the rigor cycle provides evidence of innovation; finally, the design cycle is concerned with designing artifacts and theories. The ICT artifacts include instantiations and the constructs, models, and methods of development (Hevner et al. 2004). In the area of educational technology, DBR conducts four iterative steps: analysis, development, test, and reflection (Reeves 2006) . Developed solutions are based on the analysis of practical problems in education and are enlightened by current design principles and technological innovations. Iterative tests and reflections produce new design principles. Design innovations and producing design principles are equally important (Amiel and Reeves 2008). From these different areas, the design artifacts can be explained as innovative forms, such as theories, solutions, frameworks, and products.

4.3 STUDY DESIGN AND METHODS USED

Since this PhD project touches on multiple areas, including medical education, educational technology, and information systems, I adapted the DBR cycles from the three areas presented in the previous section. While Hevner's DBR cycles encouraged me to think more about what each study should focus on, Reeves's DBR model encouraged me to use holistic thinking and practical problem priority principles. Dolmans's DBR cases showed me a design framework is necessarily. The overview of each study design is presented in Figure 4.2. My DBR studies can be characterized as using an interdisciplinary mixed methods research approach (Bannan-Ritland 2003; Hoadley 2004). Mixed methods research is defined as "*using more than one research strategy also are referred to as multi-strategy designs'* and *'using two or more methods of collecting qualitative data or multiple quantitative data collection are referred to as methods studies*" (Robson & McCartan, 2016, p.174). This multi-strategy approach is useful for trying to achieve the different aims and to answer the different research questions at each step of research.

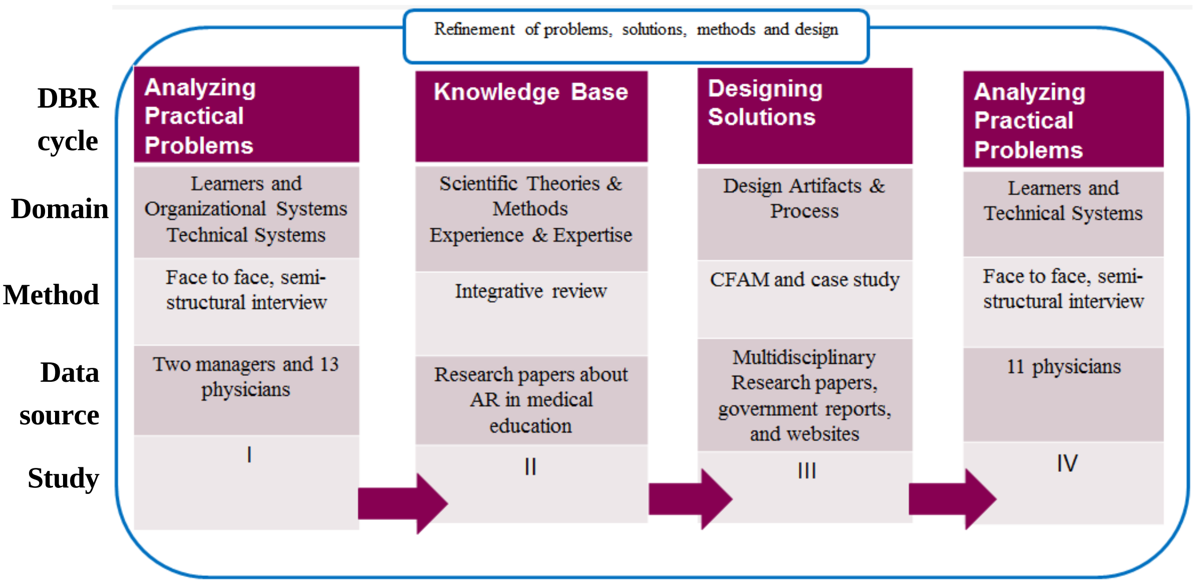

Figure 4.2 Overview of each study's design

4.3.1 Study I: Qualitatively Analyzing CPD Needs and Feasibility AR

The first study's aim was to understand the practical problem of CPD in a primary care setting, focusing on analyzing the needs of physicians' CPD and the feasibility of using AR. The physicians' roles, capabilities, and characteristics, as well as their experiences with and expectations of CPD, are important for the LCD design. At the outset of a design project, exploring the users' acceptance of the technology can help limit the development cost and add design flexibility (Davis 1993; Yusoff, Zaman, and Azlina 2011). Effective use of CPD also needs support from both managers and organization (Boudioni et al. 2007). Thus, the physicians' and managers' perspectives help explain the complexity of a social phenomenon from more than one standpoint (Bulsara 2015). A qualitative method is suitable for the discovery of the phenomenon's complexity.

4.3.1.1 Study design

A qualitative method (Marshall and Rossman 2006) was used by the physicians and managers to understand the needs and the acceptance of AR for use in CPD for physicians. The free app PlayAR Human Anatomy 4D for iPad (version 1.4.04, PlayAR Games, United States) was used as an example of AR. It is 3-D, has the various human organ systems, and can be combined with a clinical environment.

4.3.1.2 Data collection and analysis

To collect data, I conducted face-to-face interviews in Wuhan, China. The 13 physicians and two managers participated in the interviews at four CHCSs. Based on the requirements of GP in-service training programs, seven broad questions were developed for the interviews with the physicians and six broad questions for the managers. Open-ended questions were used to encourage physicians and managers to express themselves more fully during the interviews.

Convenience sampling was used to recruit managers and physicians. Snowball sampling was used to recruit more physicians. All interviews were recorded and transcribed verbatim.

An inductive thematic analysis approach was used to analyze the interview transcripts. The analysis required six phases (Braun and Clarke 2006): conducting data immersion, familiarizing myself with the data; generating initial codes through tagging and creating names for the content's meaning; collating the codes to search for themes; reviewing the themes; defining and naming themes; and finally, reporting results.

4.3.2 Study II: Integrative Review Analyzing AR in Health Care Education

Because AR is a rather new technology, it is necessary to explore the state of the AR's current use in the health care education field. This study aimed to offer a comprehensive understanding of AR's current research status in health care education and its strengths and weaknesses. Based on Study I's results (Zhu, Fors, and Smedberg 2018a), I planned to discover a set of current design principles and technological innovations to be used as a guide in applying good learning design for AR use to improve the clinical competences of primary care physicians. Thus, reviewing the current methods, theories, and empirical studies about using AR in health care education is important. An integrative review is the appropriate method to summarize existing bodies of evidence from diverse fields and to identify new insights.

4.3.2.1 Study design

An integrative review was used to understand the AR used in the health care education field (Whittemore 2005). Whittemore suggested that any kind of review consists of five stages: formulating the problem, searching the literature, evaluating the data, analyzing the data, and making a presentation to meet the review standards. Several studies were conducted during the problem-formulation stage: questions and outcomes were defined, and the study protocol, including the criteria of each identified study, the databases, and the search strategies, were discussed until agreement was reached.

4.3.2.2 Data collection and analysis

For data collection, eligible studies were retrieved from multiple databases: ERIC, CINAHL, Medline, Web of Science, PubMed, Springer-link, and other resources (article reference lists) published no later than November 2012. The studies included multi-disciplinary research publications in English and were evaluated according to a set of research, technology, and content inclusion and exclusion criteria. For studies meeting the criteria, I asked the authors to provide the full text if not available on the databases.

Both content analysis and thematic analysis were used to analyze the primary data sources. First, content analysis was used to extract the key information from each included article. The results were coded and categorized with respect to research, technology, and learning and were recorded using a standardized data-extraction form, where each category included several sub-categories. The research category included the following sub-categories: research aim, study design, participants, and result. The AR technology category focused on the following: display technologies, tracking, input devices, and development tools. The learning category focused on learning theory, learning strategies, and learning effect. Second, thematic analysis was use to analyze and synthesize the results of standardized data extraction through iterative comparisons via narrative and quantitative pooling. The prominent themes were summarized and integrated to answer the research questions.

4.3.3 Study III: Conceptual Framework Analysis for Developing AR Framework

To best facilitate learning, LCD needs to be guided by a suitable educational model (Quintana et al. 2000). From the educational technology view of DBR, the solution design should follow current design principles and technological innovations (Reeves 2006). Our interview showed that the reception to AR was positive from the primary care managers and from most of the physicians. Moreover, our integrative review found that 96 percent of 25 included papers reported that AR can be useful for health care professional development at different levels (Zhu et al. 2014). However, because most of the AR applications found lacked support in learning theory, discovering how to use theory to design effective learning strategies using AR was necessary (Kaufman and Mann 2010). This study aimed to develop a design framework that can guide the development of AR educational applications for health care professional development. I then considered how this framework could be applied to guide the design of an AR application to help GPs improve their rational use of antibiotics.

4.3.3.1 Study design

A conceptual framework analysis method (CFAM) and case study were used to design the framework. The CFAM was mainly used to build conceptual frameworks from a variety of data to develop concepts and the relationship between them. It is a flexible multidisciplinary approach based on a theory derived from different areas, including how technology can enhance health care and education (Careau et al. 2015; Chidzambwa 2013).

First, the framework was designed follow the eight steps of CFAM suggested by Jabareen: "*Mapping selected data sources; Reviewing the literature and categorizing the selected data; Identifying and naming the concepts; Deconstructing and categorizing the concepts; Integrating the concepts; Synthesis, re-synthesis, and making it all make sense; Validating the conceptual framework; Rethinking the conceptual framework.*" (Jabareen, 2009, p53)

Second, the case study applied the design framework to improving the use of antibiotics by GPs and found it to be valid. This application of the design framework consisted of four steps: 1) using the hierarchical ability model to describe the expectations for GP learning outcomes with respect to the rational use of antibiotics, 2) defining a GP's personal paradigm for the process of deciding to prescribe a drug, 3) characterizing the different learning environments, and 4) designing learning activities to support the GP learning.

4.3.3.2 Data collection and analysis

Data collection: A multidisciplinary literature search was reviewed with regard to learning and instructional experiences and was mapped. The fields searched included medicine, public health, education, instructional design, information technology, and management. Data sources were collected from research and conference papers, government reports, and websites.

Directed content analysis was used to identify key concepts and was guided by a structured process to develop the theoretical framework (Zhang and Wildemuth 2009). The structure process followed the principles of being effective, efficient, and engaging LD. After the design framework was built, it was used to analyze and was applied to the education on the rational use of antibiotics as an example. During the application analysis, the expectations of abilities for GPs moving from the knowledge level to the action level and their personal paradigm used for the rational therapeutic process were determined. Potential learning environments and learning activities were also suggested.

