The Development and Evaluation of E-Diagnostic Application Software

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Table of Abbreviations

AC	Abstract Conceptualization
ADDIE	Analysis, Design, Develop, Implement, and Evaluate
AE	Active Experimentation
AI	Artificial Intelligence
AIWBES	Adaptive and Intelligent Web-based Educational Systems
ALS	Adaptive Learning Systems
ANN	Artificial Neural Networks
ARCS	Attention, Relevance, Confidence, and Satisfaction
CAL	Computer-Assisted Learning
CAT	Computerised Adaptive Test
CBT	Computer Based Tests
CE	Concrete Experience
CLT	Cognitive Load Theory
CORAL	Cooperative Remotely Accessible Learning
CSA	Computerised Cognitive Style Analysis
ELT	Experiential Learning Theory
FSLSM	Felder Silverman Learning Styles Model
HCI	Human-Computer Interaction
IDM	Instructional Design Model
ITS	Intelligent Tutoring System
IRT	Item Response Theory
LMS	Learning Management System

LX	Learner Experience
MAS	Multi-agent Systems
MLS	Management Learning System
MITT	Microcomputer Intelligence for Technical Training
MOOC	Massive Open Online Courses
OSM	Open Student Model
RO	Reflective Observation
SRL	Self-Regulated Learning
UX	User Experience
UI	User Interface

Abstract

This paper describes the development of a new system that aims to identify the reason(s) behind learners' mistakes in solving a linear equation. The system works by studying the learner's steps during solving process, and checking whether there is any missing knowledge required for a correct solution. The system then provides, if appropriate, a correct solution path to learners, before retesting them.

In the first prototype, the system proved successful in identifying missing knowledge, but its UI (User Interface) was too complex and difficult to use. This issue was resolved, however, with the help of models and algorithms, which facilitated the development of a more user-friendly UI. Resulting tests showed that, in many cases, learners were successful in passing the test after following the remedial path suggested by the system. The evaluation, by the system, of the learners' solution process was confirmed by the (human) teacher in the majority of the cases, and learners reported finding the system helpful and easy to use.

The current study conducted five experiments. First experiment was usability evaluation to evaluate the concept of this study in real-world tests. The experiment found a significant improvement in the user interface (4.69 out of 5) as a result of using multi models which improve the UI from the first prototype. This experiment helped in understanding learner preferences. The second experiment was conducted to confirm the readiness of the system after fixing all the bugs and programming errors which were discovered during the usability evaluation experiment. In this experiment, students had to make specific errors intentionally to retrieve the system's action to those types of errors. The third and the main experiment was about the functionality evaluation which evaluated the concept of the research. With an average score of 3.32 out of 5, this experiment showed the system's efficiency in helping learners to determine their missing skills and find the right domain to learn. However, with polarity in the result and by reviewing the repetition table, this repetition is mainly in the 5 out of 5 score. This is because most students gave high scores in all of the questions. Learners become familiar with using the system, gradually as they use the system and most of them were excited to learn from the system about their mistakes. The teachers' opinion was positive to apply such a system for the other subjects. The fourth experiment was about the teachers' evaluation of the prototype, which was quite important to the research, and its different sequences. The results of this experiment shows the quantitative data about the

usability and the functionality of the system with an average score of 3.9 out of 5 indicating improvement of the system. Qualitative data with an average score of 4.3 out of 5 indicates high level of satisfaction of the teachers about such a system. The data shows the high demand for using Sequence 1. However, there are some opinions about using Sequence 2 and some concerns about the feasibility of designing such a system in Sequence 1, which needs a lot of effort, whereas Sequence 3 can be implemented faster and easier. The fifth experiment showed the comparison of the time consumed between Sequence 1 and Sequence 3. The result of this experiment shows an average of 16:57 for Sequence 1, while the average of Sequence 3 was 28:46. This result supports the importance of Sequence 1, even if its cost is higher than Sequence 3.

The results of the study were positive enough to suggest that the concept could be applied to other domains involving a learning or teaching process. Such a system may be helpful, for example, in evaluating teachers' performances.

Acknowledgements

Enrolling in a PhD program is always a major challenge, but for those of more advanced years, it can be almost Mission Impossible. I enrolled in the PhD programme at an age where my state of health wasn’t all it might be, but with the support of my supervision team I found the mental and physical resources to complete my study. I would like to express my sincere gratitude to Dr. Trevor Barker and Dr. Vito Veneziano, who gave me invaluable support, not only in my academic endeavours, but also in the wider context of my life. I would also like to thank Ms. Kathy Lee, as without her support I could not have finished this work.

Designing and testing an e-learning system needs high levels of cooperation between the research team and the field in which it can be tested. I would, therefore, like to thank the Ministry of Education of Saudi Arabia for supporting me through my study journey, and for their permission to test the system in schools in the eastern city of Dammam. I would also like to send my heartfelt gratitude to all the staff and students who volunteered to participate in my experiments.

Finally, I would like to thank all my sisters and brothers for their encouragement. My appreciation together with my love, must also go to my wife and my children for all their support and the many sacrifices they made to allow me to complete my study. All these thanks came after the great thanks to my mother as she is the reason of all my successes after my Lord will.

Chapter 1: Introduction

1.1 Introduction

For several decades now, the fields of both Artificial Intelligence (AI) and Computer-Based Testing (CBT) have offered considerable potential for aiding the learning process. In fact, according to Haladyna and Downing (2011), CBT is transforming the way tests are created and administered. Advancements in computer technology, including lower hardware costs, improved computer-based testing software, and artificial intelligence, along with the ability to connect to distant mainframe computers at a low cost, may allow for a greater emphasis on self-directed learning. In this scenario, the instructor's role would shift toward designing and developing the teaching materials programmed into the computer and monitoring and evaluating the interaction between the student and the machine. In recent years, however, advances in digital technology have spurred developments in both areas, and early generations of Adaptive Learning Systems (ALS) and Intelligent Tutoring Systems (ITS) have evolved.

Today, many researchers see ALSs as a particularly rich vein of possibility, as they are thought to present an excellent interactive environment for effective learning, while AI is a powerful tool for tailoring that environment to meet the needs of the individual user. The concept of the ALS, as defined by Sonwalker (2005) and Pavlov and Paneva (2006), is technology that is designed to personalise and adapt the learning experience of individual students based on their performance and preferences. This approach helps to optimise learning outcomes. To achieve this individualisation, the concept of a ‘student model’ is used to diagnose the learner’s state of mind and understanding (Drigas et al., 2009). This allows differentiation between individual learners through a method of storing the student’s unique characteristics, in order to gear the domain course to the needs of that student. This 'global description' of the student model (Ohlson, 1993), is different from the ‘overlay model’ (Luckin et al., 2007), which is based upon student knowledge. They are two distinct methodologies.

The aim of this project is to integrate these two distinct methodologies, in order to investigate the potential of combining the unique strengths of ALSs and models to produce a learning environment that takes support for effective learning to a new level. This thesis covers five distinct areas relating to the development of a prototype system:

- Design
- Implementation
- Test
- Expert Evaluation
- Real World Evaluation

1.1.1 Research focus

As a first phase, it was decided to focus research on an individualised learning process. This process, which has been reported as beneficial to learners (Lilley et al., 2004), is the process of finding solutions to linear equations. This report describes the development of a system which can present simple (linear) equations to learners and analyse errors in their solution path. Once the cause of the error is determined, the system will recommend a remedial pathway.

The underlying concept of the system discussed here is to break equations into smaller elements (e.g. knowledge and skill), and then use an algorithm to determine (from student input) exactly where errors may lie. This information is then used to build the student model. This thesis will describe the aims, objectives and research questions used for research.

1.1.2 Relevance of the study

Some students have great difficulty with even basic mathematics (WGBH, 2002), and solving simple equations is difficult for many learners. In this research, two particular problems that students had in this respect have been identified and investigated. These are:

- Insufficiently developed basic mathematical skills (multiplying, dividing, adding, subtracting etc.)
- Poor understanding of the (often complex) steps involved in solving equations.

Clearly, if individual students are to be helped to improve their ability to solve equations, it is important to determine exactly where the problems lie for a particular individual. However, while a good teacher might be able to help a student address the problems, there are practical barriers which often obstruct even the best teachers. For example, there are ever-greater demands placed upon teachers in terms of class size, reducing their ability to deliver an individualised learning experience. While there have been many attempts to solve this problem (Lee et al., 2015), they tend to use the 'one size fits all' approach, which is considered by many not to be appropriate ((Barker and Wright, 2002; Ryback and Sanders, 1980).

To help address this issue, this research employs computer technology to diagnose the reasons behind errors in the solution process (of simple linear equations) and to suggest the most appropriate remedial paths for each individual learner. An added benefit is that the system can not only suggest remedial paths for the specific process of solving equations but can recommend the most appropriate level for future study. The range of applications of the proposed system, therefore, is potentially very wide, ranging from the development of models of student abilities, through recommending remedial paths and providing individual feedback, to adding challenges which can aid individual learning.

A review of current and recent literature has shown that, while there exists examples of systems intended to help in solving equations, there are no examples of systems which successfully identify the reasons behind the failure to solve such equations. However, in this report, it is argued that the identification of specific errors (in the solution process) is key to providing learners with the most appropriate remedial pathways. This thesis describes a proposal for this process in detail, including system implementation and testing.

The ability to generalise the approach described here, to include different learner groups in different geographical locations, as well as different domains (subjects), is an important issue, and it is proposed that the first step in this process is to test the system with learners located in Saudi Arabia. To this end, the Kingdom's international schools were chosen, as they teach in English (the system was developed in English in preparation for the later stages of the research).

1.2 Study background

It was as long ago as the late 1990s that Web technology began to show signs of becoming a more interactive medium. Dubbed 'Web 2.0' (DiNucci, 1999), it was a technology that supported sites which allowed users to be more collaborative, and to give feedback. Essentially, the Web morphed, over a period of a few years, from a passive medium into a platform that supported high levels of interaction, sharing and personalisation (Pelet, 2013). At around the same time, the e-learning sphere began to show a similar evolution, making extensive use of emerging social media tools and other internet-based services. Perhaps this new generation of e-learning techniques unsurprisingly attracted the name: 'E-learning 2.0' (Pelet, 2013)

Despite all these advances in Web technology, however, users were still not in charge: they still had to conform to constraints imposed by the website in question (Cormode and Krishnamurthy, 2008). The same was true in the e-learning sphere. Although, in the early days of e-learning 2.0, the emergence of the LMS (Learning Management System) helped to structure and organise learning content more systematically.

But this soon began to change. As Web 2.0 technologies evolved and matured, and online tools became increasingly sophisticated and easy to use, user-participation and user-to-user interaction increased rapidly. One measure of this progress is the explosive growth in the use of social media. By 2012, WordPress claimed over 70 million users (bloggers) worldwide, while Twitter was gaining eleven accounts per second (Pring, 2012). It seemed that the 'read/write Web', originally envisioned by Tim-Berners-Lee, the person widely acknowledged as the 'father' of the World Wide Web, was truly coming to pass (Plomaritou, 2017).

