# SMART MOBILE AUGMENTED REALITY FOR ORTHODONTICS TEACHING AND LEARNING ENVIRONMENT

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# SMART MOBILE AUGMENTED REALITY FOR ORTHODONTICS TEACHING AND LEARNING ENVIRONMENT

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| 4IR | $4^{th}$ Industrial Revolution |
| CAL | Computer-Assisted Learning |
| SBLi | Scenario-Based Learning interactive |
| 2D | Two-Dimensional |
| SLE | Smart Learning Environment |
| MAR | Mobile Augmented Reality |
| SmARTLE | Smart Autonomously Rendering Teaching and Learning Environment |
| AR | Augmented Reality |
| e-Delphi | electronic-Delphi |
| MAR-ORTHO-EDU | Mobile Augmented Reality Orthodontic Education |
| CAI | Computer-Assisted Instruction |
| CBL | Computer-Based Learning |
| PBL | Problem-Based Learning |
| SBL | Simulation-Based Learning |
| DP | Deliberate Practice |
| CBI | Computer-Based Instruction |
| ODET | Orthodontic Electronic Tutorial |
| VLE | Virtual Learning Environment |
| 3D | Three-Dimensional |
| CT | Computed Tomography |
| e-Learning | Electronic-Learning |
| u-Learning | Ubiquitous-Learning |
| MEST | Ministry of Education, Science and Technology |
| ICT | Information and Communication Technology |
| AI | Artificial Intelligence |
| QR | Quick Response |
| SUS | System Usability Scale |

| | |
|---|---|
| IMMS | Instructional Materials Motivation Survey |
| VARK | Visual, Aural, Read/Write and Kinaesthetic |
| PLE | Personal Learning Environments |
| GPS | Global positioning system |
| DAG | Directed Acyclic Graph |
| GB | Giga Bytes |
| GUI | Graphical User Interface |
| SQL | Structured Query Language |
| ASP | Active Server Page |
| JS | JavaScript |
| CSS | Cascading Style Sheets |
| HTML | Hypertext Markup Language |
| ARCS | Attention, Relevance, Confidence, and Satisfaction |
| NGT | Nominal Group Technique |
| IOTN | Index of Orthodontic Treatment Need |
| PAR | Peer Assessment Rating |

## LIST OF SYMBOLS

| | |
|---|---|
| % | Percentage |
| SD | Standard Deviation |
| $\lambda$ | lambda |

# REALITI TERIMBUH BERGERAK BAGI PERSEKITARAN PINTAR PENGAJARAN DAN PEMBELAJARAN ORTODONTIK

## ABSTRAK

Pendidikan ortodontik, yang kini menggunakan pendekatan didaktik dan perantisan, menjadi asas kuat pengajaran guru. Pendekatan ini menghadapi banyak cabaran pedagogi yang mempengaruhi penyampaian pengetahuan dan secara tidak langsung kemahiran yang diperolehi pelajar. Kaedah pengajaran mempengaruhi pelajar di pelbagai peringkat yang membawa kepada pemahaman yang tidak berkesan terhadap prinsip asas dan teknik sains ortodontik. Pendidikan ortodontik yang tidak mempunyai teknologi yang menyokong persekitaran pembelajaran telah mengakibatkan persekitaran yang tidak mencukupi untuk pelajar ortodontik. Untuk mengatasi cabaran ini, kajian ini menggunakan teknik pengumpulan konsensus (e-Delphi) untuk mendapatkan pendapat pakar mengenai cabaran yang dihadapi dalam pendidikan ortodontik dan keperluan untuk persekitaran pembelajaran yang pintar. Setelah ianya dikenal pasti dan diperkuat oleh para pakar, rangka kerja konseptual telah direka bentuk dan dibangunkan. Reka bentuk dan pembangunan melibatkan penggunaan 16 komponen berdasarkan asas teori konstruktivisme, kelakuan dan konektivisme termasuk prinsip reka bentuk pengajaran Gagne. Berikutan perkembangan itu, aplikasi (SmARTLE dan MAR-ORTHO-EDU) menjalani ujian kebolehgunaan untuk menilai kebolehgunaan yang dilihat dari pelbagai kumpulan pakar teknikal, pakar ortodontik dan pelajar pergigian. Skor kebolehgunaan purata bagi kedua-dua aplikasi (SmARTLE = 71.19 dan MAR-ORTHO-EDU = 71.72)

adalah dalam julat yang baik hingga cemerlang. Setelah pengujian kebolehgunaan selesai, aplikasi telah menjalani penilaian motivasi untuk menilai sebarang perbezaan tahap motivasi purata antara aplikasi tradisional dan yang dibangunkan. Tahap motivasi yang dinilai melalui kajian motivasi bahan pengajaran dan empat komponen sub perhatian, kaitan, kepercayaan dan kepuasannya menyaksikan skor purata yang signifikan secara statistik (3.66; $p$-nilai $<0.001$) untuk skor motivasi keseluruhan dan empat sub komponen. Ini menunjukkan bahawa aplikasi mempengaruhi perubahan tahap motivasi pelajar. Oleh itu, kajian ini menekankan pentingnya penggunaan persekitaran pembelajaran pintar dan keperluan untuk mempunyai SmARTLE dan MAR-ORTHO-EDU sebagai sebahagian daripada pengajaran dan pembelajaran dalam pendidikan ortodontik untuk menyokong pembelajaran berasaskan diri (heutagogy), pembelajaran berorientasikan peer (paragogy) dan pembelajaran berasaskan maya (cybergogy).