4.3.4 Study IV: Applying AR Framework in Qualitative Analysis AR Design Needs

The learner is the center of learning design. In my first study, I investigated physicians' expectations of CPD for continuously improving their clinical competences to become a qualified GP. Among those in favor of using mobile-based AR to improve their integrated clinic competence and suggested topics, one of their expectations is learning about rationally using pharmaceuticals (Zhu et al. 2018a). In the case design of Study III, I investigate the expectation of the reasonable use of antibiotics, which is the result of the AMR growing public health threat and is a problem in Chinese primary care. Based on the framework that we designed (Zhu et al. 2015), an effective AR design needs to understand the physicians' personal paradigm and their expectations about learning assets, learning environments, and learning activities. Study IV aimed to identify AR design needs for the development of educational applications in the context of primary care physicians rationally using antibiotics.

4.3.4.1 Study design

A qualitative approach was used to identify the AR design needs for primary care physicians to use AR in their CPD and was applied to the rational use of antibiotics (Marshall and Rossman 2006). The qualitative approach was based on face-to-face semi-structured interviews. The free app PlayAR Human Anatomy 4D for iPad (version 1.4.04, PlayAR Games, United States), which shows the various organ systems inside the human body in 3-D and can be combined with the clinical environment, was used to help the physicians express their expectations with regard to learning and AR-based education.

4.3.4.2 Data collection and analysis

I carried out face-to-face interviews with 11 physicians at three CHCSs during their daytime working routine to collect data. Convenience sampling and snowball sampling were used to recruit physicians. The interview was led using a template with 11 pre-defined questions according to the AR design framework. Additional open-ended questions were used to allow the physicians to express additional opinions during the interview process. All the interviews were recorded and transcribed verbatim.

The analysis process was guided by the MARE framework. First, a hybrid thematic analysis approach was used to analyze the collected data (Fereday and Muir-Cochrane 2006). The coding scheme for deductive analysis was developed from four key components of the AR design framework, and inductive coding grew out of the analysis process. Second, we identified the LOs and the paradigm issues based on the result of thematic analysis.

4.4 ETHICS CONSIDERATIONS

Ethical approval for this PhD study was applied for and received from Tongji Medical College of Huazhong University of Science & Technology's ethics committee (2012 approval No. 5454). This thesis aims to explore ways to improve medical CPD and to study how AR can be used when designing for learning. In Study I and IV, I orally informed participants about the study using the informal letter before the interview. They could take read it if they wanted. I did not ask them to sign the agreement, as it would be impolite to do so in Chinese culture, but they we able to drop out at any time. The main participants were physicians working in CHCSs. We performed neither medical examinations nor animal experiments and used data from the interviews. There was no unnecessary physical or psychological damage/suffering in our project, participation was voluntary, and all the participants had the right to withdraw. The only risks of research related to any adverse effects from the disclosure of information were from the following: 1) personally identifiable information, 2) interview questions about working experiences, and 3) the relationships between doctors and patients. These risks were minimized by transforming the data and encryption. To ensure that an individual is fully informed, the Nuremberg Code requires that the person seeking consent should include a number of elements in the explanation of procedures. The physicians are participants, and they are learners in our research. They have a right to express what they need to learn and how to learn it, and their suggestions are important to improving the system. The consequentialist theories suggest that alternative actions are based on the rationale that a person ought to do what is best for the community. Situation learning is based on the respect for an individual, and that individual's acceptance of new technology and new ways learning should be asked about. The short-term effect is to improve the GPs' ability to work in CHCSs. The long-term effect is the well-being of the patients.

5 RESULT SUMMARY

5.1 PRACTICAL INVESTIGATION

CPD Needs and AR Feasibility (Study I)

This study explored the needs, opportunities, and barriers of CPD for physicians seeking to become GPs in the primary care field, with a special focus on identifying reasons for attending CPD and the possibilities of employing AR-based learning methods. Thirteen physicians and two managers were interviewed with respect to their views of the physicians' roles, capabilities, and characteristics, as well as their experiences and expectations of CPD and their attitudes regarding the AR-based CPD possibilities. Three key findings were identified:

I. *The needs of becoming a GP*. When working at a CHCS, the physicians mostly took on the role of a specialist, although they sometimes acted as GPs. More GPs are needed at CHCSs according to the current community development and the requirement of the Chinese health care system reform. Not all physicians were trained as qualified GPs after graduation, despite studying the basic knowledge of internal medicine, surgery, gynecology, and pediatrics in medical school. They needed a CPD to become a GP and needed broader and more integrated competence compared to a specialist. They expected to learn about new guidelines and new treatments, especially with respect to the rational use of medications applied to common diseases, pre-hospital emergency care, and chronic disease management.

II. *The CPD models and challenges at CHCSs.* Physicians stated that there was no well-organized access or exposure to CPD. They sometimes attended lectures hosted by different organizations, participated in subject-based learning at their CHCSs, or joined specialized training at a tertiary hospital for several months; they also did different kinds training activities for GPs. With the exception of the scheduled GP training, which training time, the way of learning, and the GP training content were different. Often, the CPD training did not focus on GPs' needs. Although a national outline of GP in-service training was published, few GPs were given the opportunity to participate in training according to these requirements. Managers needed to make sure that enough physicians were on duty, restricting physicians' ability to participate in the GP in-service training. Some of the physicians who had the opportunity to participate in the training were disappointed in the training's impact, and managers complained that the training was not enough for GPs to continue to be qualified.

III. *The experience of ICT-based CPD and acceptance of AR.* Physicians sometimes used ICT for their CPD, mainly to search for information online, to share knowledge with peers on social media, and to discuss things in virtual communities for physicians. Although ICT- based CPD was considered to be flexible and convenient, the authority of the information was one challenge, and its usefulness depended on the individual physician. With the exception of one physician, who had negative feelings about AR-based CPS, the managers and most of the physicians felt positively toward AR-based

CPD. AR-based CPD was viewed as being a convenient, visual, and impressive learning method. When shown the 3D visualization of AR, participants said that it could provide them a better understanding of human physiology and that it was good for remembering details and for motivating them to learn. They suggested that we develop smartphone-based AR courseware and organize systematic learning activities for them. Among the topics suggested, the nervous system, different kinds of surgery, emergency care, and rationally used medicine, such as antibiotics-based treatment, were suggested as suitable topics for which AR could be developed.

5.2 THEORY RESEARCH

5.2.1 AR in Health Care Education (Study II)

This study aimed to identify a suitable AR learning mode based on current AR applications in health care education that could be used for training by primary health care physicians. Twenty-five research papers on AR in medical education were identified from 2,529 English papers on ERIC, CINAHL, Medline, Web of Science, PubMed, and Springer-link, all published before November 2012 (Figure 5.1). Of these, 20 were quantitative studies, three qualitative studies, and two mixed studies.

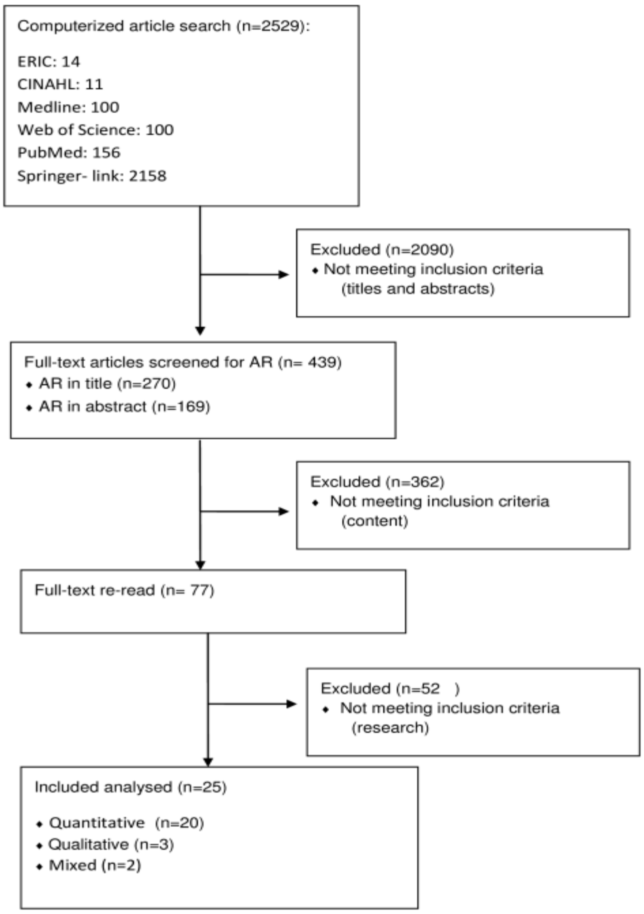

Figure 5.1 The review process described in Study II (Zhu et al. 2014, p.6)

We thus investigated and summarized an overview of AR in health care education (Figure 5.2) and its strengths and weaknesses:

I. *Overview of AR in health care education research.* AR in health care education has been broadly investigated from several perspectives, including user acceptance, system development and testing, and learning effects. It has been implemented in several areas of health care education, primarily for surgery and for learners at all levels, including different health care staff categories, such as surgeons, nurses, clinicians, and other health care workers not clearly described in the published papers. Although the technical aspects of AR are different depending on whether the technology was developed for use on a computer or a mobile device, results showed that AR can improve learning effects and that it was accepted as a learning technology by health care professionals.

II. *Strengths of AR in health care education research.* Although the aims of research and the role of AR in health care education varied, 96 percent of the papers reported that AR is helpful for improving health care education. Based on how AR was used, the benefits of AR for health care professionals were described as adding subjective attractiveness, simulating authentic experiences, understanding spatial relationships and medical concepts, and assisting in the acquisition of skills and knowledge. Moreover, AR provided a new role for technology-enhanced learning, such as immersion in a scenario and participatory reality with learning. However, many studies continue to use a similar role with current technology for technology-enhanced learning, such as in feedback, navigation, and simulations.

III. *The research weaknesses of AR in health care education.* A majority (56 percent) of papers that investigated AR in the health care field used technology at an early stage of development with the exception of the ProMIS AR, which was developed for surgeons to improve their skills in performing laparoscopic surgery applied to colorectal surgery. The identified big weakness of AR in health care education in this research is that the design and application lacked the support of learning theories. Because of this, 64 percent of studies showed that AR applications used traditional learning strategies and, even worse, that a learning strategy was not described in 12 percent of the publications.