It is certainly true that, within the e-learning arena, Web 2.0 technologies began to play an even greater role. This, in turn, led to the growth and effectiveness of a new way of looking at the learning process; a perspective focused on student-centred learning which became known as constructivism. This model of the learning process claims that learners develop (construct) an understanding of the world based on a foundation of knowledge and learner involvement (Larochelle et al., 1998). As a result, educational practices have been built around e-learning 2.0 principles and methodologies. One example of how the ideas of constructivism can be applied, is Moodle (modular object-oriented dynamic learning environment). Originally launched in 2002 to apply the rapidly advancing Web 2.0 technologies, Moodle is, today, a learning platform which provides educators, administrators, and learners alike with a single, personalised learning environment, using integrated RSS feeds, blogs, and user forums, as well as e-portfolio functionality and a wide variety of plug-ins.

It should be noted, however, that technological development and theoretical learning models are not the sole drivers of change in e-learning. It has been claimed (Trembach and Deng, 2018). that the latest generation of learners (known as Millennials, born between 1981 and 1996) have unique characteristics that differentiate them from previous generations, and that these learners require a new way of discovering the world. For these learners, the use of social media and online interactive behaviours have become normalised (Throuvala et al., 2019). Unlike the previous generation, for whom such technologies were peripheral and inessential, millennials regard the use of interactive and mobile technologies a fundamental part of their social lives and key to their understanding of the world. As what have been labelled ‘digital natives’ (Prensky, 2001), this generation learns in a different way to their predecessors. Instead of learning (as previous generations tended to do) in a formal, structured way, viewing the learning process as a theoretical process to be applied at a later stage, millennials tend to learn through an ‘experiential’ process, picking up content and learning processes as part of the daily interaction with the world through technology.

One result of this is that millennials have higher expectations of educators and the educational process. Their easy and seamless access to learning resources that are highly personalised to their needs, tastes, and abilities, coupled with their increasing levels of control over their own learning environment, means that educators of this generation must focus on the use of models which meet higher standards of interactivity than ever before.

1.2.1 A brief history of E-Learning

The inception of e-learning can be traced to the 1960s, when scholars and researchers began to explore the use of computers in the domain of education (Clark and Mayer, 2016). Before that, the more common term was ‘online learning’, described by the U.S. Department of Education as "education that uses one or more technologies to deliver instruction to students who are separated from the instructor and to support regular and substantive interaction between the students and the instructor.” It wasn’t until 1998, when Jay Cross wrote that "e-learning is learning on internet time, the convergence of learning and networks”, that the expression ‘e-learning’ began to be commonly accepted. However, when, during a CBT Systems seminar in Los Angeles in October 1999, the term was used for the first time in a professional environment, it was still considered an oddity of language.

The term 'e-learning' is currently used in various contexts with a range of precise meanings, as suggested by Campbell (2004). These meanings depend on the context in which the term is used. In the school sector, it encompasses the utilisation of both software-based and online learning, whereas in the business, higher-education, military, and training sectors, it is limited to a range of online practices, as suggested by Campbell (2004). Today, with the advancement of technology, the definition of e-learning has evolved to encompass various forms of digital learning. In the early 2000s, the European Union defined e-learning as "the use of new multimedia technologies and the Internet, to improve the quality of learning by facilitating access to resources and services, as well as remote exchanges and collaboration" (European Commission, 2000).

Another issue that makes a single and precise definition of e-learning difficult to pin down is that e-learning encompasses a wide range of delivery methods and content. For example, a report by the National Centre for Education Statistics defines e-learning as "instruction delivered primarily or wholly via electronic means, or via the internet" (U.S. Department of Education, 2017, p. 1). This definition highlights the delivery method rather than the specific content or instructional approach. Similarly, a report by the International Association for K-12 Online Learning notes that e-learning can take many forms, including "synchronous or asynchronous, self-paced or instructor-led, [and] individualised or cohort-based" (Watson et al., 2014, p. 2). This report emphasises the variability of delivery methods and highlights the importance of considering the specific context in which e-learning is being used.

Overall, these definitions illustrate the diverse ways in which e-learning can be conceptualised and practised, highlighting the importance of designing e-learning experiences that meet the needs and preferences of individual learners. It is important to note that e-learning is a 2-way process that requires both instruction and evaluation. For example, a study by Huang et al., (2016) notes that "learning is a process of continuous change and adaptation, and e-learning is no exception". Similarly, a report by the National Research Council (2012) notes that "effective learning is a process of active engagement with ideas and experiences". The report emphasises the importance of feedback and assessment in promoting active engagement and improving learning outcomes.

Another example of the 2-way nature of e-learning comes from a study by Hrastinski (2008), who argues that "online learning requires dialogue and interaction between the learner and the instructor". The author emphasises the importance of feedback and collaboration in promoting active learning and improving e-learning outcomes.

1.2.2 E-Learning with Meta-Cognitive Support

Metacognition is a self-regulation system that helps individuals comprehend and regulate their cognitive abilities (Malamed, 2010). In e-learning, metacognitive support refers to the provision of strategies that enable learners to monitor and regulate their own learning processes, including, but not limited to, setting goals, tracking progress, and reflecting on performance, as stated by Azevedo and Cromley, (2004).. It empowers learners to take ownership of their education by fostering awareness of their learning processes, evaluating their own learning requirements, and devising and implementing strategies (Hacker et al., 2009). Meta-cognition essentially consists of two components:

- Knowledge:

The concept of metacognitive knowledge is discussed in a paper by Hacker et al., (2009). They note that metacognitive knowledge involves understanding one's own learning processes and how to use different learning strategies effectively. It is an important component of effective learning. Learners who are aware of their own learning processes, and who understand how to apply various learning strategies in different contexts, are more likely to succeed in their academic pursuits. This claim is supported by a report by the National Research Council (2012), which notes (p.88) that "metacognition, or thinking about one's own thinking, is essential for effective learning". The report emphasises the importance of metacognitive strategies, such as setting goals, monitoring progress, and evaluating outcomes, in promoting effective learning.

Another example of metacognitive knowledge can be found in a study by Schraw and Moshman (1995), who argue that metacognition is "critical to academic success" (p. 207). The authors emphasise the importance of metacognitive knowledge in helping learners understand their own learning processes and make informed decisions about how to approach new learning tasks. The importance of metacognitive knowledge in promoting student learning is also discussed in a paper by Pintrich (2002), who notes that it (metacognitive knowledge) can help students monitor their own learning, set goals, and adjust their learning strategies as needed.

- Strategy/regulation:

Self-regulated learning is a process in which learners take an active role in managing their own learning activities by setting goals, monitoring performance, and adjusting strategies to attain the desired outcomes. The significance of goal orientation in self-regulated learning has been emphasised by Pintrich (2000), while Boekaerts (1999) has provided an overview of the current state of research on self-regulated learning, underscoring the importance of learners being able to regulate their own cognitive processes to achieve their learning objectives. To help learners acquire these metacognitive skills, and in order to enhance academic performance, support can be provided, as suggested by Panadero (2017).

Of course, solving linear equations, while simple to some, can be challenging for others. It doesn't rely on a single skill. Instead, it demands a variety of skills, and especially metacognitive skills, to improve the motivation of the learner to practice. Meta-cognitive skills also increase the ability to self-regulate, which gives the learner a positive learning experience. Li and Chen (2014) suggest that a model of metacognitive scaffolding in game-based learning can be employed to facilitate self-regulated learning in e-learning environments. This approach involves guiding and supporting learners in the development of their metacognitive skills through game-based activities.

According to Hsu et al., (2013), personalised recommendation-based mobile learning approaches have the potential to promote metacognition and self-regulated learning in e-learning environments. This is achieved by offering learners tailored feedback and recommendations based on their unique learning needs and preferences. This is a particularly relevant observation to the context of this paper, which describes the development of an e-diagnostic and personalised feedback tool to aid the learning process. A learner's ability to understand their own learning processes, and to employ the most effective learning strategies (for them) is important in delivering the best outcome. (Ormrod et al., 2009).

1.2.3 General principles of assessment

Assessment is a multifaceted process that involves defining, selecting, designing, collecting, analysing, and interpreting information to enhance students' learning and development. It entails setting clear expectations for learning quality, gathering, and interpreting evidence, and using the results to improve performance. Angelo and Cross (1993) emphasised the importance of making expectations explicit and public to guide the assessment process. Black and Wiliam (1998) argue that assessment should be an essential component of the learning process and should be aimed at fostering learning, rather than solely measuring it. This requires aligning assessments with learning objectives and providing feedback to steer student learning. Understanding the purpose of assessment enables educators to choose the most appropriate assessment tools/methods: a point that will be expanded upon when types of assessment are discussed. For example, the purpose of assessment may be diagnostic (aiming to identify weaknesses in students' knowledge and/or reasoning), or predictive (e.g. aiming to forecast the percentage of students passing at certain levels). Teachers must know the purpose of assessment before they design the process.

1.2.3.1 Error types

Whoever implements an assessment process must know about expected errors in assessment and measurement, such as those outlined in Audah (2010). These are:

- Sampling errors:

  The topic of sampling methods is discussed in many texts and academic papers. In a teaching environment, Brookhart (2010) posits that assessments which focus solely on lower-level thinking skills, such as the recall of information, may not offer a comprehensive assessment of student learning. This point is supported by Anderson and Krathwohl (2001), who argue that assessments that concentrate solely on a single (lower) level of Bloom's Taxonomy (level of cognitive skills), such as knowledge, may fail to adequately measure higher-order skills, such as analysis and evaluation.

- Guessing errors:

  The issue of guessing is discussed in a paper by Haladyna and Downing (1989), regarding the effective utilisation of multiple-choice questions. The authors observe that guessing behaviour can vary, depending on the difficulty level of the questions and the stakes of the assessment. The tendency to guess, rather than leave a question unanswered, is discussed by Roediger and Marsh (2005) concerning the demands of the test on memory and knowledge. The authors note that students often feel compelled to respond to all questions on a test, even if they are uncertain of the answer, under the assumption that guessing may increase their chances of receiving a favourable score. The current study implemented an e-diagnostic system which intends to avoid multiple choice questions and give a blank text box where learners input their answers. Furthermore, the issue of guessing in True or False questions is examined by Cohen and Swerdlik (2018) in the context of psychological testing and assessment. The authors contend that True or False questions may be susceptible to guessing errors, particularly in instances where the questions are ambiguous or difficult to interpret.

- Bluffing errors:

Bluffing errors in assessments, particularly in essay writing, are a well-documented phenomenon. A research by Kuncel and Hezlett's (2007) on the prognostic acceptability of standardised tests stressed on the efficiency of standardised tests in accurate prediction of students' success and highlights the limitations of deceiving in tests. Similarly, McKeachie (1994) provides teaching tips for college and university instructors, highlighting that students may use bluffing as a means of avoiding admission of a lack of knowledge, or to gain marks by using high-level vocabulary or technical jargon incorrectly. Wainer and Thissen (1993) expand on test completion strategies and their impact on test scores, noting that students may employ bluffing tactics to compensate for knowledge gaps or to gain marks using general or vague statements without providing specific evidence. Additionally, Birenbaum and Tatsuoka (1987) highlight the tendency to write irrelevant information as a strategy to gain marks, particularly when students are close to passing or failing a course. To minimise the occurrence of bluffing errors in assessments, it is recommended that assessments are designed to measure specific knowledge or skills, and graders are trained to evaluate the quality of evidence for this knowledge in student responses.