**SMART MOBILE AUGMENTED REALITY FOR ORTHODONTICS TEACHING AND LEARNING ENVIRONMENT**

## ABSTRACT

Orthodontic education, which currently employs a didactic and apprenticeship approach has been a stronghold of teacher-centric instruction. This approach is facing numerous pedagogical challenges that affect the knowledge delivery and indirectly the skill gain of students. The teaching methods affect the students at various levels leading to ineffective comprehension of underlying principles and techniques of orthodontic science. The orthodontic education which lacks a technology supported learning environment has resulted in a deficient environment for orthodontic students. To overcome these challenges, the study utilised a consensus gathering technique (e-Delphi) to seek expert opinions on the challenges facing orthodontic education and need for a smart learning environment. Once these were identified and reinforced by the experts, a conceptual framework was designed and developed. The design and development involved the use of 16 components based on the theoretical foundations of constructivism, behaviourism and connectivism including Gagne's instructional design principles. Following the development, the applications (SmARTLE and MAR-ORTHO-EDU) underwent usability testing to evaluate the perceived usability from various groups of IT technical experts, orthodontic experts and dental students. The mean usability scores for both the applications (SmARTLE = 71.19 and MAR-ORTHO-EDU = 71.72) were in the range of good to excellent. Once the usability testing was completed, the

applications underwent an evaluation of motivation to assess any difference in mean motivation levels between traditional and the developed applications. The motivation levels assessed through instructional materials motivation survey and its four sub-components of attention, relevance, confidence and satisfaction saw a statistically significant mean scores (3.66; $p$-value $<0.001$) for the total motivation score and the four sub-components. This indicated that the applications affected changes in motivation levels of students. Therefore, the study has highlighted the importance of using smart learning environment and the need to have SmARTLE and MAR-ORTHO-EDU as part of teaching and learning in orthodontic education to support self-based learning (heutagogy), peer-oriented learning (paragogy) and virtual-based learning (cybergogy).

# CHAPTER 1

# INTRODUCTION

## 1.0 Introduction

This chapter introduces the research undertaken in the field of orthodontic education and will provide in a brief the background of the study, problem statement, research question, research objectives, research hypothesis, significance of the study and thesis overview.

## 1.1 Background of the Study

### 1.1.1 Overview of Malaysian Higher Education

The Higher Education sector of Malaysia has been constantly redesigned has for the past 5 years to reflect the nation's commitment in achieving a developed nation status in the coming years which is aligned with the United Nations sustainable development goals (Sustainable Development Goals Voluntary National Review, 2017). Malaysia has been focussing on achieving this status through transformation and changes in Higher Education policy and the establishment of the 11th Malaysia Plan as well as Higher Education executive summary (Malaysia Education Blueprint 2015-2025) envisaged through 10 shifts in the Higher Education sector. The plan aims to support student learning experiences and talent excellence and create a nation of lifelong learners. It also emphasizes on creating an innovation ecosystem to support globalised online learning and development of massive open online courses thereby transforming higher education delivery in Malaysia. In addition to these initiatives, in 2017, the Malaysian Government embarked on the mission of integrating 4th Industrial Revolution (4IR) with the education sector and facilitate changes in curriculum design through support mechanisms for flexible learning pathways (Ainur, 2018). The Higher Education sector has also seen measures initiated in 2018 with the launch of "Higher Education 4.0: Knowledge, Industry and Humanity" which has called for revamping the Malaysian higher education system with 4IR whereby converging the man and machine (Brahim & Dahlan, 2018). The Higher Education 4.0 further stresses on the interplay of interactive and immersive technology with Higher Education and its effect on the current methods of teaching and learning.

Although the road map has been created for inclusion of technology supported learning in higher education, the level of implementation is limited in the health professionals' education but for a few applications created to simulate clinical training. Most of the training applies the didactic formats with very little scope for implementation of educational technology. A growing concern on the implementation of technology assisted learning initiatives is due to the non-comprehension of technological terms and their working environments. The non-proficiency in understanding these affordances is what prevents the development of technology supported learning resources (Rao et al. 2019). This is evident even in a specialised field as orthodontics, where the technology has played a huge role in clinical aspects but is poorly utilised in the educational spheres. The lack of realisation of a smart learning environment in orthodontic education has been understated. The learning benefits offered by these blended learning approaches must be recognised and guidelines established for supporting ubiquitous, personalised and persuasive learning environments in orthodontic education. With this background, the next section will introduce orthodontic education and the technologies used in orthodontic education to reflect on the current scenario of this clinical and educational field.