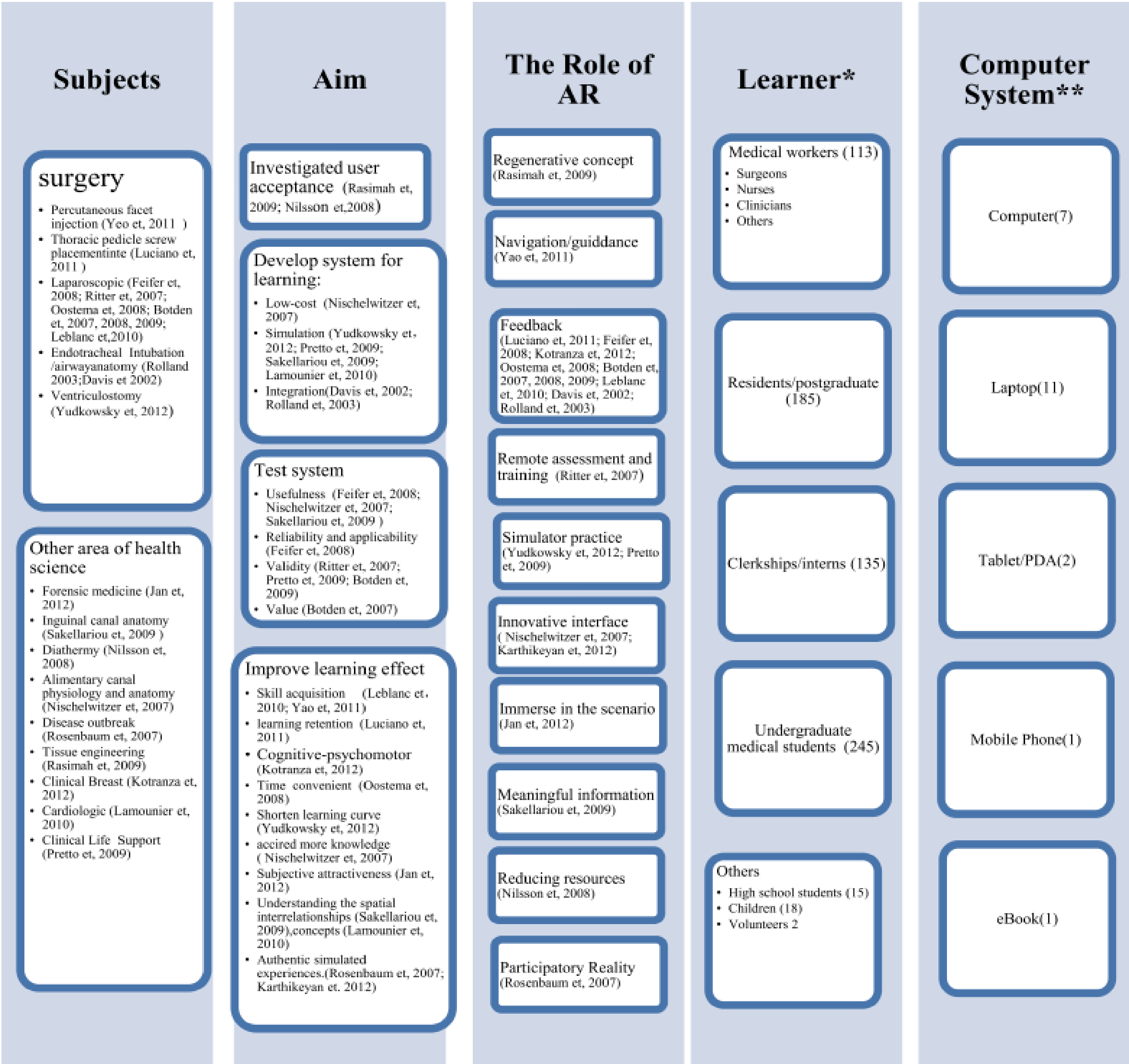

Figure 5.2 The overview of AR in health care education research described in Study II (Zhu et al. 2014, p.8)

5.2.2 Mobile AR Education Framework Design (Study III)

This study attempted to design a Mobile AR Education (MARE) framework driven by appropriate learning theory that could better guide the development of AR educational applications, especially focusing on CPD for use by primary health care physicians. A case study of training GPs in the rational use of antibiotics was used. Three learning theories—situated learning, experiential learning, and transformative learning theory—can be used to provide the foundation of a MARE function design. These three learning theories provide different sides of learning, learning environments, and learning activities, which can all support a MARE design. The differences between the learning theories are shown in Figure 5.3.

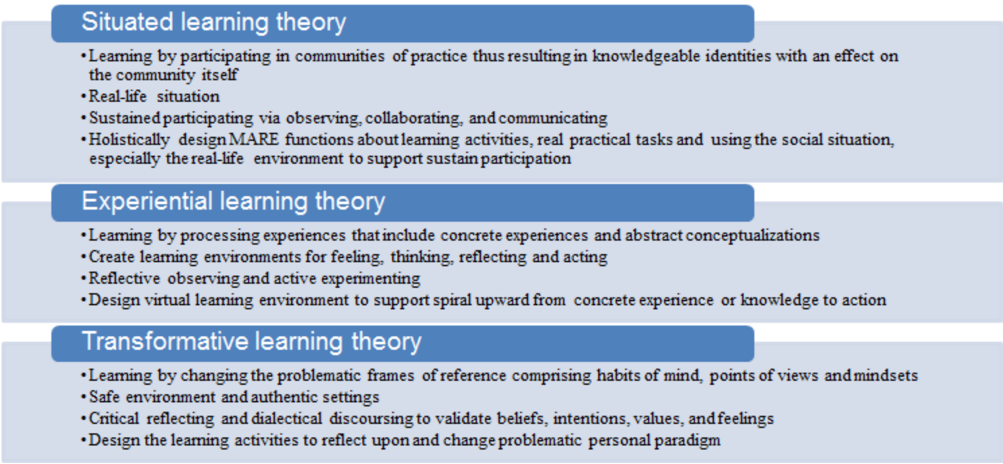

Figure 5.3 The supporting learning theories adapted from Study III (Zhu et al. 2015)

The main design framework constituted several concepts and was separated into three layers. Figure 5.4 shows the key concepts of the MARE framework and the relationships between the concepts. The design is centered on the learner. All other conceptions were expected to support the learner in developing a suitable personal paradigm.

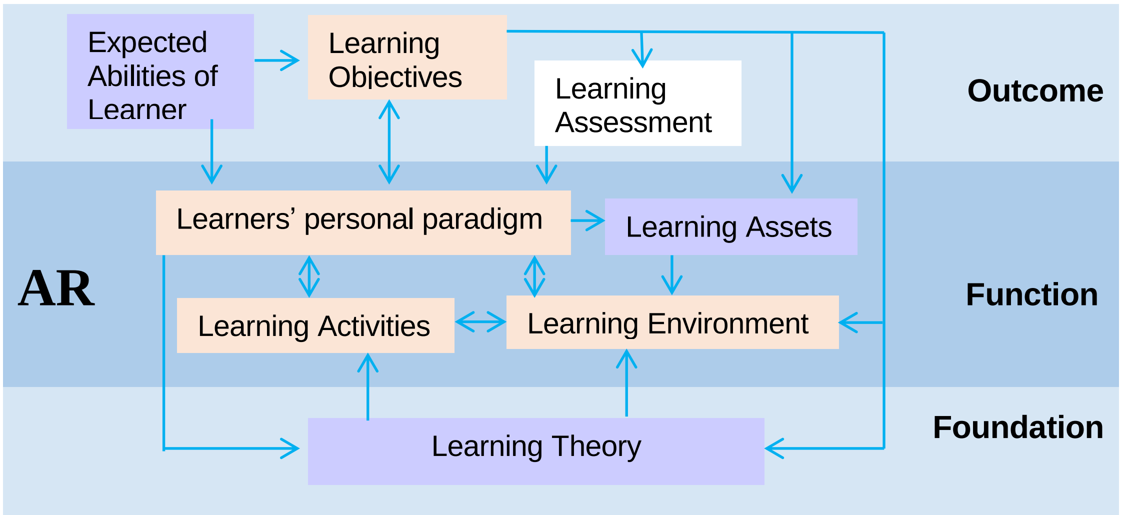

Figure 5.4 The main elements of the MARE framework described in Study III (Zhu et al. 2015, p.4)

The main concepts are interpreted as follows:

I. *Learner's personal paradigm*. The concept of a personal paradigm is according to Kuhn's "paradigm," which Mezirow defined as the frame of reference in transformative learning theory. The learner developed his or her personal paradigm though learning and/or practice and experience. A physician's personal paradigm refers to his or her personal style of decision making regarding diagnosis, treatment, prescription, and drug choice, which the WHO has defined as P-diagnosis, P-treatment, P-prescription, and P-drug. Functional design AR needs to start by identifying the problems of personal paradigm and by being developed to be appropriate though AR-based learning.

II. *LOs.* The LOs are defined as what the learner should learn through AR-based learning. The LOs can be identified from the expected abilities of learner and the problems of learners' personal paradigm. It also defines how the learning achievement should be assessed after learning.

III. *Learning environment.* The learning environment is the combination of conditions and the external stimuli of learning. The strength of AR is that it typically allows real clinical environments and virtual environments to be mixed to facilitate learning through feeling, watching, thinking, doing, and transforming the learners' personal paradigms.

IV. *Learning activities.* The learning activities are defined as how learners are engaged in in the learning environments.

V. *Learning assets.* The learning assets are the learning content and its media forms.

The main part of the MARE framework is the AR functional layer design. The foundation provides the theory supporting it, and the outcome layer feeds into the functional design and describe what the physicians should achieve through the MARE. The functional layer design consists of five steps and can be structured as described in Figure 5.5. The physicians' abilities are based on the outcome layer on the expected learners' abilities. The learning environments and learning activities are supported by the foundation layer-learning theory.

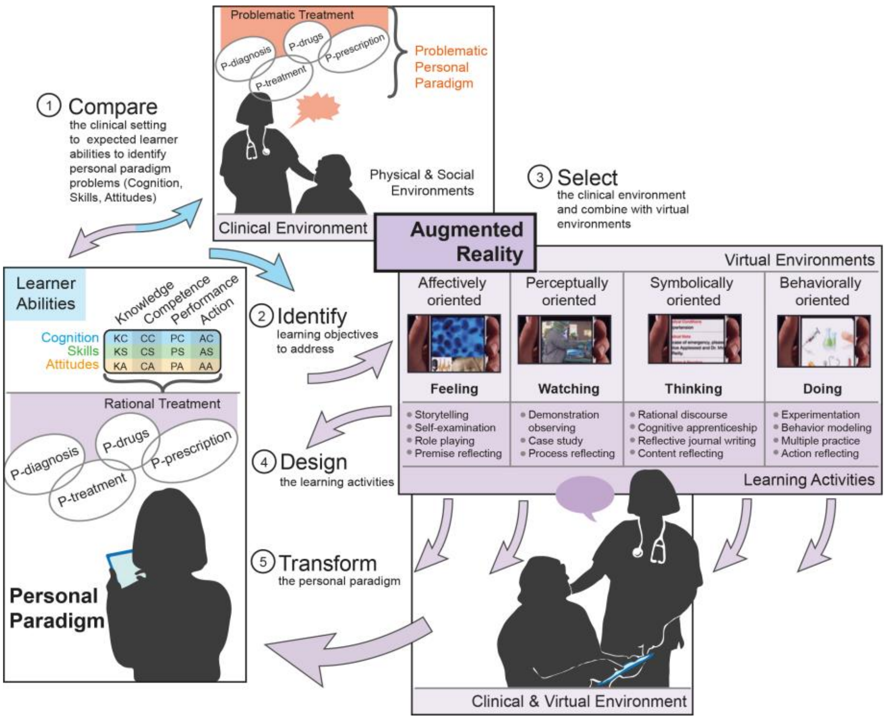

Figure 5.5 MARE function structure process described in study III (Zhu et al. 2015, p.9)

The outcome layer component describes the expected abilities of physicians with respect to the professional certification requirements; the LOs, which can be identified from the expectations; and the problem of the personal paradigm in clinical practice. The model of hierarchical ability from knowledge to action, which integrates the cognition, skill, and attitude domain, as well as the learning assessment of AR, is shown in Figure 5.6.