- Personal partiality errors:

Another factor which can affect the validity of assessments is personal partiality. This topic is explored by Lipnevich and Smith (2009), who argue that a teacher's personal biases, such as their attitude towards a student, can result in inaccuracies in the assessment process. The issue is also discussed by Brown and Knight (1994), who suggest that a teacher's personal biases, such as their preference for specific writing styles or topics, can lead to flawed assessments, while Wiggins (1993) addresses the issue of the design of assessment tasks. The author emphasises the importance of using assessment processes and practices that are equitable and impartial.

1.2.3.2 Assessment types

As diagnostics are fundamental to the research discussed in this thesis, the various types of assessment will be looked at here. Although all assessments follow the same basic steps, there are different types of data, and, therefore, different measurement processes required to acquire the information needed to define remedial pathways and improve the educational process. The different assessment types are:

1. Based on position in the educational process

   Educational processes are based on well-defined steps, from the determination of learning aims to the forecasting of learning output. These steps form the basis of assessment, which plays a key role in decisions about progression to the next learning phase, and/or the need for extra educational methods to increase student achievement. Wiggins (1998) defines educational assessment as a process which not only measures student learning, but also aids its progression through the provision of targeted feedback that supports students in improving their understanding and skills. Figure 1.1 shows the position of assessment in the overall teaching process.

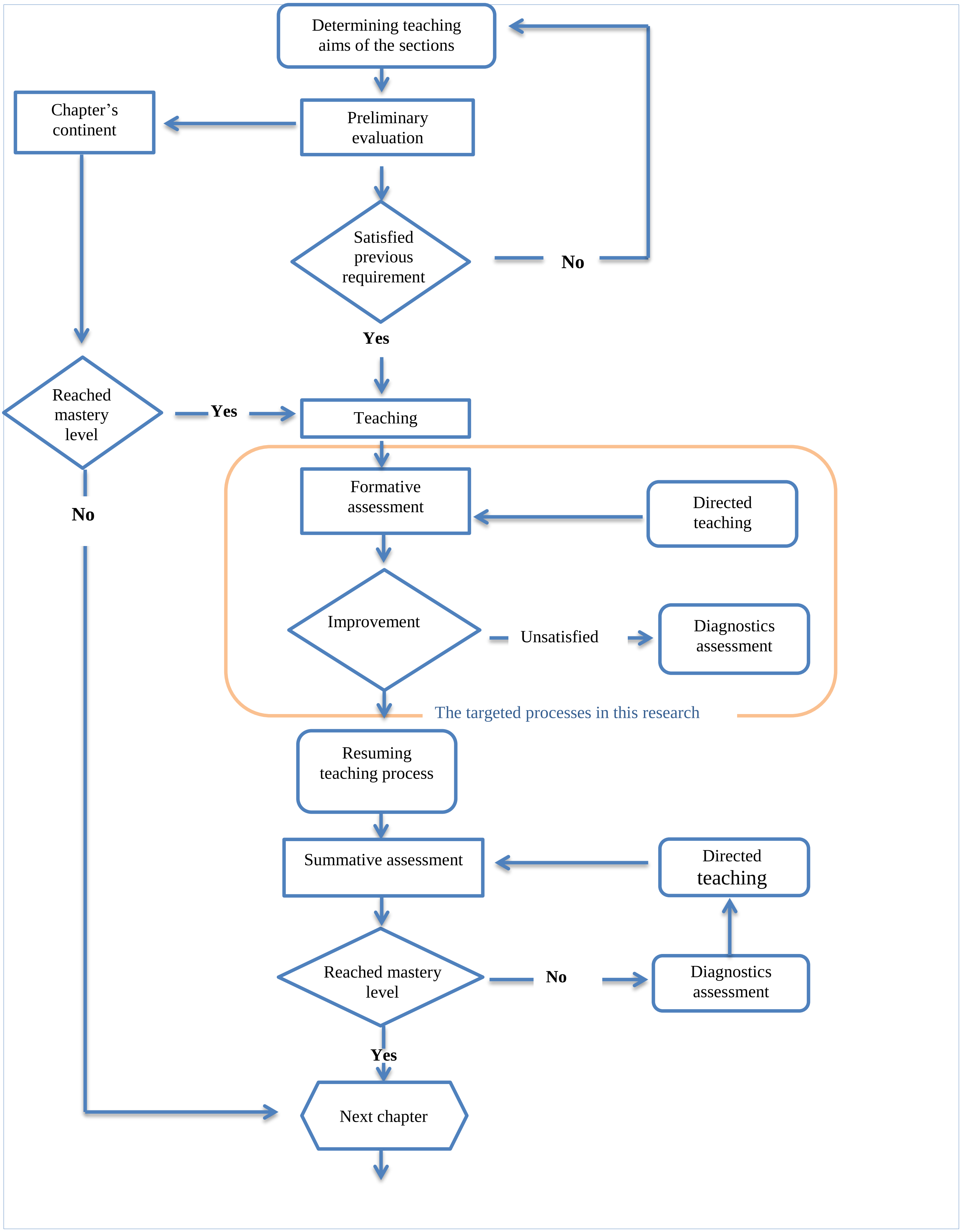

Figure 1.1: The position of evaluation in the education process (Brown, 1983)

Some aspects of assessment, such as the preliminary phase, are designed to ensure that students have what is required to enable them to understand new topics. The importance of this (preliminary) phase of assessment was stressed in a study by Birenbaum and Tatsuoka (2008), which found that it is critical in helping to identify students' learning needs and enabling the development of appropriate instructional strategies. The results of the preliminary assessment stage could lead to actions such as a redefinition of the aims of the current learning phase, or a decision to progress to the next learning phase, as reported by Black and Wiliam (1998). The authors of this study argue that feedback from assessments can be used to adjust teaching and learning activities to better meet students' needs. They might also lead the assessment team to the decision that it is necessary to split students into groups based on ability or background. These groups can then be taught with specific strategies, such as readiness assessments or placement tests. These teaching approaches are discussed by Popham (2011), who notes that such assessments can help ensure that students are appropriately challenged and supported in their learning.

In order to identify students' learning needs, and adjust instruction accordingly, formative assessments are used (Black and Wiliam, 1998). Following this process, diagnostic assessment methods are used, if required, to identify students' weaknesses and realign the teaching process appropriately (Alharbi and Alshumrani, 2018).

The final (assessment) stage in the teaching process is summative assessment. These are assessment processes which aim to determine the extent to which learning objectives have been achieved (Stiggins, 2007), and should be carried out at the end of each relevant modular phase of the teaching programme (e.g. each chapter, semester, or year). While summative assessments are often used to evaluate individual performance, they can also be used to compare student levels in different areas (domain or geographical), as discussed by Birenbaum and Tatsuoka (2008).

2. Based on the type of result and information collected

According to Audah (2010), there are two assessment types in this category:

- Quantitative measurement:

Tests can provide a precise and reliable quantitative measure of student achievement (Crocker and Algina, 2008). This type of assessment is often used in educational environments, as it is not only easier to implement, but can be used as the basis of statistical analysis (Shavelson and Ruiz-Primo, 2009).

- Qualitative measurement:

  This category of assessment includes processes such as verbal grading systems, as described by Crookes and Lehner (1998), who note that these systems, which use techniques such as holistic scoring, can provide rich and nuanced information about students' language abilities.

In practice, however, the world of education does not typically use either of these techniques in isolation, but usually combines the two approaches, as described by Banta et al., (1996). They note that using multiple assessment methods can provide a more complete picture of student progress and program effectiveness. Additionally, conceptual models such as the value-added and outcomes-based assessment models, as described by Palomba and Banta (1999), can provide a framework for understanding the complex relationships between assessment, teaching, and learning. Such systems can be helpful in designing intelligent interactive tutors, based on the use of student models as described by Woolf (2010). Woolf notes that student models can be used to track students' progress and provide personalised feedback and guidance.

1.3 Reasons for research

In the field of e-learning, the question of how to motivate students and support them through the learning process is the subject of an increasing number of research projects. The focus of these has ranged from the design of adaptive learning systems to studies of personal learning environments and learning styles/preferences. From these projects, it is clear that one of the main challenges in designing an effective e-learning assessment and feedback system is understanding the range of issues that can inhibit student progress. This is especially difficult when the topics being studied are complex, and learners are unclear as to whether their learning decisions are optimal (Azevedo et al., 2003). Using a conventional assessment method, such as a typical paper or computer-based test may not yield an accurate picture of why a student has made a mistake.

This means that there is an opportunity to create an e-diagnostic system that can be used as part of an e-learning assessment system designed to give a full and accurate analysis of the missing skills/knowledge that cause learning errors.

1.3.1 Thesis aims

The research's aim is to design, implement, test, and then evaluate an adaptive e-diagnostic system to help in the assessment of learner solving equations. This e-diagnostic system will:

- Allow the recommendation of a remedial path for learners, based on a step-by-step analysis of answers.
- Identify missing/weak skills faster than would be possible by testing students' skills singly.

1.3.2 Thesis objectives

Specific objectives of this research include:

- To design, implement and test a usable system, with the properties defined in Chapter 4, using a prototyping approach.
- To understand the factors that affect the efficiency of such a system.
- To evaluate the system in a real word context.
- To develop a student model based on this idea.

1.3.3 Research questions

In order to achieve the aims and objectives outlined in Sections 1.3.1 and 1.3.2, this research will set out to answer a number of specific questions. These are:

RQ1: What are the main factors in the learning process (of solving equations) that an E-diagnostic system must identify?
RQ2: How can these factors (from RQ1) be identified by an E-diagnostic system (in the context of solving equations)?
RQ3. What type of models and UI would achieve the goals of an e-diagnostic system most effectively?
RQ4. How can a student model be designed and implemented in an adaptive system or an E-diagnostic system?
RQ5. How can this application be tested in a real-world context?
RQ6. What are the potential benefits of such a system?

1.4 Significance of the study

Many assessment systems have been designed and built to provide an indication of a learner's understanding/knowledge level of a particular domain (subject). However, while these may successfully provide an indication of level, they do not provide reasons why a learner is actually at that level – in other words, they do not provide information as to what, if any, skills/knowledge the learner is lacking. There are many challenges in determining what these missing skills are, including:

- Learner levels are based on test answers. However, these answers merely provide evidence of missing knowledge related to that particular question.
- Learner mistakes can be caused by a wide range of factors (such as learner background, pre-skills, dyslexia etc. Conventional testing systems are inadequate for identifying these factors.
- The complexity of the domain itself. In maths, for example, there can be different reasons for the same mistake. In solving the linear equation, $3x - 5 = 7$, for example, a student may arrive at the step $3x = 4$. This, clearly, is wrong and may be a result of a mistake in addition or a mistake in changing signs. There are many ways a mistake can be made, and they are more fully described later in this paper.
- Cheating by the learner.
- Learner guessing – this is often an issue in multiple choice testing.