### 1.1.2 Health Professionals Education

The education comprising various fields of medicine, nursing, dentistry, pharmacy, physiotherapy and other traditional medicines form the spectrum of health professional's education. These fields have their pedagogies set in strong apprenticeships leading to hierarchy in training and learning. The same is true for dentistry where in the student learns the principles of diagnosis and treatment planning through the eyes of an apprentice. The dental education though has for years held strong pedagogically sound approaches are yet limited to delivery of content. This is reflected greatly in the absence of a mechanism for rendering teaching and learning at various levels of undergraduate and post graduate education. This general lack is what has kindled the field of orthodontic education to embrace advances in technology for delivering pedagogically sound methods. However, the current methods have shown to be greatly hindered and limited in their reach and utilisation. With this background, the next section will introduce how the educational aspects of orthodontics are conducted currently.

### 1.1.3 Orthodontic Education

Orthodontic education is an ever-changing dental speciality with evidence-based changes in techniques and treatment planning. The delivery of orthodontic training and education has been through a combination of didactic teaching and an apprenticeship to learn clinical skills (Derringer, 2005; Will, 2015). The learning occurs in several phases. The theoretical learning incorporates large group lectures and small group tutorials. The students receive structured information based on the pre-established curriculum. The theoretical learning emphasises on memorising factual information and recall. The learning happens in various stages and can be represented in steps described by Moayedi and Torres (2012). These steps although not specific to orthodontic training are however a process for learning a procedure in medical specialities which have a close resemblance to orthodontic procedural training. Each step bears a close connection to the principles utilised in orthodontic training and hence will be discussed in detail.

Step 1: Conceptualisation: This is achieved by the memorisation of factual data and recall. The students are expected to be able to relate previous theoretical knowledge and find correlations with the new knowledge being taught. This learning closely follows the principle of the zone of proximal development wherein new knowledge is constructed on existing knowledge.

Step 2: Visualisation: This form of learning is achieved through demonstrations of procedural tasks and observational learning (Mnguni, 2014). The tasks performed by the educator is observed, developing a mental image of the concept and technique. The cognition hugely depends on the student's ability to decipher the relationships of the procedure with theoretical knowledge or previous knowledge. The demonstration approach requires clear communication as the knowledge is implied and not straight forward (Alqahtani et al., 2015).

Step 3: Verbalisation: This step entails an apprenticeship approach wherein the educator uses multiple modes of communication to teach a procedure or task. The students follow or repeat the procedure building from their experiences and previous knowledge. This step, in addition to step 2 follows the cognitive apprenticeship principle of constructivism. This stage also requires effective feedback from the educator. The feedback both positive and negative have implications on student learning. The clinical setting demands feedback on several levels. Mager (1997) have provided an understanding of different feedbacks by classifying it into adequacy, diagnostic or corrective. Following feedback, the next stage a student undergoes is an assessment of their gained skill. The current trends in orthodontic training follow assessment driven learning which does very little towards skill development and active learning (Fugill, 2005).

Step 4: Guided practice: Building on the earlier knowledge gained through steps 1, 2 and 3, the student is now able to perform the procedure in a simulated environment. The learning happens with constant support from the educator under close supervision. This step supports both collaborative learning and reflectivity. The complexities or challenges of a procedural task can create collaborations amongst students and help device new solutions. The ability to reflect on such scenarios and adapt them to others makes learning a rich experience. The procedural knowledge thus gained is further reinforced through deliberate practice to gain competency and mastery. A deliberate practice which is characterised by attention, concentration, effort and repetition of skills until a competent level is reached enables students to gain an insight on their strengths and weaknesses thereby facilitating procedural cognition (McGaghie et al., 2015).

The orthodontic clinical skills encompass communication skills, history-taking, professional attitudes, awareness of ethical basis of healthcare, physical examination, procedural skills, clinical laboratory skills, diagnostic skills, therapeutic skills, critical thinking, clinical reasoning, problem solving, team-work, organization skills, management skills, and information technology skills (O'Brien & Spencer, 2015).

These skills are developed over the learning years of a student with several learning events overlapping each other. The skills are further enriched through a multitude of modalities.

The above skills which are an absolute requirement are generally transferred through an apprenticeship approach in which the knowledge exchange remains hugely didactic and controlled (Chadwick et al. 2002). The apprenticeship followed in orthodontic education closely follows observational and simulation-based learning, where students learn through observation of procedural task demonstrations (Darnis & Lafont, 2015; Chris et al., 2017;). Practical exercises are demonstrated by a tutor, and subsequently the tasks are repeated by the student in the laboratory. The skills necessary to gain competence include close observation, motor coordination, and a desire to progress (Horst et al., 2009). These demonstrations include practical exercises, such as model analysis, cephalometric analysis, and wire bending and appliance construction.