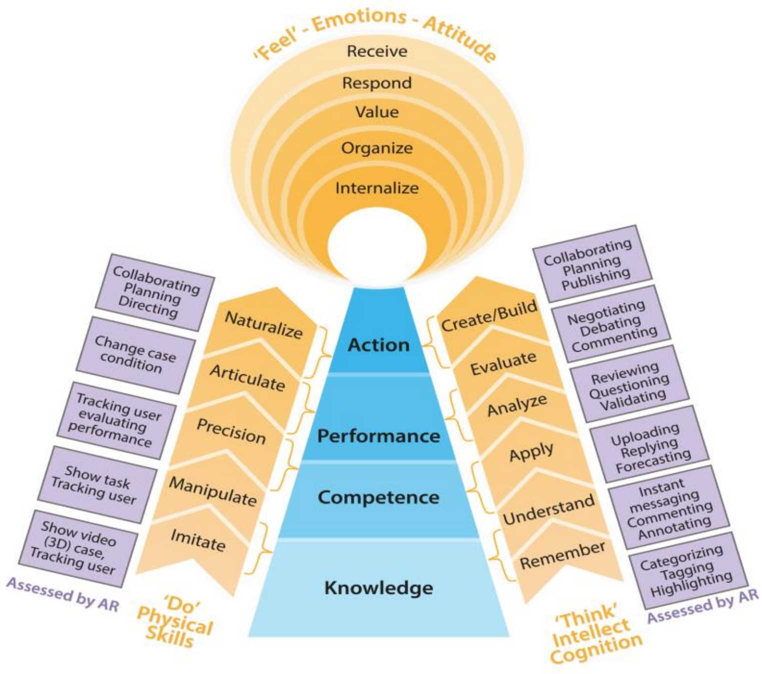

Figure 5.6 The hierarchical abilities model described in Study III (Zhu et al. 2015, p.5)

How to apply the MARE framework to design GPs' education of rational use of antibiotics is described below:

I. The hierarchical abilities model—the spectrum of the expected abilities with respect to cognition, skill, and attitude from knowledge, competence, and performance to action level—can easily be used to describe the LOs for GPs in the rational use antibiotics. This spectrum is listed in Study III.

II. The GPs' rational therapeutic process with P-diagnosis, P-treatment, P-prescription, and P-drug is described in Figure 5.7. This process can be used to check the GPs' personal paradigm in the real clinical environment and identify the LOs within the spectrum of the expected abilities.

III. Different learning environments were suggested in the MARE function structure: The affective-oriented environments of AR can be designed to affect GPs' attitude by sharing their values and feelings with concrete experiences. The perception-oriented environments of AR can be designed to help GPs observe the process simulations of infecting and examining their problem-solving strategies by reflecting on their habits of using antibiotics. The symbol-oriented environments of AR can be used to show the tasks, guidelines, and alarms and help GPs update their knowledge and develop new abilities. The behavior-oriented environments of AR can be designed to inspire GPs to interact with the object, to practice what they learn, and to reflect on what they do.

IV. Based on the suggested learning activities in the MARE function structure are examples of how GPs can learn about the rational use antibiotics, even though the abilities in different AR learning environments vary; to modify their personal paradigms, see Study III.

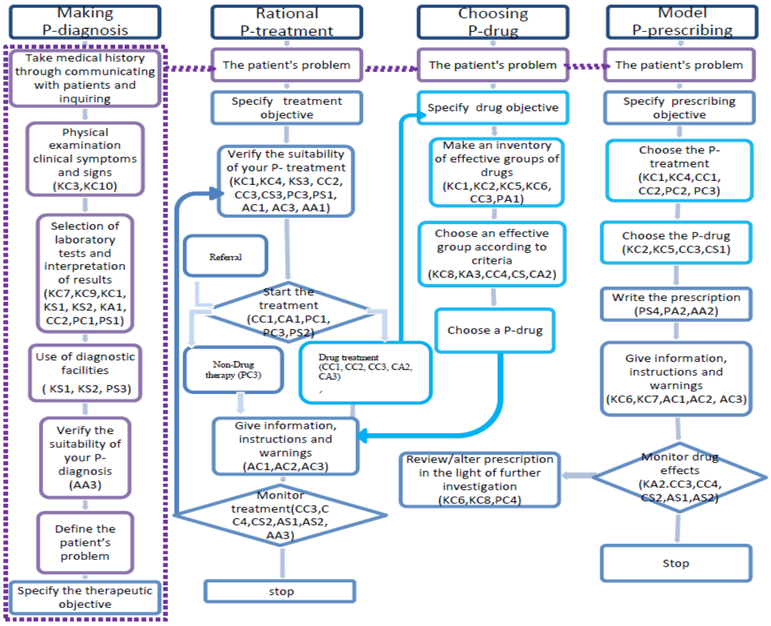

Figure 5.7 GPs' personal paradigm of rational therapeutic process described in Study III (Zhu et al. 2015, p11)

5.3 PRACTICAL APPLICATION AND INVESTIGATION

Primary Care Physicians' Personal Paradigms for Prescribing Antibiotics and AR Design Needs (Study IV)

This study aimed to identify AR design needs through applying the MARE framework to analyze the current personal paradigms for prescribing antibiotics among primary care physicians at CHCSs in Wuhan, China, and their expectations for AR-based CPD. Eleven physicians shared their experiences of P-diagnosis, P-treatment, P-prescription, and P-drug, as well as their thoughts about prospective AR-based CPD. The key findings are summarized as follows:

I. Missed steps

The coding scheme based on the MARE design framework can be used to analyze the AR design needs according to physicians' P-diagnosis, P-treatment, P-prescription, and P-drug, as well as their different expectations of learning assets, learning environments, and learning activities with AR. Several steps, including "specify the objectives" in the rational therapeutic process, were missed according to the physicians describing their thought process and how they have used antibiotics therapy. These missed steps indicate that the physicians did not believe that those steps were important in their clinical practice or that they might not train with those steps.

II. Identify PPP issues

There are different personal paradigms among the physicians. The personal paradigms for the antibiotic prescription process have been summarized in Figure 5.8. They differ from the rational therapeutic process shown in Figure 5.7. Moreover, none of the physicians were familiar with the current national guidelines for using antibiotics (PPP3). The distribution of physicians' PPPs is shown in Table 5.1

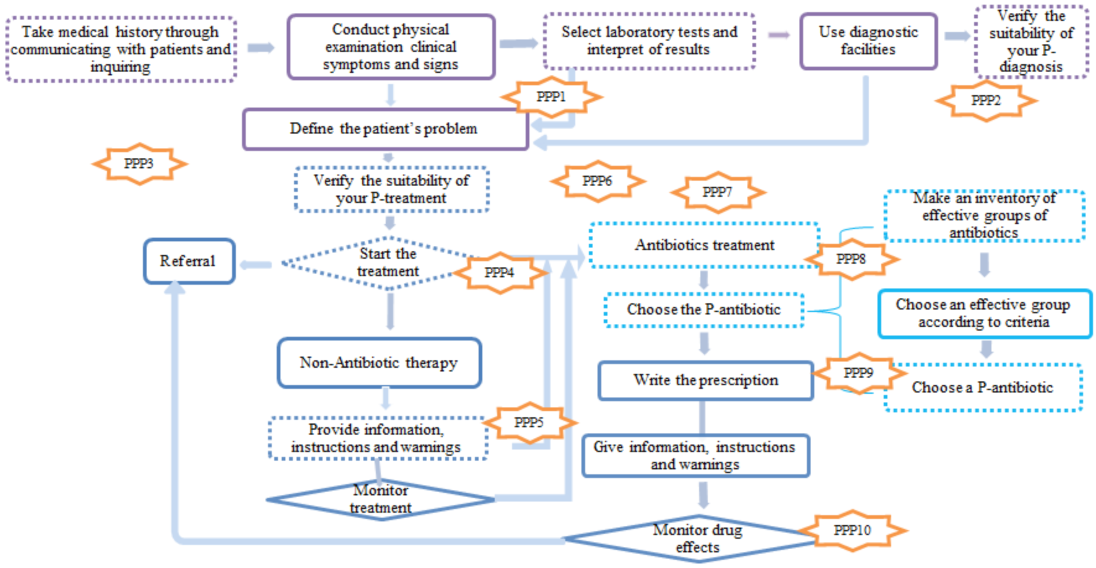

Figure 5.8 Physicians' aggregated personal paradigms for prescribing antibiotics described in Study IV (Zhu, Fors, and Smedberg 2018b)

The workflow for the possible problems can be explained as follows:

- *P-diagnosis:* With the exception of patients' medical history, clinical symptoms, and signs, the laboratory blood test results were reported as having the most influence on deciding whether to initiate treatment with antibiotics. However, physicians might not perform blood laboratory testing before prescribing antibiotics, and other laboratory tests were hardly ever reported (PPP1). Moreover, physicians felt that diagnosis was easy and even not important for the rational use of antibiotics (PPP2).
- *P-treatment:* Three treatments consisted of referral, no antibiotic therapy, or antibiotic treatment, based on the diagnosis and how the physicians defined the patients' problems. Although physicians realized the problem of misusing and overusing antibiotics and understood the importance of improving their competencies, antibiotics were still unnecessarily prescribed in three situations: They believed the patients had a bacterial infection without supporting laboratory results (PPP4), they sought to prevent infection in the absence of support from a guideline, and if the patients insisted on a prescription (PPP5).
- *P-prescription and P-drug:* With the exception of unnecessary antibiotics prescriptions, patients who were diagnosed with or monitored while having a bacterial infection were immediately prescribed intravenous infusion with antibiotics. However, only a limited variety of antibiotics are available in CHCSs, in addition to a lack of knowledge of local AMR patterns (PPP6) and drug sensitivity testing (PPP7). The physicians tended to use broad-spectrum antibiotics (PPP8) and expensive antibiotics if the patients could afford them (PPP9). They also reported stopping antibiotic treatment when clinical symptoms vanished (PPP10).

Table 5.1 Physicians and their personal paradigm issues

Participants	PPP1	PPP2	PPP3	PPP4	PPP5	PPP6	PPP7	PPP8	PPP9	PPP10
P1 Internist	X	X	X	X	X					
P2 Surgeon		X	X	X			X		X	
P3 Dentist	X		X					X		
P4 GP	X	X	X	X	X	X	X	X	X	
P5 Internist	X	X	X	X	X	X	X		X	
P6 CDM		X	X	X		X				
P7 Surgeon	X		X		x					
P8 CDM	X		X	X		X				
P9 GP	X	X	X	X		X	X		X	
P10 Pediatrician	X		X	X		X		X		
P11 Internist	X		X		X	X	X			X

CDM: Chronic disease management

III. Identify their LOs

Based on their personal paradigms, we identified 13 LOs according to the MARE framework (Zhu et al. 2015 p5-6). They are shown in Table 5.2.