Currently there are no diagnostic systems which have the ability to provide reasons for student mistakes which are accurate enough to lead to effective feedback and the recommendations of a remedial path. The aim of this research is to develop such a diagnostic system.

It is intended that the findings and frameworks of this research will help e-learning professionals in higher education and other educators attain insights in, and help improve, the design of online learning in the field of solving linear equations. With some adaptations, the resulting system could be repurposed for other subject areas and will, therefore, prove useful in teaching and training across sectors that include government, private corporations, civilian and non-civilian establishments, and non-profit organisations.

1.5 Limitations in the research

The scope of this research is limited by the following factors:

1.5.1 Substantive limitations

This research focuses on students aged 14 - 16 in the domain of mathematics (specifically linear equations), and uses quantitative data collected using surveys, as well as qualitative methods such as self-reporting (by participants) and interviews.

1.5.2 Limits of technology

Research has been conducted entirely online, and is, therefore, limited to students in environments that support the appropriate technologies (e.g. computers, software, plug-ins, etc.) and device performance (e.g. internet speed).

1.5.3 Time limitations

Schools chosen for research were international schools in Saudi Arabia. Research was limited to the short period after the domain had been taught, and before the start of examinations. This limited the time available to collect data.

1.6 The basis of the study - solving a simple linear equation

In order to develop the system defined in Section 5.1, it was important to have a detailed understanding of how simple linear equations are solved. It is intended that the system could be applied to higher-order equations in the future.

First, of course, a definition of an equation is needed. According to Flat World Knowledge, (2015) this is "…a statement indicating that two algebraic expressions are equal. A linear equation with one variable, x, is an equation that can be written in the general form $ax + b=0$, where a and b are real numbers and $a\neq 0$."

To solve such an equation, a value for x must be found. For example, in the equation: $2x + 3 = 13$, where x is the unknown variable, the solution is $x=5$. This can be verified by replacing x with 5, giving: $(2 \times 5) + 3 = 13$. As both sides of the equation are equal, $x = 5$ is the correct solution.

The ability to solve such equations is valuable in many areas of life, but to do so requires the correct application of specific knowledge and skills. Defining these skills is not easy, as there are many forms of linear equations. For the purposes of this research, three forms of equations have been chosen from the National Curriculum (Gov.uk, 2013; Anton, 1994) and modified by the researcher to be compatible with the needs of this research.
These are:

1. $ax + b = d$
2. $ax + b = cx + d$
3. $n (ax +b) = m (cx + d)$

Each of these categories can be illustrated in terms of four levels of difficulty. These levels are described in Appendix (1). An example of the learning objectives of equations in Category 3 is shown in Appendix (2).

The tables shown in Appendix (1) and (2) are designed in such a way as to avoid overloading the student with information. With this in mind, many researchers have discussed the importance of Cognitive Load Theory (CLT) in the design of learning tutorial systems (Sweller, 1988; Van Gerven et al., 2002; Paas et al., 2003), especially with respect to reducing the cognitive load on learners as they work through complex problems. For this reason, the system proposed in this thesis will have usability as a key design objective.

Another important concept that students must understand is that of (mathematical) equality. Students who do not have a firm grasp of this concept have trouble in understanding the very notion of an equation (Asquith et al., 2007; Capraro et al., 2010). This need to understand mathematical equality has been exploited in the design of the proposed system, by using it as a way to identify errors by students in the solution of equations. This is discussed in further detail in Section 3.0 of this report.

An error in the expression of an equation occurs when the concept of mathematical equality is violated. Students make many common errors that lead to this, and these errors are held by the system in the form of an error model, or 'bug library' (Woolf, 2009). This library helps the system identify the type of error that a student has made. The idea is discussed in more detail in Section 3.0 of this report.

1.7 Thesis outline

In this section, the thesis outline acts as a general guideline presenting the structure of the research in detail. The structure of the thesis is organised with the help of the research activities undertaken during this study.

Chapter 1 has provided a background of the research study, and clearly identifies the gap in the literature that the study will fill. The remainder of the thesis comprises of a further five chapters. Chapter 2 offers and reviews recent literature related to the application of AI to learning and Computer Based Tests (CBT) in detail, which focuses on education theories, current instructional design and e-learning models, meta-cognition, learning styles, and user experience (UX). Chapter 3 provides a fundamental review about common theories and models that have been used in an e-learning environment. This chapter explores the field of associated technologies and methods, adaptive e-learning systems, and student modelling is examined, all as points of inspiration and departure for the current research study. Adaptive approaches will be compared and contrasted with adaptable approaches in this chapter. Chapter 4 is about the designing and the implementation of the e-diagnostic system that has been used in this thesis. Chapter 5 describes the most common methodologies used in this research giving a detailed account of the choice of methodology, and procedure, experimental design set up, along with how the data was collected and measured. The final chapter, Chapter 6 presents and analyses the results of the data collection, including qualitative and quantitative data. It revisits the research questions, discusses the research findings, recaps on the contribution along with its strengths and limitations, ending with recommendations for future works.

Chapter 2: Literature Review

2.1 Introduction

This project is concerned with the development of an e-diagnostics system, designed to aid the learning process at the individual level. To achieve this, it was decided, as noted in Section 1.1, to focus initially on a specific learning process (solving linear equations), as this is considered valuable by students (Lilley et al., 2004). Once developed to an acceptable level of effectiveness, the process can then be generalised.

The purpose of this chapter is to discuss the development of computer-based testing (CBT), and the issues related to its use in education – in particular, the evaluation of the quality of a CBT application. This is a complex subject, as CBT quality has been shown to be influenced by many factors, such as the personal characteristics of the user (e.g., prior skill, language level, individual learning style, motivation etc.), the specific type of learning application, CBT design and delivery, the mode of interaction between user and system, and the underlying pedagogical principles of learning. The chapter will, therefore, look at the thinking and initiatives across a range of fields relevant to CBT, including recent developments in the field such as e-diagnostics and adaptive systems. As this research, ultimately, is concerned with testing and assessment, we will begin with a brief review of CBT and related concepts.

2.2 Computer-based testing: a brief history

The value of standardised testing was recognised as long ago as the early 19th Century, but it was not until the 1930s that the first attempts were made to eliminate human error by automating the test grading process through the use of early computer technology. These prototype systems, developed initially by IBM, soon evolved into relatively sophisticated systems which encompassed other areas of the test process, and – by the early 1980s – computer technology was being used not only for scoring, but also to help with test design, delivery, and construction. The results of these developments, soon began to provide clear benefits, and by the mid-90s CBT, there was evidence that it improved student performance (Bocij and Greasley, 1995). However, the introduction of downloadable, Web-based testing was still decades away. Today, CBT provides many advantages over traditional tests, including greater flexibility in assembling and administering tests and more effective decision-making (Dolan and Burling, 2017). Further, effective test design considerations, such as the size and quality of the item bank, candidate volume and test administration frequency, can all be better addressed using CBT. Overall, CBT allows test administrators to benefit from the convenience, efficiency, accuracy, and consistency of technology to deliver a more seamless testing experience for all participants.

2.2.1 The challenges for CBT

In recent years, many institutions and certifying bodies have adopted Web-based techniques as part of the testing process, and the field of CBT is evolving rapidly. However, there remains a number of significant challenges, in order to achieve mass adoption, including the specification of assessment content, the calibration and maintenance of the item bank, challenges concerning teachers' and students' assessment literacy, as well as ethical and data-protection requirements (Tomasik et al., 2018). Despite these challenges, however, there is little doubt that CBT offers great potential for helping to evaluate the outcome(s) of educational processes, particularly in the form of its close relation, e-diagnostic.

2.2.2 E-Assessment

Although the terms 'test' and 'assessment' tend to be used interchangeably, they have different meanings in an educational context. A test is method of measuring a student's learning at a specific point in time, and is essentially summative, while assessment is the process of documenting skills and knowledge on an ongoing basis. Assessment is, therefore, essentially formative, and has the goal of making improvements, as opposed to simply judging (Bennett, 2011; Dixson and Worrell, 2016). Assessment is usually carried out during and after instruction has occurred.

The process of assessment plays an important role in the cognitive and affective development of learners (Maisoni et al., 2020), and many recent developments in e-assessment have been adopted by educational institutions around the world. These new methods often complement traditional assessment methods and provide opportunities for both educators and learners to enhance the learning and evaluation experience (Appiah and van Tonder, 2018; Alruwais et al., 2018). The current e-assessment technology offers a range of benefits, including:

- Flexibility: Learners can take advantage of the ‘anytime, anywhere’ facility of e-assessment, reducing scheduling conflicts.
- Immediate feedback: Learners receive instant feedback on their performance, helping them identify and understand areas for improvement.
- Enhanced efficiency for educators: The automation of parts of the assessment process can save time for educators.
- Data-driven insights: E-assessment systems can provide valuable data on learner performance, assisting educators in the identification of trends and the development of instructional strategies.
- Inclusivity: E-assessment can provide accessibility for students with diverse needs, such as those with learning differences or disabilities.

While the current capabilities of e-assessment are significant, advances in digital technology are enabling yet more sophisticated developments. New techniques in e-assessment which are, today, either in development or in the early stages of application, are:

- Adaptive e-assessment: The use of artificial intelligence (AI) and machine learning algorithms to adjust the type and difficulty of questions, based on a learner’s previous responses, facilitates a more personalised approach, enabling a more accurate and reliable evaluation of a student's knowledge and skills (Chrysafiadi et al., 2020). As personalisation and feedback is central to the development of the system discussed in this research, these systems will be discussed in more detail in Section 2.2.4.

- Gamification and interaction: E-assessment platforms are integrating gamified elements and interactive features, in order to make the assessment process more engaging and enjoyable for students. The aim is to improve learner motivation and retention, while retaining assessment accuracy (Vapiwala and Pandita, 2020).

- Data and learning analytics: E-assessment platforms are developing the ability to leverage data analytics to gain insights into learner performance and behaviour. The analysis of data collected during assessments allows the identification of areas for improvement as well as the individual’s learning patterns (Barana et al., 2019)

2.2.3 E-Diagnostics

For the purposes of this research, e-diagnostics is defined as the use of digital technologies and tools for assessment and evaluation in a learning context and can help to identify any incorrect learning behaviours and misconceptions the learner may have, as well as skillsets that need to be developed. While e-diagnostics in an educational context is a relatively new field, it is evolving rapidly and is already being used by many learning institutions, as it has been shown to support and improve the learning process and outcomes in a number of subject areas, such as reading, mathematic and the sciences (Resta et al., 2020; Csapo and Molnar, 2019).

The concept of e-diagnostics can be applied in a learning environment for a variety of purposes. However, some of these purposes are particularly pertinent to this research, which aims to deploy models to help develop an e-diagnostic system that can evaluate a learner’s progress and provide feedback that will help them, if they have not understood, or are misapplying, any part of the domain. While this process is already an integral component of most teaching strategies and is considered by many to be – if used appropriately (Orrell, 2006) - an important tool for improving student academic performance (Tawafak et al., 2019), it is currently a (mainly) manual process, which can be slow, inconsistent, and inaccurate. The introduction of the system proposed in this research will address these issues. The methodology for building such a system is described in detail in Chapter 4 of this paper, but it is relevant here to briefly describe the applications of e-diagnostics that have formed the development process in this research. E-diagnostic process is a powerful and effective method of delivering:

- Formative assessment: E-Diagnostics facilitate formative assessment processes, which focus on understanding students' progress, and can help identify potential learning gaps at an early stage. This allows educators to intervene promptly and help students improve their learning.