Practical exercises are usually repeated to reach a certain level of mastery acceptable to the standards and norms set by the curricular needs and competency. In the simulation laboratory, the student needs to constantly reflect and receive feedback on their work (Alqahtani et al., 2015). Feedback is usually provided by the tutor at the completion of the task before proceeding to the next task (Icopino, 2007), with face-to-face discussion with the instructor usually occurring after the procedure (Garrison & Vaughan, 2008).

Clinical competence is learnt under the direct and close supervision of a tutor (Horst et al., 2009). Clinical skills are typically transferred from the teacher to the student via demonstrations either in a simulated environment and or on a patient.

The demonstrations also teach skills related to patient assessment and clinical examination essential for formulating a diagnosis and treatment plan based on the individual traits of the patient.

The students acquire their practical skills by performing hands-on exercises, which are demonstrated beforehand. The theoretical background which is presented previously as lectures and seminars at a different time is combined into a clinical exercise where the techniques are demonstrated on patients. Thus, the learning progresses through several stages and at different times.

The orthodontic education employs to a limited extent the use of educational technology to provide enhanced learning experiences and these will be introduced in the next section.

### 1.1.4 Technologies used in Orthodontic Education

Orthodontic education has adopted computer-assisted learning (CAL) in its curriculum for the last two decades (Schorn-Borgmann et al., 2015; Ludwig et al., 2016). CAL resources have influenced combined the traditional lectures with interactive, simple animation, and self-assessment components on a range of topics (Miller et al., 2007). The School of Dentistry at Birmingham University in the United Kingdom was one of the front runners in implementing an online orthodontic e-course (Ireland et al., 2005). The virtual learning environment is another system which supports both the didactic and clinical components of the undergraduate orthodontic curriculum (Linjawi et al., 2009). Live participation in seminars via video conferencing has been used for a live demonstration of techniques (Bednar et al., 2007). A visual hypertext system is another technology-supported learning approach that has been studied. The system allows students to have an interactive experience with text linked to numerous graphic images. The system utilises case-based situations for learning clinical problems in the orthodontic setting. The system also allows self-assessment and automatic evaluation (Aly et al., 2003). The use of interactive technology is also an area which has seen very limited application in orthodontic education. SBLi for Orthodontics - Scenario-Based Learning interactive SBLi® software developed by the University of Queensland was used to develop modules on clinical and procedural parts of orthodontics (Naser-ud-din, 2015).

The current technologies have limited functions to support content delivery, access to learning resources, submission of assignments and simple online quiz-based assessments and evaluation (Aly et al., 2003). These limitations have created a disinterest in using the technology for catering to the overall needs of students thereby affecting knowledge delivery and instruction. Further, the orthodontic education has also received very few evidence-based findings to support the use of educational technology to help drive future learning experience.

### 1.1.5 Mobile Augmented Reality and Smart Learning Environments

Mobile Augmented Reality (MAR) is a technology that provides a new paradigm for human-computer interaction to enable the integration of real-world experience with digital world content (Barab et al., 2001; Kroeker, 2010) based on the principles of augmented reality (Azuma et al., 2001). MAR has shown promising benefits (Aleksandrova 2018) for various applications in education (Chen et al., 2017; Sural, 2017) as implementation is happening at a rapid pace globally and is covering the entire range of subjects and disciplines in primary education (Parhizkar et al., 2012) to tertiary medical education (Kamphuis et al., 2014). In the field of orthodontics, however, the extent of usage of these advances has been rather limited.

An augmented reality (AR) based guided bracket placement using a computed tomography (CT) scan of the jaw using a video image for tracking teeth for has been reported (Aichert et al., 2012). AR visual and haptic cues can be embedded in a system for learning the skill of bracket positioning on teeth without the need for a CT image (Rao et al., 2017) and for learning orthodontic cephalometry using AR and machine learning (Rao et al., 2018). These technologies are conceptual designs with absence of any full-fledged AR based applications in orthodontic education.

Smart learning environments (SLE) are an advanced degree of technology-enhanced environments, with a considerable number of new improvements to support everyday learning activities in any discipline of study. The SLE comprises of smart devices and intelligent technologies to bring about ubiquitous and adaptive forms of learning. This level of technological advancement and the adaptation and use of smart learning environments across the spheres of orthodontic education is very limited and hence forms the basis for exploration on the usage of smart leaning environment including mobile augmented reality for effecting orthodontic training.

With the above background on orthodontic education and the technologies employed in orthodontic education, we can deduce the different challenges and problems facing the traditional learning formats and these will be presented as problem statement in the next section.

## 1.2 Problem Statement

The orthodontic education which involves an understanding of highly complex interactions between the biological, physiological, biomechanical and material science requires intensive training in the form of observation, apprenticeship and repetition (Frey & Gerry, 2006; Mitchell et al., 2017). All the 3 processes create difficulties in knowledge transfer and in turn affect effective learning. These hindrances are exaggerated when the students receive improper visual cues through demonstration. Following demonstration, the apprenticeship followed favours quick learning than deeper learning owing to the factors of the task completion and peer pressure of progression (Garrison & Vaughan, 2008). The task repetition which happens after the first two processes requires constant feedback and error identification. However, with the current means this judgment is left to the subjective discretion of the supervising teacher. All these factors can lead to ineffective learning.