Table 5.2 Personal paradigm issues related to LOs and abilities

Personal paradigm category	Personal paradigm problem (PPP)	Learning objective (LO)	Type of expected ability
P-diagnosis	PPP1	*1. Implementing microbiological and other investigations to diagnose*	Knowledge: Skill
	PPP2	*2. Maintaining patient respect in line with best practices, regulatory standards, and contractual requirements*	Action: Attitude
	PPP3	*3. Stating public health antibiotics' national guidelines*	Knowledge: Cognition
P-treatment		*4. Selecting and prescribing antibiotic therapy according to national/local practice guidelines*	Competence: Cognition
	PPP4	*5. Not initiating antibiotic treatment in the absence of a bacterial infection*	Competence: Attitude
	PPP5	*6. Mastering delayed antibiotics therapy and negotiation with the patient*	Performance: Skill
		7. Educating patients and their caregivers, nurses, and other supporting clinical staff	Action: Cognition
P-prescription and P-drug	PPP6	*8. Using local microbial-/antimicrobial-susceptibility patterns when conducting empiric treatments*	Competence: Cognition
	PPP7	*9. Understanding the importance of taking microbiological samples for a culture before starting antibiotic therapy*	Knowledge: Attitude
	PPP8	*10. Avoiding the unnecessary use of broad-spectrum antibiotics*	Competence: Attitude
	PPP9	*11. Working within an ethical code of conduct*	Performance: Attitude
		12. Applying legal and ethical frameworks affecting prescribing practice	Performance: Attitude
	PPP10	*13. Constructing the prescription for an antimicrobial with its pharmacokinetics and knowing how this affects the choice of dosage regimen*	Competence: Cognition

IV. Physicians' expectations for AR-based CPD were different with respect to learning assets, learning environments, and learning activities.

- *Learning assets:* The combination of different media and AR was expected to improve competence; 3D AR was expected to help physicians understand AMR, imagine the location of the infection, how best treat an infection with antibiotics, and help them explain it to the patient. Simple text- based information was expected to be used to describe new antibiotics, indications, and contraindications.
- *Learning environments:* Physicians expressed indifference with the respect to the learning environment. Affective-oriented environments and perception-oriented environments were suggested as being necessary. An affective-oriented environment was expected to include humor, making it interesting, attractive, and impressive, but the perception-oriented environment was expected to be used for simulating the infectious process. The symbol-oriented environment was expected to be combined with another environment or to be independent to fit physicians' reading habits. The behavior-oriented environment was not viewed as being of less use, as two physicians lamented the lack of hands-on skills, nor is it easy to use for practical hands-on skills. Only one physician said that it could be used for simulation and hoped we could develop the technology as soon as possible.
- *Learning activities:* Hardly any ideas about the learning activities voiced were related to AR; the suggested learning activities were derived from the physicians' current technology-based learning experiences. Thus, the main suggestions were learning through lectures by specialists combined with watching video recordings, collaborating, and sharing information with peers through social media, as well as searching for information online.

6 DISCUSSION

The aim of my doctoral research was to explore one way to improve medical CPD for primary care physicians in China and to study how AR can be designed to support this objective. This exploratory process went through practical inquiry, theory research, and then practical application and investigation. Thus, several aspects of practice and theory regarding AR-based design for learning were investigated. The implications for the design will be discussed in this chapter.

6.1 DISCUSSION OF MAIN FINDINGS

The transitional CPD method was criticized for delivering the content pre-specified by experts rather than for enhancing learning (Boud and Hager 2012; Oxman et al. 1995; Webster-Wright 2009). This critique of forgotten essential learning elements is also present when learning is supported by different technologies (Todd 2003). As discussed in the introduction of this thesis, to make effective use of technology to support in CPD, one needs a clear understanding of the learner, the learning method, and the technology's capabilities. LCD has been suggested for the design of an e-learning system to bridge the gap for learners to become experts (Henry et al. 2013; Quintana et al. 2006, 2000).

6.1.1 CPD Learning Needs in Chinese CHCSs

Although there are different individual learning needs in the setting of Chinese CHCSs, the general objective of improving clinical competence to become as qualified GPs was reported in Study I. This finding agrees with the finding in a systematic literature review of the development of CHCSs in China (Wang et al. 2015). Clinical competences were expected to be more integrated, especially the integrated competence of diagnosis and treatment by the physicians and managers in Study I. This expectation about integrated competence was emphasized in the Chinese national requirement for GP in-service training by and for GPs' core competencies in the EU (Allen et al. 2002; National Health and Family Planning Commission People's Republic of China 2010). The physicians participating in Study I suggested learning topics, such as new guidelines; new treatments, especially the rational use of medications; pre-hospital first-aid emergency; and chronic disease management. The variety of learning topics suggested must be reflected in a flexible learning design (Sanchez and Mahoney 1996).

Considering the integrated competences required and their suggested topics, a specific learning needs analysis applied to the rational use of antibiotics was further investigated in Study IV. The rational use of antibiotics is not only a problem in the setting of primary care delivery in China but is a well-documented globe challenge (Costelloe et al. 2010; Shallcross and Davies 2015; Yin et al. 2013). For example, unnecessarily treating acute respiratory tract infections with antibiotics is one of the major issues in primary care globally (Dempsey et al. 2014; Tonkin-Crine et al. 2011; Vazquez-Lago et al. 2012). The overuse and misuse of antibiotics in treating acute gastroenteritis might be a common problem in China (Hou et al.

2013), but it also was discovered in Austria and Switzerland (Bless et al. 2016; Zollner-Schwetz and Krause 2015). Two common diseases were mentioned by the physicians in Study IV. In this study, physicians were asked to freely express what common diseases they treat with antibiotics and how they treat the diseases with. The physicians reported that different diseases were treated with antibiotics; however, we focused on analyzing their personal paradigm relative to their decision-making process. Their P-diagnosis, P-treatment, P-prescription, and P-drug were analyzed by comparing the WHO guide as a standard of good prescription practice (de Vries et al. 1994). We found that physicians were not only unfamiliar with the current national guidelines and local AMR patterns but with many personal paradigm issues on the process of decision-making relative to their P-diagnosis, P-treatment, P-prescription, and P-drug. This decision-making issues were confirmed by the Icelandic study (Björnsdóttir, Hansen, and Bjornsdottir 2002). Moreover, we identified the LOs from their unfamiliar and personal paradigm issues by checked them within the MARE outcome layer, which listed the expected abilities of GPs for rational use of antibiotics in different levels as examples.

My analysis of specific learning needs was guided by the MARE framework, which we designed in Study III. We suggested analyzing the physicians' personal paradigms for prescribing antibiotics to identify the problems in the rational prescription process (Zhu et al. 2015). Although the physicians realized AMR's problem due to the misuse and overuse antibiotics, they blamed patients and other physicians while admitting that they needed to improve their competence. Assigning blame to others, including patients, was also found in a study of American primary care physicians (Dempsey et al. 2014). However, the physicians' personal paradigm (PPP) issues for prescribing antibiotics included their P-diagnosis, P-treatment, P-prescription, and P-drug, which have been found to be different with the good prescribing practices outlined by the WHO (de Vries et al. 1994). The PPP analysis revealed their intrinsic factors, which are also analyzed in other studies (Reynolds and McKee 2009; Rodrigues et al. 2013; Tonkin-Crine et al. 2011). In contrast to the learners described as novices or as having low expertise in the work domain by Quintana (Quintana et al. 2000), the physicians in our study are adults and have already established their clinical experience. Thus, the personal paradigm that we adapted from the frame of reference introduced by Mezirow (Mezirow 1997) and that is based on the guide to good prescribing behavior by the WHO (de Vries et al. 1994) is much more suitable as a tool with which to analyze their learning needs.

Due to the limited time and funding, we only further analyzed their learning needs from one of the topics suggested by the physicians and managers. The other topics that they suggested, including pre-hospital first-aid emergency and chronic disease management, are also important and need to be analyzed for further design. Pre-hospital first-aid emergency, which has been trained in some CHCSs, was expected to further learning by the physicians and could be developed in an AR-based learning environment. Several studies have discovered AR for training pre-hospital first-aid emergency (Hamza-Lup, Rolland, and Hughes 2005; Kalz et al. 2013). An AR based hands-only CPR training has been developed by the

American Heart Association in collaboration with Google (American Heart Association 2018). AR was suggested and designed for managing chronic disease but was not found to be used for learning this topic (Keogh, Rosser, and Eccleston 2010; McLaughlin, Matalenas, and Coleman 2018). It can be further analyzed and adapted to fit the Chinese physicians' learning needs.

6.1.2 AR-based CPD Acceptance and Expectation by Chinese Physicians

Health care professionals are expected to be able to use different technologies for improving the accessibility of CPD and increasing its effectiveness (Burrows 2003; Ducut and Fontelo 2008; MacWalter et al. 2016; Phillips et al. 2012). Effective, technology-based CPD needs to be well-designed before it is rushed to be adopted and not rely on traditional top-down development over bottom-up design (Hsu et al. 2013; Rowe et al. 2012). My investigation of acceptance of AR-based CPD and physician expectations fully embodied the perceptions of physicians in the design process (Studies I and IV). These investigations also fit the principle of participatory design in the field of technology-enhance learning. Participatory design requires involving all stakeholders, including learners, in the learning design with technology to ensure it meets their needs (Scanlon 2010). As discovered in Study I, there are several forms of CPD that did not meet the physicians' needs in Chinese CHCS settings.

AR-based CPD was accepted by the managers and most of the physicians who had a positive attitude toward it and perceived it as useful in Study I. Other studies have also shown that AR-based educational solutions were accepted by physicians or medical students (Nilsson and Johansson 2008; Yusoff et al. 2011). Acceptance of technology should be investigated in the early design stage to reduce the risk of rejection by users, not incur unnecessary costs of development, and extend the design flexibility (Davis 1993). Positive attitudes from managers as facilitators has also provided important support for effective CPD (Boudioni et al. 2007). Manager support was an important factor reported by the physicians who lacked opportunities to participate in in-service training for GP in study I.

In my Study IV, physicians' different expectations of AR-based CPD required the flexibility of design (Sanchez and Mahoney 1996). To meet physicians' needs and engage them, taking their expectations into consideration is necessary for design of AR-based CPD, which therefore increases the accreditation of CPD (Filipe et al. 2014). Different physicians' expectations for AR-based learning assets enriched our framework design in Study III, as we thought learning assets were related to learning content as well as to learners' media preferences. Except in the behavior-oriented environment, their expectations for learning environments partly confirmed our design in Study III, even though different physicians had different expectations. The rest of their reports, which we included in Study III, therefore became complementary. Although physicians provided few expectations for AR-based learning activities that were also based on their current learning experience with technology, they demonstrated their ability to master the technology used in current CPD. Moreover, they liked to use new technology.