- Personalised learning: Through the ongoing monitoring of a learner's performance and progress, educators can identify the strengths and weaknesses of each individual learner (Sebba et al., 2007). This allows them to provide content and activities that match the specific needs of students, thereby increasing the probability of positive outcomes.

- Immediate feedback: A major benefit of e-diagnostics is the ability to deliver immediate feedback to learners. This not only helps them identify and understand mistakes, but also facilitates immediate remedial pathways, and, therefore, a deeper understanding of the domain in question (Schartel, 2012)

- Remote and blended learning: As the use of remote and blended learning environments become more prevalent, e-diagnostics tools have become key, as they allow assessment and evaluation, independently of physical location (Koc et al., 2015)

However, although e-diagnostics can deliver significant benefits, it is important to note that there are ethical considerations concerning issues such as data privacy and security. This is another important element in the design of the system described in this paper.

2.2.4 Adaptive systems

Another concept which has played an important role in the development of the e-diagnostic system described in this paper, is the adaptive system. These are systems which provide learning environments or technology platforms that dynamically adjust and personalise the learning experience to the unique needs of individual students (Wilson and Scott, 2017). Although the use of adaptive teaching methods goes back to the 1950s (Pask, 1982), advances in digital technology in recent decades has enabled the development and implementation of a new generation of adaptive systems for the e-learning environment. These systems are able to use AI and machine learning algorithms to analyse a learner's performance and learning style (see Section 2.2) to provide, in real-time, educational content and activities matched to the learner's unique needs. As a result, adaptive e-learning systems have become recognised as able to help optimise learning outcomes over a shorter timeframe and in a very cost-effective manner (Sweta, 2021).

The benefits of adaptive systems (Mulwa et al., 2010) which are particularly relevant to this research include:

- Personalised learning: Adaptive systems integrate the concept of e-diagnostics described above (Section 2.2.3) to deliver instructional content and activities specific to the learner concerned.

- Increased learning efficiency: Learners can focus on ‘weak spots’ thus optimising learning efficiency and rate of progress.

- Targeted Interventions: Educators can more easily identify struggling students, provide appropriate interventions, helping to ensure better learning outcomes.

- Inclusivity: Adaptive systems make it easier to meet the needs of a diversity of learners, including those with learning disabilities or special educational needs.

However, designers of adaptive systems also face some challenges (Nuri and Sevim, 2013), particularly:

- Data privacy and security risks: Adaptive systems rely on collecting and analysing user data to personalise experiences.

- Limited exploration: Adaptive systems have the potential to discourage users from exploring new content or other options. This can lead to "filter bubbles" which limit the exposure of learners to diverse viewpoints and experiences.

- Maintenance and updates: Adaptive systems require ongoing monitoring and maintenance to remain effective and relevant. This can be resource-intensive and may lead to additional costs.

- Unintended consequences: These include the reinforcement of stereotypes, amplifying misinformation and favouring certain groups over others. Such consequences can be difficult to predict and mitigate.

Overall, adaptive systems in education hold great promise in advancing the learning experience, making it more effective, engaging, and inclusive for students of all backgrounds and abilities. As technology continues to advance, these systems are expected to play an increasingly significant role in the education landscape. The system described in this paper will contribute to this evolutionary process.

2.3 Learning theories

There are several theoretical constructs which underpin the system development described in this paper. These are briefly described below.

2.3.1 Cognitive learning and meta-cognition

Cognitive learning theory explains how internal and external factors influence an individual's mental processes to supplement learning. Essentially, cognitive learning is a change in knowledge attributable to experience and has three components: (1) learning involves a change, (2) the change is in the learner's knowledge, and (3) the cause of the change is the learner's experience (Mayer, 2002). Learners are, therefore, considered to play an active role in the learning process, able to construct an individualised understanding of their context.

A related concept, evolved from cognitive learning theory, is meta-cognition. Often defined as "knowing about knowing", meta-cognition has also been described as the process of enabling a learner to understand their own cognitive abilities and performance (Krathwohl, 2002; Hussain, 2015; Anderson, 2013). At a practical level, and relevant to this research, a meta-cognitive strategy helps students learn more effectively by implementing a process that involves setting their own goals, planning the study sequence, monitoring their own progress, and evaluating outcomes of the learning process.

2.3.2 Constructivism

In the 1970s, a new learning theory, called constructivism, emerged. This theory posits that learners actively construct knowledge and meaning, based on experiences, as opposed to a process in which learning is the passive transmission of information from one individual to another (Narayan et al., 2013). Constructivists claim that knowledge should be constructed by the learner, as opposed to being 'given' it through instruction, and that knowledge can only be a product of our own cognitive acts (Confrey, 1990). This emphasis on learning as an active, rather than passive, process, means, in the context of e-learning, that learners should be given the freedom to choose the type and order of learner-content interaction they prefer, based on missing skills identified by the system proposed in this research.

2.3.3 Self-regulated learning (SRL)

Broadly, self-regulated learning is said to occur when learners adapt their approaches to the learning process (Boekaerts, 1999). It is a learning process that involves many of the same activities as a meta-cognitive strategy (Puustinen and Pulkkinen, 2001; Pintrich, 1995). By monitoring, planning, and regulating their own learning, SRL helps students to develop effective learning outcomes, and learners who use meta-cognitive strategies and engage in SRL are more likely to achieve higher academic performance, according to a number of studies (e.g. Lindner and Harris, 1992; Zimmerman, 2015). The intention of this research is to apply the basic logic of SRL to e-learning environments. In other words, the aim is to design a system which encourages students to engage with, and deploy, the self-regulation process.

2.4 Learning and cognitive 'style'

Theories of learning and cognitive 'style' are also relevant to the development described in this paper. Although the terms 'learning style' and 'cognitive style' are often used interchangeably, they are in fact (subtly) different constructs (Sadler-Smith, 2001), with different implications in different contexts.

‘Learning style’ has been defined as “…behaviours that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment” (Curry, 1981) and are considered by many to be an important component of success in higher education (Romanelli et al., 2009). ‘Cognitive style’, on the other hand, is considered to refer to the fact that learners have different stylistic preferences in the acquisition and processing of information (Hayes and Allinson, 1998). One key difference between learning style and cognitive style is that the former tends to be context-dependent, while the latter is generally thought to be a hard-wired brain function (Sadler-Smith, 2001).

2.4.1 Types of learning style

Because learning styles are fundamentally concerned with active learner control, they are of particular relevance to this research, which focuses on identifying points of weakness in the learner and empowering them to use this information to improve their performance.

Nevertheless, there is a variety of identified learning styles, and many approaches to implementing them in a learning environment. In fact, Coffield and colleagues identified 71 learning style variants (Coffield et al., 2004a). Not all of these styles are equally relevant to the current context. Below, four of the most frequently used learning styles are briefly described, together with their relevance (or lack of) to the current research. However, Coffield et al, (2004b) highlighted the importance of re-testing some learning styles, for example, Apter’s Motivational Styles Profiler, Herrmann’s Brain Dominance Instrument, and Jackson’s Learning Styles Profiler, by researchers other than those who created them.

2.4.1.1 Fixed learning styles

This group of learning styles, known as “constitutionally-based” maintains that individuals are born with a particular learning style, and that it can be changed very little, if at all (Pashler et al., 2008). This analysis, however, has met with significant criticism on grounds that they entail a highly structured and prescriptive view of learning preferences, which could lead learners to a restrictive and self-limited learning style that prohibits experimentation with other learning preferences. As this research considers flexibility of learning style to be essential, these criticisms mean that this category of theories is not suitable as the basis of the learner-directed framework that is the objective of this research.

2.4.1.2 Cognitive styles

A cognitive learning style is essentially the result of the way a person thinks, and is a preferred and habitual approach to organising and representing information, as opposed to an approach mandated by inherent brain structure (Reynolds, 1997). Though less rigid than the constitutionally-based group described above, these learning styles nonetheless focus on the interactions of cognitive processes and controls (Duff, 2004). This style represents an evolution from constitutionally-based learning styles, differing from them in that these (cognitive structure) theories have a more holistic approach, rather than a rigid adherence to matching learner type with learner style. However, while cognitive styles have considerable appeal, they also have their critics, who claim that they suffer from, among other things, “conceptual confusion, contested definitions, poor measurement and lack of validity” (Peterson et al., 2009). Despite this, these styles have a clear relationship to the current study, which helps the learner reflect on what they have to learn by giving them clear and immediate feedback.

2.4.1.3 Context-sensitive styles

One of the best-known theories of learning is the Experiential Learning Theory (ELT), developed by David Kolb (1984). This, as the name suggests, is based on the premise that our experiences, including our thoughts, emotions, and environment, all impact the learning process, and can be broken down into four discrete stages: concrete experience, reflective observation, abstract conceptualisation, and active experimentation. Although Kolb’s original model has attracted criticism for various reasons (Bergsteiner et al., 2010), the concept has been widely applied by educators in higher education for several decades, across a variety of subject areas (Kolb and Kolb, 2017; Abdulwahed and Nagy, 2009; Turesky and Gallagher, 2011).

ELT is one of a group of context-sensitive learning style models – i.e. learning preferences can change (to a limited degree), as opposed to being fixed entities – although they also claim that there is a level of long-term stability in learning styles (Kolb, 2000). In general terms, this group of models maintain that learning styles are actually less of a style than a preference, and they place a large emphasis on progression and balance to give a holistic learning experience. As a result, these theories have much in common with this research project, in as much as they accommodate the notion of individual learning preferences without being overly prescriptive. Learners can use the system described by this research as a guide as to which skill to learn first.

2.4.1.4 Learning strategies

In this group, the emphasis moves away from style and towards strategies for learning, which entail a broader perspective on learning preference than is the case with previous categories. Essentially, learning strategies tend to focus more on the learner experience than the teaching methodology, and are based on the use of constructive diagnostics to improve learning. Many scholars argue that learners can learn more effectively when they are more aware of their own approaches/strategies (Riding and Rayner, 2013).

Learning strategies can be divided into two principal subgroups: deep and surface learning (Beattie et al., 1997). Both developed during the 1970s and 1980s, the former approach involves learning with understanding, while the latter relies on simple recall of facts (rote learning), and research has shown that students tend to adopt deep learning strategies when they are engaged with the learning process and their perceived value of the course content is high (Floyd et al., 2009). Studies have also found that students who adopt a deep approach tend to have better academic performance than those who use other approaches (Chotitham et al., 2014).

It is notable that, over recent years, there has been a change in research focus from the idea that styles are fixed and immutable, to the acceptance that, rather, styles are context-specific, and allow learners to choose their preferred learning strategy. As the current research project is more closely aligned with the ‘flexible’ end of this spectrum than the ‘fixed and stable’ end, it was decided, after considerable deliberation to use Kolb's theory (Section 2.4.1.3) as the design framework for the system to be developed. This is because, as a model of the learning process which allows students to choose their preferred learning style, it is well-suited to an e-learning framework - and particularly a framework which considers self-paced learning to be integral to its design. The intention of this project is to develop a system which provides the learner with immediate and accurate information about their weaknesses in the learning domain, in order to help them learn only what is necessary, rather than the entire domain.