The above-mentioned learning cycles are common across all the orthodontic faculties worldwide with a few utilising technologies to enhance the learning processes. These technologies include the use of simulation-based learning approaches. However, the simulation is limited as they are fixed, and laboratory based. Consequently, the orthodontic education does not have a single full-fledged learning environment for supporting the overall needs of students such as personalised, ubiquitous, immersive experiences (Al Hamdan et al., 2016; Rao et al., 2018).

The orthodontic education is lagging in its implementation of the Higher Education 4.0 as the educational technologies are used to a limited extent in content delivery, assessment submission and access to online learning resources (Dragan et al., 2018). This is a huge set-back in realising the goals of higher education 4.0 and $4^{th}$ IR.

There are no smart learning environments which support orthodontic education. The currently available learning environments lack several features and functionalities to support everyday learning. The learning environments combine several technologies to adapt the traditional learning formats with some levels of interaction using intelligent tutoring systems (Dron, 2018). Therefore, the smart learning environments either use one of the two forms or combine several forms to execute learning processes. This is a huge limitation as smartness is only established with the use of technology without considering the human factors of motivation, connection and knowledge sharing. In addition, none of the learning environments available for orthodontic students provide any personalised formats of learning. They do not support engagement, socialisation and ubiquitous learning. The motivation needed for task progression and skill gain is not assessed and lacks a proper mechanism for identified needs of students. The learning environment also lacks the use of immersive simulation thereby limiting the skill and knowledge continuum to specific location and time-based tasks. The ubiquitousness in learning is completely absent in the traditional learning formats leading to ineffective learning and retention. With the above issues identified, the next section will discuss in more details the challenges in orthodontic education.

### 1.2.1 Challenges in Orthodontic Education

The orthodontic teaching and learning cycles which continue to follow the didactic approach using two-dimensional (2D) learning resources in a fixed preclinical laboratory setting have resulted in several challenges facing knowledge transfer and learning. The demonstration approaches create a difficulty in learning as it lacks visual clarity of the techniques and concepts. When a technique is demonstrated by a demonstrator, the students tend to crowd around the demonstrator and have limited scope for proper observation. This kind of teaching ensures patient safety, but student learning is not efficient (Frey & Gerry, 2006). The lack of visualisation of biological and physiological systems and orthodontic mechanics working together dynamically makes it difficult for students to understand (Victoroff & Hogan, 2006).

The next difficulty arises during the transition between preclinical to clinical stages. For the student to progress from preclinical to clinical training, skill gained in the preclinical training sessions are expected to reach a certain proficiency level before the student can progress to the clinical phase (Qutieshat, 2018). Following this phase, the student is exposed to live patients in a real-world clinical environment. It has been noticed that students who lack prior clinical experience find the concepts of preclinical education inaccessible and find it difficult to transition into the clinic (Horst et al., 2009). The effect of the transition between simulated and real-world environments on learning is unclear (Serrano et al., 2018). There is also a lack of understanding of the challenges faced and methods used to eliminate the dissonance phase in learning and transferring the procedural tasks from the preclinical to the clinical setting.

The feedback received during a learning process is another area which lacks an effective feedback mechanism (Rountree & Adam, 2014; Mitchell et al., 2017). The feedback provided by the tutor is subjective in nature. In orthodontic training, procedural tasks do not include immediate feedback, yet the timing of the feedback received by the student is important because a time lapse creates learning dissonance. Instead, students receive comprehensive feedback and evaluation at the task completion stage (Victoroff & Hogan, 2006).

Another aspect of orthodontic education which is problematic is the assessment methods used. The assessments of preclinical and clinical skills combine subjective and objective evaluation to assess a student's knowledge and skill gain. This assessment however is limited to knowledge and skill gain without understanding student engagement, emotion/mood, and motivation (Suksudaj et al., 2012). The motivation and inquisitiveness to learn and acquire practical and clinical skills in the absence of a goal are seldom assessed (Orsini et al., 2015).

The personalisation of the learning formats currently employed is something of a ‘one size fits all situations’ method (Rao et al., 2018). This method does not consider the individual learning styles and preferences of students.

Finally, the limited availability of technology supported learning environments in orthodontic education has resulted in a deficient learning environment (Dragan et al., 2018). Students do not have access to procedural tasks, simulations, and patient exposure outside working hours at the dental school and hospital. For deliberate practice to take place, the student must rely heavily on the physical locations of the dental school. The restrictions on the student in accessing content and learning anywhere and anytime reflect on the ineffectiveness of the current orthodontic learning systems. The students’ need for interaction, engagement, knowledge sharing, and collaborative qualities are rarely integrated in the orthodontic curriculum.