Most of the physicians accepted AR-based CPD and expected to use it. They also shared interesting experiences in other kinds of ICT-based CPD, such as learning on social media, virtual community of practice, and searching online. This kind of ICT could be combined with AR-based CPD, and further research should be conducted on how to use the technology independently. For example, the physicians suggested that AR-based CPD could have a search function, such as a dictionary, which is another ICT tool. There are also AR applications that encourage users to share their experience (Clini et al. 2014; Kim et al. 2014).

6.1.3 AR Design Needs for Chinese Primary Care

We applied the MARE framework to analyze the AR design needs based on the learners' personal paradigms and expectations of using AR in Study IV. Through the distinguished personal paradigm issues in the physicians' clinical practices, their ignorance of existing knowledge, and their personal issues, a plentiful design context emerged. Their different learning needs and their different expectations of AR-based CPD require flexibility of design (Sanchez and Mahoney 1996). The LOs we found fit LCD with respect to the different design needs for learners, as they have different learning needs to continue to develop and grow as experts in their domain (Quintana et al. 2006). We then summarized the results and analysis of AR design needs to address design context, design tasks, tools, and interfaces, which suggested LCD (Quintana et al. 2000) as follows:

The design context is based on all of the personal paradigms for prescribing antibiotics by the physicians in Study IV, including physicians' PPPs and related LOs, which are located in the different decision-making processes of physicians.

Task design should support physicians in achieving LOs and modifying their PPPs in the design context. As we suggested in the MARE design framework, the AR function design should focus on learning activities, learning environments, and learning assets after identifying the LOs. Six of the LOs (LO2, LO5, LO9-LO12) are related to attitude, five concern cognition (LO3-LO4, LO7-LO8, LO13), and two are about skills (LO1, LO6). LCD should respect learners' expectations, although they might also be limited by their current experiences of technology. Thus, physicians' expectations and our suggestions in MARE could be combined, as they are all complementary to the design. For example, physicians' expectations of learning activities, such as observing demonstrations, which were suggested in the MARE framework in perceptually oriented environments, could be useful in addressing LO1 and LO6, in which appropriate skills for diagnosing and prescribing treatments are targeted. 2D/3D models of virus and bacteria-infected parts of the body could be displayed together with simulations of different therapeutic interventions. Real patient and local AMR patterns data could also be scanned into the system and used. This kind of application could even serve as a pedagogical tool for physicians when discussing treatment with patients, and it could be used for educating patients to achieve LO7.

According to the MARE framework, learning new attitudes and sharing values and feelings could be well supported in the affectively oriented learning environment. It is therefore suitable for achieving LO2, LO5, and LO9-12, which concern attitudes to rational therapeutic processes. The physicians mentioned storytelling, collaboration, and sharing with peers. Related to this is role-playing, which could be useful as a complementary learning activity. Supported by game-based AR and multiplayer AR, for example, the physicians could use real work situations and take on different roles (both as physicians and patients) to reflect values and attitudes. Ethical dilemmas in connection with choosing antibiotics could also be useful for reflection, specifically in addressing LO12 and LO13. The physicians also emphasized that affectively oriented learning environments should appeal to their sense of humor, which is something that needs to be explored and adapted in this context.

In symbolically oriented learning environments, physicians could learn new knowledge as well as be guided to think and learn. The learning activities in this environment could support high-level cognition objectives, such as LO4, LO7-LO8, and LO13. Rational discourse in symbolically oriented environments might also be useful for high-level attitudes, such as LO2, LO11, and LO12. LO3 might only need learning activities, such as lectures by experts and searching for information online, as the physicians suggested in our study. However, it was surprising to find that none of the physicians could state the current guidelines for prescribing antibiotics even if they reported they could search online. Although some learning activities that the physicians expected are usually performed with other types of technology than AR, it could be further investigated if they could benefit from using AR features. Through AR, objects and symbols could be added to the text description of the rational process, with special attention directed to certain steps, together with labels and close-up views with additional information required to perform the work. In addition, there is the possibility to have animations and videos added to text-based content showing how to practically proceed with examinations and tests, for example. To support self-reflection, physicians could be asked to log their experiences and thoughts about diagnosing and treating patients according to the rational therapeutic process. This self-reflection could also be valuable in addressing LO2, LO11, and LO12.

Physicians in our study did not expect behaviorally oriented environments to be beneficial for their practice, learning, and reflection on their practices. However, these are regarded as an important part of the MARE framework. Experimentation, multiple practices, and action reflecting could be valuable learning activities in this environment. The different real cases with certain goals for detection of deviations and for simulation could be integrated with the diagnosis and treatment process to practice their cognition and skills to achieve LOs, such as LO1-4, LO6-8, and LO13. The case simulation could use video, 3D or multimedia combined with the clinical environment. The physicians' decisions could be evaluated and mistakes corrected. Links could be provided to the correct answers, 2D/3D models of bacteria bursts, or a video of patients' reactions, for example.

The physicians' expectations of learning assets can help in choosing tools to build virtual environments. These virtual environments are to be combined with clinical environments elements when building AR applications. The clinical environment elements to select depend on the task and scaffolding to help modify the physicians' personal paradigms. The interface design should also respect the physicians' expectations of learning environments.

6.1.4 The Current Status of AR-Based Learning in Health Care Education

Effective design for learning requires understanding the capabilities of new technologies and how those capabilities can be used to enhance learning (Garrison and Zehra 2009). It is one of the learner-centered principles of using technology-enhanced learning design (Salinas 2008). Design was suggested to absorb existing design principles and technological innovations from current the knowledge base (Amiel and Reeves 2008; Hevner et al. 2004; Reeves 2006). As research of AR focused on CPD was scarce, we expanded it to all medical education. The current status of AR research in health care education related to research, technology, and learning has been summarized in Study II. Although we were not able to extract any effective learning design principles from the previously published studies of AR in health care education, Study II added value to AR in medical education, including evidence of the improved learning effect by using AR, new roles for technology-enhanced learning, the different benefits for learners when AR is used, and the acceptance by learners. It also provided evidence that AR has been broadly investigated, involved learners at all levels of health professional development with Dreyfus model, and used varied technical aspects in health care education. The results of Study II led us to design a framework (Study III) that is a significant contribution to the novelty and significance in DBR (Hevner et al. 2004).

6.1.5 The Theoretical Foundations of AR-Based CPD

Understand learning theories is a requirement when seeking to improve medical education and making effective use of new technologies (Kaufman and Mann 2010; Spector et al. 2014). It is also an important characteristic of DBR and LCD when designing for learning (Dolmans and Tigelaar 2012; Quintana et al. 2006). Hevner suggested that DBR should draw on theory and methodologies from the knowledge base (Hevner 2007). However, in Study II we found that 80 percent of the included papers lacked the support of learning theories. Situated learning, experiential learning, and transformative learning theories were all suggested as foundations of AR design for learning in Study III. These three learning theories provide different insights into the relationships between learning, practice, and environment, and they can all be used in medical education (Kaufman and Mann 2010).

We expected situated learning theory to be best suited for guiding AR-based CPD learning design, but it was found in only two papers included in Study II. One included paper claimed that situated learning theory was the foundation, but the aim of study was mainly for AR acceptance and not for the learning designing (Yusoff et al. 2011). Thus, it did not reference any design principles or learning effect. Another significant paper included in Study II used on-location learning where they referred to situated learning theory and other theories to discuss authentic learning environments as the foundation for AR learning design (Rosenbaum, Klopfer, and Perry 2007). Situated learning theory is viewed as an important foundation for AR learning design. One of the characteristics of AR is that it can provide physicians with authentic and situated experiences when combined with their nearby real-world environment (Johnson et al. 2016; Zhu et al. 2015). This characteristic is highlighted by situated learning theory, which pays attention to the dynamics of learners interacting with environments. Situated learning theory has influenced health care education as well as CPD in many ways (Kaufman and Mann 2010). It was used to provide theoretical foundation for virtual (online) communities mainly intended for sharing and translating knowledge (Henri and Pudelko 2003; Kaufman and Mann 2010). How situated learning theory could inform the design of AR-based learning was shown in Study III.

When they designed their new generation of AR-Outbreak @ The Institute, Rosenbaum et al. found that they needed to add authenticity and authentic learning environments to their computer-mediated simulations where participatory simulations lack of real situations and meaningful consequences (Rosenbaum et al. 2007). Experiential learning theory was used in guided design learning environments, especially design of VLEs (Holzer and Andruet 1995, 2000; Kaufman and Mann 2010). Experiential learning theory can support transformative different experiences, as the other characteristics of AR are enhanced by VLE. Thus, we suggested that AR learning design also needs to rely on experiential learning theory for support. However, we did not find it used in any included papers in Study II. We explained how it could be used when we designed the MARE framework in Study III.

Transformative learning was suggested to guide the third generation reform in health care education (Frenk et al. 2010). Kitchenham also recommended transformative learning theory for adults studying in technology-based learning environments (Kitchenham 2008). It adds value for AR-based CPD where physicians' behavior was often expected to be changed (Lundborg and Tamhankar 2014; White et al. 1985). However, no included papers in Study II were guided by transformative learning theory. We discussed using transformative learning theory as a guide for AR-based learning design in Study III. We also used the results of the personal paradigm adapted from the conception of a frame of reference in transformative learning theory to investigate the practical problems in Study IV.

6.1.6 The Theoretical Design Framework

Quintana et al. discussed using a design framework to guide LCD (Quintana et al. 2006). Designers usually use a design framework or a design model to guide learning design and instructional design in educational technology (MacLean and Scott 2011; Sharif and Cho 2015). A framework-guided design is used in medical education as well as in the information systems discipline (Dolmans and Tigelaar 2012; Hevner et al. 2004). As we were unable to find a design framework that can be used to guide AR-based learning design in my review of the current state of AR in medical education in Study II, I decided to design one, which can be used to guide future design for us as well as others. Thus, the MARE framework was the result of Study III.

The features of the MARE framework in Study III include components of design theory, design goals, methods, and situations of the AR-based learning design (Snyder 2009). The three theories I chose to use, as discussed in the section on theoretical foundation, meet the characteristics of AR and the learning needs of CPD of primary care physicians. These theories support decisions in learning environments and learning activities on the functional design of AR and how to apply AR-based CPD in primary care clinical settings. The contributions of the MARE framework to methods for AR-based learning design include the design process as well as the five components of structuring AR function: investigating the PPPs in the clinical environment, identifying LOs, building the AR-based learning environment, designing learning activities, and transforming the personal paradigms. Clarifying LOs in the outcome layer contributes to the overall goal. The outcome of integrated hierarchy frames, a combination of Miller's pyramid and Bloom's taxonomy, guide in defining the LOs and assessment from the knowledge level to the action level. Lim et al. suggested the same integrated typology in their review(Lim et al. 2007), however, they only focused on the cognitive domain and not the action level. The contributions of the MARE framework to situations are the theoretical distribution and practical application of MARE in a primary care setting for training physicians in the rational use of antibiotics in Studies III and IV. Views from both designers and learners can be used for further studies of situations. This framework also provides a guide for future research on how to best use AR in medical education (Scanlon 2010).