2.5 The importance of E-Learning

The development of an e-diagnostic tool is an important step forward in the implementation and progress of e-learning, which is, in turn, an important component of individualised learning. This (individualised learning) has become, over recent years, widely recognised and endorsed as a key approach to improving curricular engagement and academic achievement (Prain et al., 2013). Until the emergence of the concept of individualised learning, mainstream teaching principles and processes were built upon the assumption that all students learned in a similar way. However, this does not take account of individual variances in cognitive style, defined as personal and specific approach to organising and processing data during the thinking process (Price, 2004). Traditional teaching methodologies tend not to acknowledge the role and function of cognitive style in determining performance in a learning context (Riding and Sadler-Smith, 1997). Individualised learning, on the other hand, addresses this issue, and offers a range of benefits over conventional teaching methodologies. By allowing learners to follow their own learning journey, an individualised approach places the focus on a student's specific competencies, and takes into account their individual perspectives, culture and other factors, while empowering "on-demand" learning (Sampson and Karagiannidis, 2002)

2.5.1 E-learning models

E-learning models provide frameworks that help to address the specific concerns of the learner, so that the learning process is effective. They provide useful tools for assessing e-learning initiatives and identifying the key factors which are critical to success (Engelbrecht, 2003). While new e-learning models frequently emerge, as new research is completed and published, there is a genre of model which is particularly pertinent to the development process behind this process: Instructional Design Models (IDMs).

Although there are various definitions of an IDM, which vary in terms of some specifics, it is broadly agreed that such models aim to “provide conceptual tools to visualize, direct, and manage processes for creating high-quality teaching and learning materials” (Branch and Kopcha, 2014). Those who support the use of IDMs claim that they can fulfil a key role in delivering a positive and effective learning experience by not merely guiding, engaging, and motivating learners, but also giving them a high degree of control over their own learning (Hardre and Chen, 2005; Fyle et al., 2012; Tessmer and Richey, 1997). Other scholars, however, although a small minority, dispute the usefulness of IDMs.

In one critical literature review on e-learning, for example, Wong concluded that the application of these models does not necessarily improve outcomes but are a ‘mere vehicle’ for the pragmatic delivery of content (Wong, 2007). For the purposes of this research, however, the IDM is considered to be relevant and valuable. The various types of widely used IDM will, therefore, be briefly described.

There are five principal models that e-learning designers currently generally implement: the ADDIE Model; Merrill’s Principles of Instruction; the ARCS Model of Motivation; Gagne’s Nine Events of Instructions; Bloom’s Taxonomy.

2.5.2 The ADDIE Model: a learner-centred approach

The first IDM to emerge as a practical and widely-used tool, the ADDIE model was originally developed for the U.S. Army in the 1970s. Based on an earlier concept, called the Five Step Approach, the ADDIE model retained the five steps (Analysis, Design, Develop, Implement, and Evaluate), and, over the next few decades, proved effective in helping developers implement a learner-centred strategy, as opposed to a teacher-centred strategy, thereby making the program more accessible and meaningful for learners (Peterson, 2003). In recent years, the ADDIE model has begun to gain critics, largely because the model is highly linear, requiring the completion of one phase before starting the next. Further, the process is not iterative, so stages cannot be revisited once they are completed. This means that design flaws often aren't recognised until too late (Allen, 2006). However, while there is now considerable debate about its effectiveness in meeting the needs of the current generation of learners, the fact remains that many designers still use ADDIE as a process for creating e-learning courses.

2.5.3 Merrill's Principles of Instruction (MPI)

Proposed by David Merrill in 2002, this framework proposes a 4-phase cycle of instruction consisting of activation, demonstration, application, and integration. According to the model, the 'learning cycle' begins when an instruction prompts the learner to recall, relate, describe, or apply knowledge from real-world experience that can act as the basis for new knowledge. If learners have limited experience, then the instructions provided should generate relevant experience that can be used as a basis for new knowledge (Merrill, 2007). This four-phase process enables educators to present their learning exercises in a way that improves student learning and facilitates the incorporation of new methods within the process (Peterson 2007). However, while research has shown that the use of MPI in education improves student learning and satisfaction (Suartama et al., 2019) experience has shown that implementing the theory in educational practice can present problems (Reigeluth and Carr-Chellman, 2009).

2.5.4 Gagne's Nine Events of Instruction

Originally proposed in 1965, Robert Gagne's framework learner-centred consists of a series of events based on the behaviourist approach to learning. Introduced by John Watson in 1912, behaviourism formed the foundation of early e-learning systems (Ally, 2008), and is based on the idea that all behaviours are learned through interaction with the environment. Learning can, therefore, be stimulated through techniques such as positive reinforcement (Ng'andu et al., 2013). In recent years, Gagne's framework has emerged as one of the most commonly used IDMs, as it has been shown to provide an effective structure for eLearning, and has been applied in a range of domains, such as the military, leadership, healthcare and engineering (Suryawanshi, V. and Suryawanshi, D., 2015). Gagne's nine steps are shown in Table 1.

Step	Purpose
Gain attention of the students	Use stimuli that catches and engages their brain.
Inform students of the objectives	Establish the expected outcomes and criteria for measuring achievement.
Stimulate recall of prior learning	Leverage existing knowledge before introducing new knowledge.
Present the content	Deliver the content in an easily consumable form.
Provide learner guidance	Guide them with examples and other instructional support.
Elicit performance	Engage students with different activities that recall, utilise, and evaluate knowledge.
Provide feedback	Reinforce knowledge with immediate feedback
Assess performance	Test knowledge with established (and transparent) criteria.
Enhance retention and transfer to the job —	Use content retention strategies (concept maps, rephrasing, summarizing, job aids, etc.)

Table 1.1: Gagne's 9 Steps

However, despite its popularity, Gagne's model has its critics, who argue that behaviourism is an essentially flawed concept. This criticism is based on the claim that not all learning is observable through overt behaviours, and that behaviourism does not take account of non-behavioural (i.e. cognitive, representational, or interpretative) activity (Graham, 2010).

2.5.5 The ARCS Model of Motivation

The ARCS Model, introduced in the 1980s by John Keller (1983, 1987proposed four steps for promoting and maintaining motivation throughout the learning process: attention, relevance, confidence, and satisfaction (ARCS). Of these four steps, two are of particular relevance to the current research: (a) Confidence, which reflects the idea that learners should have some level of control over their learning, and that success is a function of the amount of work they put in, and (b) Satisfaction, which suggests that satisfaction in the learning experience results from (intrinsic or extrinsic) motivation.

Proponents of this model claim that it provides well-defined design strategies and reinforces learner-centred design. However, affective outcomes are often hard to evaluate, and the model offers no strategies that deal with the measurement of learner motivation (Malik, 2014; Small, 2000). The current study aims to measure specific weaknesses of the learner, and, therefore, allow the system to present the relative remedial path more quickly and accurately. The intention is to encourage the learner to increase practice levels rather than deliberate too long over why he or she does not improve.

2.5.6 Bloom's Taxonomy

Created in 1956, Bloom's framework is a hierarchical model which categorised learning objectives into six levels of complexity, from basic knowledge and comprehension to advanced evaluation and creation. These categories were Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation, and the model was predicated on the notion that cognitive knowledge is a necessary precondition for developing skills and abilities. In 2001, Bloom's original taxonomy was revised to reflect how learning is an active rather than passive process and included an important new dimension: metacognitive knowledge. This is, essentially, the process of enabling a learner to understand their own cognitive abilities and performance (Krathwohl, 2002).

Although Bloom's Taxonomy has met with several valid criticisms (Soozandehfar and Adeli, 2016), it is still widely used in the educational setting today and makes a significant contribution to helping educators get the best out of learning technologies by providing a basis for the design and/or evaluation of e-learning initiatives from a pedagogical perspective (Barari et al., 2020). Bloom's taxonomy is relevant to this project as, when applied to e-learning, it can help instructors to understand the different levels of cognitive demands.

2.6 User experience, learner experience and user-centred design

In the following section, we will describe how user experience, user-centred design and learner experience have informed the development process in this research.

2.6.1 User Experience (UX)

Although the term ‘user experience’ (UX) has been in use since the emergence of the World Wide Web, there remains no universally agreed single definition of it. In recent years, however, it has become widely accepted to be a term that describes a user’s response to interacting with a product, service, system, or an object, and which is “dynamic, context dependent and subjective” (Law et al., 2009; Allam and Dahlan, 2013).

However, while UX may be subjective and context-dependent, this does not mean that it is fundamentally unmeasurable. In fact, there are many aspects of the E-System experience which can be quantified, such as the speed with which a user can navigate a site, or how quickly and easily users react correctly to instructions. There are also ‘external’ parameters which can be reasonably assessed, such as how well (or badly) users as a group adapt to, and use, a system, and the effect that adoption has on organisational performance.

In the (e-learning) context of this research, UX is evaluated through the measurement of user-ratings for system features such as look/feel, ease of use, controllability, and performance. Measurement of these system features will use an ‘open question’ approach rather than a ‘closed question’ approach – in other words, users will have the opportunity to use free text in their responses, rather than choose from pre-set responses. The sample group for UX measurement will be confined to learners only.

In the following section, the difference between learner and user experience will be reviewed in greater detail.

2.6.2 Learner Experience (LX)

As has been noted, UX in an e-learning context has a similar, but more specific, definition than when used in a wider context. The author of this paper has, therefore, introduced the term ‘Learner Experience’ (LX) to refer to UX in an e-learning context. This term is intended to mean the overall effect, in terms of perceptions and attitudes, on a learner of interacting with a learning system. Of course, as with UX, an accurate and meaningful evaluation of LX is not a straightforward issue, although it can be done – after all, a well-designed e-learning environment can include activities which allow relatively easy observation and measurement of learner engagement. Such an environment should facilitate the collation of sufficient data to provide a reasonably comprehensive record of user engagement for each activity, allowing an accurate assessment of issues faced during the learning process. In addition, such a system should be created in accordance with the principles of what is known in the Instructional Design field as ‘design science’ – a process which extends beyond the superficial paradigm of aesthetic design (Baskerville, 2008), and helps learners engage cognitive processes such as creating, problem-solving, reasoning, decision-making, and evaluation (Blanchard and Frasson, 2004). Such a system should also implement interventions which help students understand learning strategies, and gain motivation and self-worth through academic success (Zimmerman, 2015).

2.6.3 Combining UX and LX

In designing an e-learning system, great care must be taken to ensure that the UX and LX elements are carefully and appropriately balanced. To achieve this, a number of principles are considered to be important. In particular:

- Ease of use: The system should feature an interface which is clear and intuitive. Users should be offered a limited number of choices (to avoid confusion) and be given flexibility in choice of study domain.
- Contextual support: The system should provide learners with missing knowledge by giving them the domain that they should study based on their needs.
- Directed learning: A direct link to each domain element should be provided to guide the learner to any identified missing skills.