### 1.2.2 Literature Gap

Orthodontic education which has been a stronghold of teacher centric learning following closely the methods of didactic and apprenticeship approaches is faced with numerous problems in supporting learning (Victoroff & Hogan, 2006; Horst et al., 2009; Mitchell, Gillies, Mackert, 2017; Serrano et al., 2018; Rao et al., 2020). These challenges affecting orthodontic education as revealed by the literature review was found to have an ineffective visual perception and a lack of visual clarity of techniques, concepts, procedural tasks in preclinical and clinical orthodontic training (Alqahtani et al., 2015). In addition, there is a lack of effective visualization and inadequate field of view during demonstrations (Nikzad et al., 2012). The understanding on the challenges faced and methods used to eliminate cognitive dissonance phase in learning the procedural tasks from preclinical to clinical training is lacking (Dutã et al., 2011; Serrano et al., 2018). There is a further lack of understanding of methods used to improve student engagement and motivation in preclinical and clinical training (Haden et al., 2006; Ulkur et al., 2015). The preclinical and clinical training lacks an effective feedback mechanism (Henzi 2007). The feedback which is available only at the completion of a task prevents simultaneous error identification leading to latency in procedural learning. The traditional formats provide limited use of immersive technologies thereby affecting engagement and attention of the students and is seen in the lack of any augmented reality-based learning formats currently used (Farronato et al., 2019). The orthodontic education also lacks a smart learning environment to support individual student needs such as personalisation, ubiquitous learning, collaborative learning and independent learning (Dragan et al., 2018).

## 1.3 Research Question

The central question addressed in this research is:

How to design an effective model for integrating smart learning environment (SLE) into the orthodontic education using the mobile augmented reality (MAR) approach?

## 1.4 Research Objectives

### 1.4.1 General objective:

To explore, design and develop an effective model of SLE for the orthodontic education using MAR approach.

### 1.4.2 Specific objectives:

1. To seek consensus on the challenges facing orthodontic education and the need for smart learning environment among subject matter experts.

2. To design and develop smart learning environment and mobile augmented reality applications for orthodontic education.

3. To assess perceived usability towards the smart learning environment and mobile augmented reality applications by technical experts, subject matter experts and dental students.

4. To assess and compare the motivational level of students receiving traditional learning formats against those receiving learning through smart learning environment and mobile augmented reality applications.

## 1.5 Hypotheses

The current study hypothesises that the use of SLE using MAR in orthodontic education is more effective than the traditional methods of learning. It also hypothesises that the SLE using MAR is more effective in motivating students than the traditional learning formats.

## 1.6 Significance of the Study

The study which has highlighted the challenges and problems facing orthodontic education will provide a roadmap for designing and developing a smart learning environment for effectuating learning in orthodontics. This roadmap will be the first of its kind in orthodontic education. It will utilise 16 specialised components and advances in technology such as mobile augmented reality (MAR) and automated algorithmic processes to create a smart autonomously rendering teaching and learning environment (SmARTLE). SmARTLE will provide a channel conducive of self-based learning (heutagogy), peer-oriented learning (paragogy) and virtual-based learning (cybergogy) to support and enhance orthodontic education.

## 1.7 Thesis overview

This thesis has been organised into six chapters. Chapter one provides the problem statement, research question, research objectives, hypothesis and thesis overview.

Chapter two reviews the available research in the field of study. The learning theories, an overview of orthodontic education, current technologies utilised in orthodontic education, Augmented Reality, Smart Learning Environment and gaps in SLE for orthodontic education. The chapter also describes consensus gathering methods, usability studies and motivational studies.

Chapter three presents the materials and methods used in the study, the study design, the study population, the methods of data collection, as well as the methods and procedures of data analysis.

Chapter four presents the results of the study under three categories; electronic-Delphi (e-Delphi), System usability testing for Mobile Augmented Reality Orthodontic Education (MAR-ORTHO-EDU) application and SmARTLE applications and motivational analysis using instructional materials motivation survey. Each chapter is followed by summaries drawn from the relevant results.

Chapter five provides the discussion of the findings of the results and the alignments of these findings with the reviewed literature.

Chapter six provides the conclusions, limitations of the study and recommendations for future work.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 Introduction

This chapter provides a description of the learning theories found to affect learning in general and in the context of orthodontic education. The different pedagogies employed in orthodontic education have also been incorporated to exhort the understanding of teaching and learning in orthodontics. The chapter also includes an overview on orthodontic education, the technology used in orthodontic education and concludes with a background on smart learning environment which will form the basis of the proposed conceptual framework discussed in the next chapter.

## 2.1 Learning theories

Learning is a remarkable ability common to all animals yet is a quality which is not simple to understand. This quality of humans has eluded modern psychology and has posed the longest-running controversies in the field (Petri, & Mishkin, 1994). Learning in general and in specific to the orthodontic context draws from several learning theories. The learning theories individually and together provide the necessary understanding of how a student learns. To understand the underlying philosophy of how knowledge is acquired, the study will base its epistemology on constructivism (Bada, & Olusegun, 2015), behaviourism (Watson, 1913) and connectivism (Siemans & Downes, 2009).