6.2 METHODOLOGICAL CONSIDERATIONS

To contribute to improving medical CPD and study how the design of AR can play an important part, DBR, an interdisciplinary mixed method including a multi-strategy design and different approaches, was used in my PhD exploratory research. The necessity of using DBR for research in education has been discussed from the perspectives of learning design, technology, and curriculum (Phillips, Edelson, and Kelly 2006). I took advantage of DBR as a progressive refinement (Collins et al. 2004) that includes design flexibility to achieve the aims of my research. An increasing use of DBR bridged the gap between research and practice in education and has also been suggested for use in medical education (Anderson and Shattuck 2012; Dolmans and Tigelaar 2012). DBR was been used to explore virtual reality in the field of dental hygiene education by Hanson in her PhD study (Hanson 2011). My DBR pattern is different from that used by Hanson because I wanted to exceed purely designing and testing particular interventions that otherwise limit the evidence of DBR methodology (Anderson and Shattuck 2012; Baumgartner et al. 2003). There is no solo design-based research paradigm. My PhD project was conducted in a multidisciplinary context. The methodology that I used combined the advantages and strengths of DBR in medical education, in educational technology, and in information systems. Even so, it still encounters some limitations within the time and resources for my PhD research as well as the advantages and disadvantages of any methodology.

6.2.1 The Strengths and Limitations of DBR Used

The Design-Based Research Collective has suggested that the value of DBR could contribute to and be measured in four areas: novel learning environments, learning theories, design knowledge, and capacity for educational innovation (Baumgartner et al. 2003). The strengths of my DBR exploratory research can be evaluated by these four measurements. First, exploring the possibilities of using AR for creating novel learning environments has been done throughout my PhD research. The interviews in primary care with managers (Study I) and physicians (Studies I and IV) investigated a practical application of AR in creating novel learning environments. The integrative review (Study II) provided the evidence that AR can be a useful technology in novel learning environments within the medical education domain. The MARE framework (Study IV) explored the possibilities of designing novel learning environments with AR.

Second, three learning theories, including situated learning, experiential learning, and transformative learning, have been suggested as foundations for learning design using AR, and they guided us in the design of the MARE framework (Study III). Although AR has been used in different health care education contexts, it has lacked support by learning theories and has also not been used in primary care (Study II). The design process described how to use learning theories to support design and how the design framework can be used in a primary care context.

Third, the MARE framework and the example application for improving the rational use of antibiotics by GPs, as described in Study III, provided a better understanding of design knowledge. The application of the MARE framework in a Chinese primary care setting described how it could work and linked the theory to an application, resulting in better understanding (Study IV).

Fourth, my ability to innovate has been stimulated through collaborating and interacting with different partners during my research. I believed my collaborators have also increased their capacity for innovation, as some of them have published papers on related topics. The physicians participating in this study have also shown abilities for innovation when exposed to AR-based CPD during my interviews (Studies I and IV).

DBR is a time-consuming methodology relying on iterations of progressive refinement dealing with uncontrolled variables (Collins et al. 2004). In their review paper, Anderson and Shattuck found most studies that used DBR methodology were not in their final stage (Anderson and Shattuck 2012). This is a limitation of a PhD research project because of restrictions of time, resources, and funding as well as personnel changes. Although this PhD project has resulted in the design of a framework applied to a Chinese primary care setting, much more research needs to be conducted, including developing prototypes of AR-based CPD to meet the design needs and solve the different problems of physicians' personal paradigms and their expectations for AR-based CPD, applying AR prototypes and refining them in Chinese primary care settings and evaluating the learning effects, comparing the effectiveness of different learning activities in the same learning environment to improve the design principle, and using the MARE framework in other clinical settings to validate, modify, and improve it.

6.2.2 Quality of DBR

DBR has been found increasingly utilized in education research, especially with technological interventions (Anderson and Shattuck 2012). As design science often deliberates artificial things in terms of imperatives and descriptives that are different from the natural science (Simon 1996), DBR has an inherent risk to be precise (Fishman et al. 2004; Shavelson et al. 2003). Reeves called on DBR researchers to pay attention to a desirable balance between rigor and relevance (Reeves 2011). Kelly suggested that DBR was exploratory and ambitious by comparing the confirmatory and conservative from randomized field trials(Kelly 2006). McKenney and Reeves suggested several important issues, including the balance of information richness and efficiency, optimizing processes, impact, and generalizability to address inherent challenges of DBR (McKenney and Reeves 2013). We used these issues to improve the DBR quality in this study and discuss them as follows:

I. Information richness, efficiency, and optimizing processes

As discussed previously, DBR is a time-consuming methodology. Thus, we need to balance information richness and efficiency to optimize the process. The overall aim of my study is to explore a way to improve health care professional CPD, in particular to discover how AR could play an important part in the design. We should gather rich information of AR for health care education in practice needs and theory support. Based on the findings of practice from a needs and context analysis in China (Study I) together with a clarified problem of AR being used in health care education (Study II), the design framework was developed (Study III) and applied to identify the design needs in China (Study IV). The methodology of each study and data collection depended on the aim of each study to maintain efficiency. The adapted DBR framework stacked the four small studies together in practice, design, and theory to provide a holistic view of the whole study. The four small studies have been independently presented to inner collaborators and external audiences who accepted the emerging insights for each, which have fostering my reflection of each study and the overall design. The process of communicating was difficult, especially from different research areas; however, reflection improves design processes. I also found, from my experiences, that a stable DBR team is important for optimizing processes.

The independent findings of the four studies that have been published help maintain the balance between rigor and relevance (Reeves 2011). Of the different methodologies used in the four studies of DBR, the triangulation design mixed approach was rigorous (Robson and McCartan 2016). Triangulation was considered to enhance the credibility and confirmability of a qualitative study (Shenton 2004). The triangulation method has been used in different subjects, including education and primary health care, to provide delineation or explain the complexity of social phenomenon from more than one standpoint (Turner and Turner 1970). The triangulation method is suggested as suitable when the debatable value of education needs to be estimated more fully (Cohen, Manion, and Morrison 2000). Seven types of triangulation—data, investigators, theories, methods, time, space, and level (Cameron 2013)—were used in this DBR study: 1) A variety of data sources from mangers, physicians, research papers, government reports, and websites provided data triangulation; 2) Although I am the primary investigator, my supervisors and other collaborators were involved in the different stages of this DBR study, providing investigator triangulation; 3) Three learning theories were suggested in Study III, which provided multiple perspectives for AR learning design and triangulation of theories; 4) Method triangulation included face-to-face interview, integrative reviews, and conceptual framework analyses; 5) Time intervals between interviews was eighteen months, providing time triangulation; 6) Interviews took place at four CHCSs, and the whole study crossed practice and theory sectional design, providing space triangulation; 7) Level triangulation was found in individuals (physicians, managers, and researchers), groups (CHCSs, the research team), and organizations (the research community of AR in health care education).

II. Impact and Generalizability

The impact and generalizability of the DBR results are considered important for scientific inquiry and have been discussed as challenges of current DBR in education (Anderson and Shattuck 2012; McKenney and Reeves 2013). We adapted the DBR framework to deal with this challenge in our study. Because our research on DBR seeks to impact practice and theory of health care education toward wider acceptance (McKenney and Reeves 2013) and improvement of methodologies, we consider practice needs, design artifacts, and supporting theories to have equal importance for the adapted DBR framework. The practice findings in Study I and Study IV are based on the investigated learning needs of physicians in four CHCSs in Wuhan, China, and they are not representative of all primary care settings and for all GP groups. However, they could be understood by audiences though the context that we have described in each study and the introduction of this thesis. They might be translated into the same situation. Moreover, Study II provides a general understanding of AR being used in health care education where a theory framework is needed for guiding better design. The design framework in Study III could inform the work of others in different AR design situations in health care education, and it could be refined and evaluated by others. Further, the use of conceptual frameworks by medical education researchers has been increasing (Teunissen 2016). DBR in education *focusing on the design and testing of a significant intervention* (Anderson and Shattuck 2012, p16) could be extended to different kinds of design (Ørngreen 2015). Kelly mentioned that DBR was experimental in generating and cultivating the hypothesis (Kelly 2006).

Kelly also mentioned that the satisfaction of internal validity was not the central value of DBR but should be established over time (Kelly 2006). We provide only limited validity of six different types of validities suggested by Reeves (Reeves 2011). Face validity could be shown in Studies I, II, and IV. Mangers and most physicians showed interest in AR-based CPD from the example we provided in Study I, and physicians provided more information about how it could be used for their CPD in Study IV. Study II showed the face validity from the wide range of domains being interested in AR for health care education. Moreover, it was evaluated or shown in three papers (Botden et al. 2008; Nilsson and Johansson 2008; Yusoff et al. 2011). Content validity was established during Studies I, III, and IV. Study I focused on the learning needs of Chinese physicians by providing appropriate content and its breadth for design. Objective identification, which was created in Study III and tested and discovered in Study IV, further validated the content for design. Learning validity was been found in Study II and supported by Study III. In Study II, 96 percent of papers claimed AR could improve learning in health care education. The MARE framework provides scientific learning theories that afford sufficient opportunities for learning activities and environments to support learning in Study III. Learning validity could be ensured if the design fit the learning needs and design needs of the physicians in Studies I and IV. We need to continuing evaluate learning validity when we develop and apply our own AR application to a practice setting. We did not seek curriculum validity, as CPD is different from tradition, formal courseware. It could be settled based on physicians' suggestions of other kinds of ICT tools in Study IV. AR might provide good predictive validity, too, as it is easy transferring learning to performance in the real world. However, we did not do this because our project is in the early design stage, and we did not find it evaluated in any of our papers included in Study II; most included studies were prototypes. We did not evaluate the construct validity in our design process because we did not distinguish novices from experts.

6.2.3 The Strengths and Limitations of Each Method Used

To meet the research goals and answer the research questions, I have used multi-strategy designs and different approaches at different research stages. A qualitative approach was used to investigate the needs of CPD for a group of physicians in a Chinese primary care setting and the possibility of using AR as a component (Study I) for identifying AR design needs (Study IV). An integrative review was used to identify the possibility of learning design principles and technology innovation of AR-based CPD models through understanding the current state of AR used in health care education (Study II). A CFAM, driven by learning theories, was used to design the MARE framework (Study III).