The design of an e-learning system should consider all the ideas discussed above. These include education theories that allow the application of individual learning preferences and encourage autonomous learning, the inclusion of meta-cognitive activities associated with self-regulation and learner-directed processes, the blending of UX and LX principles, and consideration of instructional design models that support learner control. As per Yakit and Ismailova (2018), UX is crucial for the success of learning management systems. According to Revythi and Tselios (2021), based on the UX, construction is an important factor in e-learning technology acceptance research. Their report states that the satisfaction factor significantly influences the intention of the users using e-learning technology.

2.7 Summary

This chapter reviewed the literature related to the current study in five areas: education theory, test and assessment models, learning styles, instructional design models and user experience. The first area described the ideas behind current and emerging test and assessment models, with a focus on the latest thinking within an e-learning environment, while, in the second area, education theories were discussed with an emphasis on the models which informed this research. These models are built upon the premise that, to enable learner-directed learning to materialize, learners need to participate actively in their own teaching. The third area explored various learning style theories and their classifications and discussed how these theories have evolved over the years, from assuming learning styles are a fixed trait, to recognising that they have a certain degree of flexibility. In the fourth area, we described instructional design models with an emphasis on those which have learner-control and learner-direction elements. The main types of models were briefly discussed, as well as the present gaps between these models and what this research aims to achieve. Finally, we discussed user experience (UX) as it is related to online learning design, and how it is differentiated from learner experience (LX). This account of UX and LX highlighted that there is a necessity to be provided with an alternative learning design which can (a) facilitate holistic learning, (b) augment learner-control and self-regulation processes, and (c) support learning preferences in new learning environments. In a Chinese study (Dong et al., 2020) it was found that it's possible that the low quality and dull content of online learning is what has prompted Chinese parents and children to resist and even reject it. The next chapter will look at providing learner-directed learning and learner control through the point of view of student modelling. A review of popular user and student models will be provided, as well as a discussion of the adaptive versus adaptable approach. These chapters all contribute to the knowledge required to create an online learning environment based on identifying missing areas of knowledge and providing an immediate and effective remedial pathway that optimises the learning process.

Chapter 3: Using student modelling in adaptive E-Diagnostic systems

3.1 Introduction

The previous chapter provided an overview of the current state of thinking and development across a range of fields relevant to CBT. This chapter looks more closely at the role of adaptive e-learning systems and associated technologies and models, in the design and implementation of the e-diagnostic system which is the subject of this research. The aim of this e-diagnostic system is to identify the cause(s) of errors in a student's reasoning when they attempt to solve a linear equation, and to then provide (and re-test) a remedial path. The development of such a system requires the use of a range of modelling techniques, together with an understanding of how to meet specific learner needs. This is the domain of adaptive systems. Although the concept of adaptive e-learning systems was briefly discussed in Chapter 2, in this chapter, the idea is examined in more depth.

In an educational context, an adaptive system is defined as a learning environment or teaching methodology that has the ability to tailor the learning experience to meet the specific requirements and capabilities of individual students. Using advanced technologies, such as machine learning and AI, an adaptive system dynamically adjusts the pace, content, and presentation of instructional materials to deliver a personalised learning journey for each learner, with the aim of optimising outcomes (Taylor et al., 2021; Wilson and Scott, 2017). In order to achieve this, the system captures data about the learner via the concept of a User Model: i.e. a dynamic representation of an individual learner's characteristics, preferences, abilities and learning behaviours (Glushkova, 2015; Brusilovsky and Millan, 2007). Information captured will typically include data points that describe factors such as performance, progress, motivation, knowledge, and skills.

3.2 User and student models

In the following sections, user and student models will be defined and described, and their use in adaptive learning systems will be discussed.

3.2.1 The user model concept

In the overall context of computer science and human-computer interaction (HCI), a user model is a representation of a user's personal characteristics, preferences, behaviour, and interactions within a specific digital environment, such as a software application or website. User models are often used in high-functionality systems, to make them more usable and useful (Fischer, 2001). In an educational setting, the concept of the user model refers to a system that facilitates an adaptive and personalised approach to learning that matches content and experiences to individual learners' needs, preferences, capabilities and learning style (Martins et al., 2008), as described in Section 2.4.1 of this paper. This type of user model is known as a 'student model', and this will be discussed in more depth in the following section (Section 3.2.2). In general terms, however, user models play a key role in field of human-computer interaction (HCI) that aim to provide personalised user experiences and are constructed by collecting data on user-system interactions, user choices, content consumed and user feedback (Biswas and Robinson, 2010). A model that captures various aspects of the user's characteristics and preferences is then built, based on the collected data. User models are continually and dynamically updated as the user interacts with the system over time, and AI technology is used to deliver personalised services, recommendations, and content, depending on the individual's specific preferences and needs. This form of user model is widely used across application areas, ranging from recommendation systems (e.g. movies on streaming platforms), to the presentation of personalised advertising.

User modelling can be seen as an approach to resolving the technical conflict presented by the challenge of designing a system that can meet the needs of many users, while functioning in a way that is specific to individual users (Fischer, 2001).

3.2.2 The student model

One specific variant of the user model is the student model, which is a concept used primarily in educational technology or ITS (intelligent tutoring systems). The term refers to the representation of an individual learner, and is created by analysing the learner's progress, strengths, weaknesses, and other relevant educational data. The main purpose of a student model is to provide personalised learning experiences and support to each learner. The model can include information such as:

Learning progress: the topics the learner has mastered, and areas where help is required.

Learning style: the learner's preferred approach to learning and absorbing information.

Skill levels: the student's proficiency level in a particular domain (subject).

The benefits of the student model include:

Individualised learning: Learners receive instructions specific to their needs and abilities, making the learning process more efficient and effective.

Increased engagement: Tailored content helps to keep students motivated and engaged in their learning journey.

Targeted intervention: The system can identify learner problems at an early stage, thus enabling timely intervention and help.

Diverse learners: The user model concept can be adapted to many different learning styles and abilities.

Faster progress: Students can learn and progress at their own pace, often resulting in faster learning.

Data-driven decision making: Educators can make data-driven decisions concerning the curriculum and teaching strategies.

Student models continuously gather data concerning the learner's performance and behaviours, in order to provide feedback, and help the student understand their progress and identify areas where further development is needed. Such models are usually implemented using a blend of various educational technologies, data analytics and AI, and have the aim of enhancing the learning process and optimising outcomes. One important aspect of the student model, which is particularly relevant to the models implemented by e-diagnostic systems such as that described in this research, is the need for a mechanism that can identify and represent misconceptions or false information which the student might have acquired, and which could hinder learning progress (Rafi and Pourdana, 2023). The development of such a model requires a knowledge base gained by asking the learner questions about how they intend to solve the problem being considered, and analysing their response (Antonio et al., 2008).

Essentially, therefore, a (student) user model is an abstract representation of the learner within an e-learning system (Tadlaoui et al., 2016). They (student models) can be described in terms of three individual components: a profile, a cognitive overlay, and a course overlay. The first of these components, the learner profile, stores basic personal and demographic data, such as name, gender, age, preferred learning styles, etc. The second and third components use overlay modelling, which enables the system to infer a learner's knowledge levels dynamically, using evidence collected during the learning process (Nguyen and Do, 2009). These two aspects of the student model are the cognitive overlay model, which stores the system's 'beliefs' relating to the learner's knowledge, and the course overlay component, which stores information about the learner's interactions with the system. These last two components (cognitive and course overlay) are discussed in more detail in Section 3.2.3.

3.2.2.1 The student model: main challenges

The development of an effective student model represents a considerable intellectual and practical challenge. This has been recognised since the mid-1980s, when pioneers in the field introduced the concept of Adaptive and intelligent Web-based educational systems (AIWBES) to provide an alternative to traditional teaching methodologies (Brusilovsky and Peylo, 2003). Since then, there have been significant advances in the technology, largely due to developments in fields such as big data, learning analytics and scalable architectures (Essa, 2016). Despite this, however, the development of a model that can perform consistently and reliably with many individual students, each of whom have different learning abilities, preferences and cognitive styles is a far from trivial issue (VanLehn, 1988). The principal challenge facing developers is the creation of a model that can accurately understand and capture the complexities of the learning process while addressing individual differences among students and generating an accurate remedial pathway.

This can be broken down into the following key issues:

1- Inferring intention from user actions: This is a particularly complex challenge, as intention is not always positively associated with behaviour. While the Theory of Reasoned Action posits that there is a clear and direct relationship between intention and behaviour (Fishbein, 1979), there have been many critics of this idea (Sarver, 1983), and it is now widely accepted that there is an 'Intention-Behaviour Gap' (Sheeran and Webb, 2016; Grimmer and Miles, 2016). This means that the system's analysis of user intention may be wrong, and this could cause learners to cease interaction. One real-world example of how a flawed inference of intention can lead to user irritation was the Microsoft's Office Suite Assistant, "Clippy", which was removed from the application in 2007, as it was deemed to be intrusive, insulting, and incorrect in its analysis of user requirements (Baym et al., 2019).

2- Real-time adaptability: In a learning context, students' learning needs can change rapidly. An effective student model should be able to adapt in real-time to address these changes. This adds a further layer of complexity.

3- Individual differences: Learners vary widely in their needs, differing in learning styles (how they absorb and process information, see Section 2.4), approaches to learning (surface, deep, and strategic, see Section 2.4.1.4), and attitudes about the nature of knowledge and how it should be acquired and evaluated (Felder and Brent, 2005). A model that meets the specific and unique needs of each student, therefore, requires considerable flexibility and adaptability.

4- Complexity of learning: Learning is a complex process that consists of a mixture of several factors, including prior knowledge, attention, motivation, and memory (De Houwer et al., 2013). Capturing and modelling this complex process is not straightforward.

5- Adaptability and scalability: The education environment is often very dynamic, and can change rapidly (Priestley, 2011). This requires a student model to be easily adaptable to changes in the curriculum, learner needs and teaching methods. Furthermore, student models should be highly scalable – i.e. able to accommodate large numbers of students. This can be a major challenge.

Notwithstanding these challenges, student models offer great promise for the delivery of personalised learning experiences, identifying learning problems at an early stage and providing educators with valuable feedback for better, data-driven, instructional decision-making (Chrysafiadi and Virvou, 2013). By using data patterns techniques (Blockeel and Struyf, 2022), students can be categorised based on their learning aspects which were recorded by the student models. The e-diagnostic system proposed in this paper will make an important contribution to the field.

The following section describes an approach to addressing these issues using overlay modelling techniques. There are two important types of overlay modelling: the cognitive overlay and the course overlay.

3.2.3 Overlay models

The value of overlay modelling in adaptive learning systems has been recognised for over 40 years, when the technique was first described as a method of improving a student's problem-solving skills (Carr and Goldstein, 1977). It was subsequently successfully deployed in the 1990s, in the development of interactive online learning applications which provided personalised curriculum sequencing (Weber, 1999). In an educational context, such models are termed 'overlay' models, because they typically refer to a technique which superimposes additional components or features onto an existing system, to enhance the learning experience and cater to the varying needs of a large number of individual learners. Although the technologies used in overlay models have changed, the fundamental idea is the same in that, essentially, it (the overlay) consists of a set of hypotheses concerning the learner's familiarity with the domain stored by the expert system. These hypotheses are then tested with a set of 'rules' and modified based on learner performance. Using an iterative process, the difference between student and expert knowledge is reduced.