The fundamental theory of constructivism and its tenets enable us to understand the intricacies of learning and instruction (Bruner, 1966). Constructivism through a combination of situated cognition, activity theory, experiential learning, anchored instruction with authentic learning as a common feature place emphasis on learning as a process (Mattar, 2018). Other theories specific to but not limited to health professional education such as threshold concepts, narrative, dialogism and active learning provides the continuum of knowledge exchange in various forms (Kamel-ElSayed & Loftus, 2018).

Behaviourism emphasizes on things that can be observed and measured to understand and predict human behaviour (Watson, 1913). This theory states that observable, measurable, outward behaviour is worthy of scientific inquiry (Bush, 2006) and learning occurs almost always if the right environmental influences are present. The theory also states that all students can learn and acquire identical understanding (Weegar, & Pacis, 2012).

On the other hand, connectivism is a conceptual framework which views learning as a network phenomenon influenced by technology and socialization (Siemens, 2006). Connectivism is also presented as a new and important constructivist theory, however, connectivism or distributed learning is proposed as a theory more adequate to the digital age, when action is needed without personal learning, using information outside of our primary knowledge (Siemens, 2006).

### 2.1.1 Constructivism

The constructivist theory of learning, whose philosophical origins are frequently ascribed to the works of Dewey, Piaget and Bruner (Bada, & Olusegun, 2015) is based on the premise that the act of learning is based on a process which connects new knowledge to pre-existing knowledge.

The constructivist theory received significant contributions in the early nineteenth and twentieth centuries (Buchler, 1955) from constructivists, like Vygotsky (1980), who consider that learning is the process of constructing new knowledge on the foundations of what you already know.

Constructivism, briefly, is the idea that, as learners, we cannot simply absorb knowledge from the world around us. According to Elliott et al., (2000), constructivism is an approach to learning that holds that people actively construct or make their own knowledge and that reality is determined by the experiences of the learner. McMillan (2015) states that learners must actively construct their knowledge and understanding. In elaborating this idea, Arends (1998) states that constructivism believes in personal construction of meaning by the learner through experience, and that meaning is influenced by the interaction of prior knowledge and new events.

Richardson (2005) states that classroom methods and environments grounded in a constructivist theory of learning and development of deep understandings in the subject matter of interest aid in future learning leading to a constructivist education. This understanding provides the required evidence that constructivist theory can be applied to education in general and not to a specific instruction (Yang et al., 2019).

This viewpoint holds true for orthodontic education as the students over their training years (undergraduate and postgraduate) are expected to become active participants in constructing knowledge thereby becoming lifelong learners (Dennick, 2008). To sum it up, orthodontic education emphasises on the tenets of constructivism to effect both the aspects of teaching and learning.

### 2.1.2 Behaviourism

The theory of behaviourism follows the conditioning of observable human behaviour (Forrester, & Jantzie, 2013). This understanding was expanded by Skinner (1968) who stated that behaviour is voluntary or automatic and is either strengthened or weakened by the immediate presence of a reward or a punishment. Skinner (1968), in his book entitled, The Technology of Teaching, wrote: The application of operant conditioning to education is simple and direct. Teaching is the arrangement of contingencies of reinforcement under which students learn. They learn without teaching in their natural environments, but teachers arrange special contingencies which expedite learning, hastening the appearance of behaviour which would otherwise be acquired slowly or making sure of the appearance of behaviour which otherwise never occur (Skinner, 1968).

The behaviourist model of learning highlights the concept of directed instruction. In this model, the complex learning could be achieved by the process of contingencies and reinforcement (Skinner, 1968). The same applies to a teacher providing the knowledge to the students either directly or indirectly through the setting-up of records. Behaviourism has further influenced learning in the way exams are used to measure observable behaviour of learning (Forrester & Jantzie, 2013). The use of rewards and punishments, and the breaking down of instruction into smaller bits of information (Gagne & Briggs, 1974; Gagne & Walter, 2004) are all examples of this influence.

The computer assisted instruction (CAI) from a behaviourist perspective is an effective way of learning (Forrester et al., 013). The CAI provides the learner with a question which acts as a stimulus eliciting a response. This response may be rewarded. Based on these principles, CAI has been espoused as an effective learning approach (Forrester et al., 2013). Thus, behavioural learning theory has demonstrated to provide a systematic approach to teaching and learning.

In health professional's education, the development of competencies (technical and psychomotor skills) orients itself to the philosophy of behaviourist learning (van Vonderen, 2004). The theory has been found to be advantageous if a desired outcome of change in behaviour is affected by an educational intervention. The students receiving immediate corrective feedback on their incorrect concepts immediately after the performance of behaviour from expert tutors or any other means is in principle a behaviourist learning model (Joseph et al., 1992; Hewson, & Little, 1998).