A qualitative approach is an important method of inquiry in education to understand a frequently complicated situation (Marshall and Rossman 2006). Qualitative and quantitative approaches offer a balance beyond the strong theoretical inquiries in the field of instructional design and technology (West and Borup 2014). Qualitative approaches have increased in health-related research, where research paradigms with positivism and post-positivism have traditionally been overly emphasized quantitative methods (Guba and Lincoln 1997; Rodrigues et al. 2013). Qualitative research has been suggested for use at the beginning of education interventions (Lundborg 1999). Interviews using a qualitative approach are useful in understanding the meaning of learning experiences from physicians' points of view and to clarify their clinical environment (Steinar and Brinkmann 1999). As discussed in the section on main findings, the two rounds of interviews (Studies I and IV) provided us with a deep understanding of the physicians' needs, acceptances, and expectations for AR-based CPD. The general learning needs for CPD and the acceptances of AR did not change over the two interviews in Study I. Moreover, the progressively refined interviews (Study IV) provided a deeper understanding of physicians' needs and expectations for design. The result of interviews in Study IV also provided evidence of evaluation for the MARE framework (Study III) in the field study (Hevner et al. 2004). Even so, there are still limitations to these two studies. First, it took a long time to collect and analyze the data of Study I to provide a comprehensive analysis to be used for design until Study IV, which added more details on specific learning needs thereby prolonging the design cycle. Second, we focused on a few primary care providers in a single city. Thus, the data lacked the views of primary care providers in other cities and rural China. Third, even though we interviewed managers whose supporting is important in Study I, it might be interesting to also interview patients, who are an important external factor, as reported in Study IV. Moreover, physician teachers were not interviewed, as there are few teachers for GPs in this environment. Last, the results might have been influenced by the convenience sampling and snowball sampling strategies used in these two studies (Marshall and Rossman 2006).

A growing body of articles has published support for evidence-based decision-making in health care, while other types of reviews might lack a formal quality assessment (Grant and Booth 2009). Systematic reviews have been used to produce clinical guidelines and evaluate the effect of interventions in medical education (Cook and West 2012; Haig and Dozier 2003; National Health and Medical Research Council (NHMRC) 1999). The result of systematic reviews depended on the measurement points chosen by the researcher, and this kind of review was not intended to describe the conceptual, theoretical frameworks important for guiding the design (Ringsted et al. 2011). An integrative review is similar to the research process of a systematic review but allows the researcher to include various research designs (Whittemore and Knafl 2005). Because of this, an integrative review is better suited to more fully understand AR in health care education (Study II). It has also been used to understand the factors and evaluation of instruments for CLE in health care education (Hooven 2014; Jessee 2016). Despite several published reviews of AR, including one overview, two literature reviews, and two systematic reviews (Al-Issa, Holger, and Hale 2012; Botden and Jakimowicz 2009; Carmigniani and Furht 2011; Sherstyuk et al. 2011), none provide the comprehensive evidence for its use in health care education as we did in our integrative review, the first integrative review in health care education. However, our study does suffer from some limitations. First, this study prolonged the design cycle because we did not find useful design principles that can guide us in the design. Instead, we revealed the necessity to design a framework. Second, there is a risk that studies might have been missed because of inherent restrictions on time, language, and research papers. Last, AR technology has continued to develop after we published our study, allowing applications built for wearable technologies and smartphones to now utilize AR.

Design models and frameworks to guide effective use of technology are an important work in the field of educational technology (West and Borup 2014), and it is one of the requirements of DBR (Baumgartner et al. 2003). CFAM is a multidisciplinary research approach (Jabareen 2011, 2009), which has been used to design conceptual frameworks in different discipline, including health care, education, and work/practice research (Chidzambwa 2013; Darojat

2013; Jabareen 2011; Vashist, Mckay, and Marshall 2011). CFAM adds scientific value to theoretical inquiry in educational technology when the research quality is adequate for descripting the instructional design of products, processes, or systems (West and Borup 2014). Using CFAM was useful for invoking critical thinking when designing the MARE framework during the iterative processes in Study III. Moreover, the case study was used to evaluate the MARE framework as well as provide a deep understanding how the framework could be used to guide design of AR-based CPD in a primary care setting. Our MARE framework was created through theoretical inquiry with CFAM, we showed how it could be applied to our case study, and it worked well to guide us in analyzing interview data in Study IV. It needs further testing with different evaluation methods, such as architecture analysis and experiment, and more field study to refine and improve it (Hevner et al. 2004). Further, it needs interdisciplinary application and evaluation from experts interested in AR-based learning, such as instructional designers, AR developers, medical educators, and ICT specialists.

6.3 REFLECTIONS AND IMPLICATIONS

In this thesis, I have explored AR-based CPD in practice and theory using DBR. I have reflected on the research process, results, and implications in different areas at different levels as applied to design, education, primary care, understanding of physicians' personal paradigm for therapeutic processes, and society. Further discussion follows:

Implications for design: My PhD research has explored how to design AR-based CPD for Chinese primary care physicians. The most important contribution is that we have designed the MARE framework and applied it to analyze the problems of physicians' personal paradigms as well as to understand physicians' expectations of AR-based CPD in a Chinese primary care setting. The MARE framework added the design method, goal description, theory foundation, and the framework itself to the knowledge base for design (Hevner 2007). Designers can use the MARE framework to guide them in designing their own AR-based education applications by using the design method and the underlying supporting theory. Designers can use our findings as a design context and be guided by the MARE function structure to design AR-based CPD. The revising the personal paradigm for rational therapeutic processes in the MARE framework provides a scaffold for learner-centered design as well as a method for analyzing the physicians' PPP issues. We found that AR-based CPD was accepted by most primary care providers, while the current CPD did not meet their needs. These results have been confirmed by other studies with respect to learner acceptance by different categories of health professionals in our integrative review. The high user acceptance can inspire designers to better design AR to meet the needs of their learners. The integrative review we conducted in the second study provided a conclusive use of AR in health care education. The results showed the characteristics of AR in health care education; how the strengths and weakness can help designers during research design and learning design, as well as how to avoid design weaknesses when creating AR-based education applications.

Implications for education: My PhD research has explored different educational aspects of theory and practice with respect to AR. The learning design process we proposed is suited for build bridges between these different aspects. In practice, we explored learning needs in general and special as well as views on AR in particular from Chinese primary care physicians on their acceptance of and expectations for AR-based CPD. Our results document real-world educational needs for AR-based CPD. Although there are numerous theories about learning and education, we found that almost all previously published studies did not rely on a theoretical foundation as reported in Study II. Developers of AR and health care practitioners might not be fully cognizant of suitable learning theories when they develop AR-based educational interventions. The three learning theories we suggested benefit users and help improve design and development of AR-based education. Further, these three learning theories also helped us better understand how AR-based learning activities and learning environments should be designed so as to enrich educational experiences when applied to learning environments using novel technologies. We demonstrated that Chinese primary care physicians expected AR-based CPD to provide better learning environments, not only in theory but in practice. The learning assets for AR suggested by physicians cannot only be used for building learning environments but also for meeting their needs when designing education interventions. Hierarchical frames across knowledge, competence, and performance all the way to action in the MARE framework provide a practical approach for describing educational LOs. It has helped us analyze personal paradigm issues of Chinese primary physicians prescribing antibiotics and formulate specific learning objective for the design of AR-based CPD. It can also be used in other educational contexts by educators who need to design educational interventions.

Implications for primary care: In my research, I have explored alternative CPD solutions for Chinese primary care physicians where AR could be an important component. To prepare this journey of exploration, I conducted some preparatory work starting with government requirements for patient surveys, which I did not include in this thesis. In-service training of GPs is required in the latest Chinese primary care reform. The patient surveys revealed to me that improving the competence of Chinese physicians is important in attracting patient visits to primary care, as only nine percent of patients who chose CHCSs as the primary point-of-contact viewed the competence of physicians as good. Improving the integrated clinical competence of physicians becoming GPs was ranked as important by physicians and their managers as well as the Chinese government, although the current CPD model does not focus on these expectations. We developed the MARE framework to guide the design of AR-based CPD for primary care and demonstrated it by using the case of the rational use antibiotics by GPs to show how AR-based CPD can be used in primary care. The personal paradigm for a rational therapeutic process, which we developed in Study III, can be used to analyze real-world aspects, as we did in a Chinese primary care setting in Study IV to further explore integrated clinical competence. Our interviews in a Chinese primary care setting show the practical design needs of AR-based CPD based on the physicians' meaningful expectations and ideas for the AR design to eliminate the issues related to their decision-making when their personal paradigms may result in improvements in the delivery of primary care. The problems we found in a Chinese primary care setting provide an AR-based CPD design context for Chinese physicians. We proposed how this can be applied to GPs learning in different environments using AR in Study III. We also considered Chinese physicians' meaningful expectations about learning environments, learning assets, and learning activities and proposed how to design AR-based CPD to meet their needs and help them in the goal of rationally using antibiotics in Study IV. We welcome other researchers interested in addressing the ability of physicians to rationally use antibiotics and who can apply this to physician problems with designing solutions utilizing AR or other novel technologies. We hope that addressing the issues of physicians' personal paradigms with respect to prescribing antibiotics will contribute to reducing incidents of AMR in the world.

Implications for society: This PhD project attempts to make a contribution to several important areas in society. The implications for design may result in the design of more useful AR products. Improving education through learning design is another benefit to society. Primary care physicians in most societies are gatekeepers in the health care sector. Improving their competence will, hopefully, lead to a reduction in the incidence of AMR improved global health equality.

7 CONCLUSION AND FUTURE STUDY

In my research, I explored learning design for CPD utilizing AR in a Chinese primary care setting and theory. The results showed that AR-based CPD is accepted by most of our interviewees and that primary care physicians expressed a high level of interest. Our development of the MARE framework supported by learning theories to guide AR-based CPD design is important because current use of AR in medical education lacks theoretical support. The MARE framework provides a holistic view of AR-based CPD learning design while relying on primary concepts, such as learner personal paradigms, LOs, and learning activities and environments and how they are related to each other. I applied this to the use-case of training GPs in the rational use of antibiotics and analyzed the AR design needs among Chinese primary care physicians, and found different issues with their personal paradigms with respect to prescribing antibiotics. Different physicians also had varied expectations of AR-based CPD with respect to the learning environments, learning assets, and learning activities. Thus, the main concepts of AR-based CPD learning design were not only supported by the theory, they were expected by the physicians.

I would like to see novel, prototype, educational solutions based on our findings to best meet physicians' expectations. The problems of personal paradigms require good design contexts that respect the expectations of physicians and are guided by the MARE framework. The physicians' different expectations provide the design flexibility of AR-based CPD to be able to modify their personal paradigms.

In our study, physicians suggested different educational topics that could be addressed in AR-based CPD, although we focused on their personal paradigms of prescribing antibiotics. How to design for learning other topics could be further analyzed by using our MARE framework. Physicians were also shown to be experienced in using other kinds of ICT for their CPD. Research on ICT-based CPD needs to continue to further increase our knowledge of how and when to use it effectively.

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