### 2.1.3 Connectivism

Connectivism is a theoretical framework with roots in principles of chaos, network and complexity and self-organization theories (Siemens, 2005). This framework has viewed learning to be a network phenomenon influenced by technology and socialization (Siemens, 2006). The theory is also found to have been supported by connectionism, associationism and graph theory (Downes, 2012).

In connectivism, the knowledge is said to be distributed across an information network. This information can be stored in a variety of digital formats connected to a learning community described as a node (Downes, 2006). These nodes when connected form a network of linked nodes which can share resources.

The learning in connectivism is a cyclical process wherein the learners will connect to a network to find information and modify their prior beliefs in addition to connecting back with the network to share the new belief. This pathway repeats itself as new information is found and shared (Kop & Hill, 2008).

Connectivism further states that knowledge and learning are not located in any given place and are found in networks of connections formed from experience and interactions between various individuals, societies and organizations linked through the technology used by them (Goldie, 2016). This pedagogical form has been massive open online courses and were conceptualised by Siemens and Downes (2008, 2009). These platforms use traditional course materials, theories of learning and methods of teaching. The use of blogs and social media platforms to make connections for knowledge creation and construction is what forms the basis of these interactions which are in essence the principles of connectivism. For this theory to suit the learning demands of health professionals, Downes (2012) has advised the learning content to be interactive, usable and relevant.

The next section will describe in more details the different educational methods employed in orthodontic education to provide clarity on how the knowledge transfer occurs.

## 2.2 Educational methods Employed in Orthodontic Education

### 2.2.1 Cognitive Apprenticeship

The concept of a cognitive apprenticeship is defined by Collins et al., (1989) as a method of learning through guided experience on cognitive and metacognitive, rather than physical, skills and processes. In cognitive apprenticeships, the learning mainly occurs through the pathways of observation, enactment, and practice under the guidance of a teacher (Collins et al., 1987). Bandura's (1999) theory of modelling supports the claims of cognitive apprenticeship which posits that learning to be successful requires the learners to be attentive, motivated and possess retaining skills in addition to having the ability to accurately reproduce the desired skill.

The literature shows that three stages of skill acquisition are supported by cognitive apprenticeships such as: the cognitive stage, the associative stage, and the autonomous stage (Anderson, 1983). In the cognitive stage, learners develop declarative understanding of the skill. In the associative stage, mistakes and misinterpretations learned in the cognitive stage are detected and eliminated while associations between the critical elements involved in the skill are strengthened. Finally, in the autonomous stage, the learner's skill becomes honed and perfected until it is executed at an expert level (Anderson, 2000). The cognitive apprenticeships shapes learning through behavioural modelling (Bandura, 1999). The process allows the student to initially listen whereby creating a conceptual model of the new knowledge imparted. This is followed by imitation by the student under the guidance of the tutor. According to Vygotsky (1980), this is known as the Zone of Proximal Development and is believed to foster rapid development. The guidance or coaching can involve as necessary various methods such as, corrective feedback and reminders. This guidance under normal circumstances becomes lesser as the student learns and develops the skill through repetition (Johnson, 1992) and eventually fades away once the student has reached a competent state.

The above process has found several applications across diverse faculties of medicine (Stalmeijer et al., 2013), dentistry (Kilistoff et al., 2013) and pharmacy (Pinelli et al., 2018) under different settings (e.g., classrooms, clinical, and online). This mechanism of behavioural modelling is what enables students to learn the motor skills required for orthodontic training where learning happens through observation, subsequent imitation and repetition of procedural task demonstrations (Chris et al., 2017; Darnis & Lafont, 2015).

### 2.2.2 Narrative

Strong theoretical arguments supporting narratives have emerged in the spheres of teaching and learning within medicine (Easton, 2016). The narrative inquiry places storytelling as a natural learning process that humans have developed and in recent years has enabled a better understanding of clinical practice and education (Hunter, & Montgomery, 1993).

Narrative learning theories can be found under the broad umbrella of constructivist learning theory which sees learning as a construction of meaning from experience. The ideology is based on the premise that learning occurs through construction and connection of educational messages and is related to lived experiences of the teacher and in cases that of the student which are weaved into the existing narratives of meaning (Rossiter, 2002).

In addition to meaning making the narrative has in its ambit several benefits in medical education which can be extrapolated to dental and orthodontic education. The benefits such as, the development of identity (Hunter et al., 1993), enhancing memory (Maguire et al., 2003), promoting empathy (Greenhalgh, 2001), reflection on practice (Hunter & Hunter, 2006), and the development of clinical reasoning through what are known as illness scripts (MacNaughton, 1995).

The common mechanism of clinical reasoning is also an area which has utilised narrative as a method for reaching a diagnosis and treatment plan (Loftus & Higgs, 2008).

These promulgate that narrative forms an efficient way for a doctor to relate their biomedical knowledge with that of the patient's complaint of illness thereby