Several types of overlay model have been used in an educational context. For the purposes of this research, however, two forms of overlay are relevant. These are briefly described below.

1- Cognitive overlay: This is an overlay element of the model which focuses on how learners process information, solve problems, make decisions, and acquire knowledge. It is a layer which seeks to understand how learner behaviour relates to performance at different stages of the problem-solving process, and to provide suggestions for a remedial pathway (Galeev et al., 2004). The cognitive type of overlay has been proven as a useful technique in building effective adaptive systems (Doleck et al., 2015).

2- Course overlay: This superimposes additional learning experiences, relevant to the learning domain, onto the current curriculum. The goal is to enhance the educational experience by providing more diverse learning opportunities, and to meet specific learning objectives. In the current context, there are three elements of the course overlay:

   - Interdisciplinary integration. By integrating ideas from different domains, educators can help to create a holistic understanding of the topic in hand and show how knowledge is interconnected across various domains.
   - Skill development: This integrates specific skill-building activities that align with the course objectives. These activities relate to communication, critical thinking and problem-solving.
   - Inclusive practices: This addresses the needs of the diversity of learners by providing additional support or specialised instruction within the existing course structure.

Overall, the use of overlays in student modelling can play an important part in enabling personalisation of the learning experience, by creating an environment that supports the widely varying needs of individual learners. It is important, however, to ensure that the collection and use of data, via the overlay, complies with security and privacy legislation, and is ethically handled to keep the trust of learners (see Section 3.4).

3.2.4 Psychological student models

In the previous sections we have discussed a type of student model (the overlay model) which compares learner domain knowledge with (domain) knowledge stored in the model itself, and provides a remedial pathway based on this comparison. However, there is another type of model used by adaptive systems, based on student profiling. These are known as psychological models, and they store a range of individual descriptors, such as language skills, intelligence, motivation, and learning style or preference (McTear, 1993; Chin, 2001). These psychological models are designed to hold any characteristic of a learner which may help the system to enhance the learning process and have proved to be effective solutions in several environments. They have, for example, been widely implemented in the context of Massive Open Online Courses (MOOC), which are typically used by tens – or even hundreds

- of thousands of users. It is worth noting, however, that, as the system cannot usually determine details of a user profile (such as learning style or preferences) from interaction only, it is necessary for the user to provide some information to the system themselves (Brusilovsky, 1996).

Psychological models are also known as cooperative (or collaborative) models, and there are three such models which are particularly relevant to this research, as they take a highly flexible, learner-centric approach and can be considered to support learner control. This section will look at each of these three models in turn, with a focus on how they support learner-directed learning, and how they have inspired key elements of this research.

3.2.4.1 Cooperative modelling in multimedia-based learning applications

A multimedia application is an interactive software that combines several forms of media (such as sound, text, video, and animation), and has been deployed in education and training for over three decades [Chang and Chen, 1995). In recent years, they have been commonly used as an educational tool (Savov et al., 2019; Andresen and van den Brink, 2013), and are especially effective in this context, as the various media components can be varied to meet the different needs of individual learners. However, building multimedia applications that are adaptive in nature, and which, therefore, use feedback to help enhance the learning process, is a complex issue. This is where cooperative student modelling can prove valuable, as it shifts the design focus of the system away from a system-centred approach to a user-centred approach. Instead of relying on the system to make an accurate assessment of the student, cooperative models combine the perspectives of the learner and the educator as the basis of a more comprehensive model (Beck et al., 1997). Although creating such a system for multimedia, using cooperative modelling, is a complex undertaking, it was successfully achieved by Barker et al., (2002), who constructed a psychological student model that comprised of a series of descriptors (language level, cognitive style, help level, and task and question levels). This model was then tested as a learning tool, and a Grounded Theory study was used to analyse the many intricate interactions that occurred between students, educators, and the learning environment.

The aim of the research by Barker et al., (2002), was to investigate ways in which multimedia learning applications can be supported and enhanced using a co-operative student model of learner characteristics. The study concluded that such a model can significantly improve the quality of learning for individuals. However, for this improvement to occur, it was important that the presentation was aligned with learners' language styles as well as their particular cognitive styles. This result was echoed by a later study which found that effective multimedia applications must be built by the educators who are familiar with their students' abilities and learning styles (Babiker and Elmagzoub, 2015). Unless this is the case, the use of the student model can be counterproductive, and result in actually demotivating, rather than encouraging, the learner. Despite this potential danger, however, the research provided a clear differentiation between aspects of learning that can benefit significantly from computer-based control and those which benefited from human input. This result provides the insight that the cooperative model, which involves input from both the learner and the system, is a viable alternative to system designs which rely on fully automated presentation of information.

3.2.4.2 Adopting a constructivist approach

Constructivism in an educational context stresses the active role of learners in developing their own competencies and understanding. Instead of receiving information passively, students are encouraged to reflect on their personal experiences, in order to construct their own meaning and knowledge (Elliott et al., 2000). This is the fundamental design philosophy at the core of the multimedia applications discussed above, as learners collaborate with the system, and their tutors, to establish an optimum configuration of the student model, as described by Neo and Neo (2009). The system discussed in this paper was inspired by this philosophy, as it represents the framework of a methodology which facilitates a fundamental shift in focus, away from automated control and towards a system that operates through direct learner feedback. However, while such a system offers significant benefits, it also presents some significant challenges. One of these challenges is that the system makes considerable demands from the learner (by requiring cooperation), and this has the potential to distract the learner, or even cause them to 'switch off' from the learning process. Another potential problem is that incomplete, or inaccurate, information supplied by a user could result in incorrect inferences by the system, such as attaching an inappropriate learning style to the student (Weibelzahl and Weber, 2003). This is a particularly relevant problem in the context of the learner in the current research, as the proposed system requires interaction with multiple cognitive styles. However, one possibility for supporting learners in interacting with learning applications, is to adapt system content according to Riding’s Cognitive Styles Analysis (CSA) test (Riding and Cheema, 1991). This is essentially a psychometric tool which is designed to evaluate an individual's learning style preferences. The assessment typically involves a series of questions that, when answered, provide insights into the learner’s cognitive preferences, strengths, and weaknesses. Riding’s theoretical construct, however, has been criticised by several scholars over the years (e.g. Peterson et al., 2007; Parkinson et al., 2004), so further investigation into how students can best be supported would be useful. Despite this, the Riding process was considered to be sufficiently proven to contribute to the development of the system under discussion in this paper.

3.2.4.3 Changing focus to visual and verbal skills

Mass adoption of computer technology began in the mid-1980s (Lin, 1998). Since then, the skills required to interact with online and other digital systems have moved on, so that, today, users often need a toolkit of visual and verbal skills to use such systems successfully. These skills include the capacity to navigate virtual worlds, together with the ability to perform complex tasks involving specific information (Ren and Bao, 2020).

It has also been shown that text and graphics work synergistically together to aid comprehension and cognitive function in a learning environment (Molitor et al., 1989; Scheiter et al., 2014; Hochpöchler et al., 2013). One practical example of this effect is the widespread use of infographics to augment the information transmission process and to improve understanding. This has been shown to be true in many environments, and especially in the education sphere (Elaldi and Cifci, 2021). As this shows that text and graphics can contribute to the construction of a domain-based mental model, accommodating various levels of verbal and visual abilities, a set of verbal and visual skills were considered as an important component in facilitation interaction between learners and the student model.

3.2.5 The student model and cognitive style

The aim of this research is to design an e-diagnostic system which can make the learning process easier and more effective for learners by identifying any missing knowledge, or gaps in understanding, that are behind a learner's errors in solving a linear equation. The remedial pathway provided by the system will be based on the learner's cognitive style. Although this (a learner's cognitive style) is known to be among a number of factors which play a critical role in the learning process (Riding, 1991), there have been few studies which examine how cognitive style influences outcomes within an adaptive environment (Liu and Ginther, 1999). One study, however, found that, when learners are faced with tasks that are relatively difficult and complex, they cannot be related exclusively to a single dimension of cognitive style, for example (Martinsen and Furnham, 2015). Another factor which is important in the learning process is learning style (as opposed to cognitive style), which is defined as the personal preferences and skills that shape how learners perceive and process learning materials (Sadler-Smith, 2001). While, in recent years, there have been some attempts to build adaptive learning systems using either cognitive or learning styles, examples of projects which take both into account are rare (Hsieh et al., 2011; Mampadi et al., 2011).

In the current research, cognitive style played a key role in the design of the prototype that was tested in the real world. This prototype was evolved over a number of different stages. In the initial version, many users found the UI (user interface) difficult, as it required high levels of input from the user to determine how they solved the equation provided. This required the user to read and follow many instructions on using the UI, as well as follow instructions on solving the equation. The result was that many users were distracted from the task and felt negative about the UI. The final prototype, however, employed a more visual and intuitive UI design, and was found to be much easier to use. This is consistent with evidence from the literature that cognition (thinking) processes in individuals vary, with some using words and others using images as the internal representational mechanism (Mayer and Massa, 2003). However, there is, as yet no general consensus on how this difference affects learning (Kirschner and van Merrienboer, 2013).

The following section describes the next stage in the evolution of learner-adapted systems that give the learner greater control over the learning process, with a particular focus on interaction with the learner model. There is also a proposal for the creation of a learner-adapted system that is flexible and gives learners a choice of learning tools and other on-demand elements.

3.2.6 The shift towards learner-adaptable systems

In recent years, there has been a significant shift in the focus of student modelling and adaptive systems, towards support for higher levels of learner control over the learning process. Today, systems are emerging that give the learner greater responsibility for their own learning and provide a model which shifts the emphasis from an automated, adaptive environment to an environment which is more user adaptable. As Kay (2001) has pointed out, this shift is illustrated by the very terminology used in the educational environment today. Whereas the early teaching systems referred to the user as ‘student’, the term now often used is ‘learner’, reflecting a greater recognition of the learner's need for control over the learning process. The same scholar (Kay, 2001) has also provided a high-level architectural proposal for a flexible learner-adaptable system, able to offer the level of support available in the latest ‘species’ of adaptive learning system. Such systems incorporate a range of advanced educational features, such as guided learner-adaptable scaffolding, as described by Jackson et al., (1998). This is a process which is designed to help learners develop their abilities gradually, by building upon existing knowledge and skills, and involves breaking complex tasks down into smaller, more manageable tasks. As the system detects that the learner is becoming more competent, the ‘scaffolding’ is gradually removed, allowing them, over time, to complete tasks independently. The concept of scaffolding is an integral element of the system proposed by the current research (Chapter 4).

The next section discusses the relative merits of adaptable versus adaptive approaches to system design, and how they have influenced the design philosophy of the model described in this thesis.

3.2.7 Adaptive versus adaptable approaches to the learning process

Adaptive and adaptable frameworks represent different approaches to the design of educational systems that cater to the unique needs and preferences of individual learners.

Although they share some similarities in their aim to enhance the learning process, there are also some key differences between the two concepts (Opperman and Rasher, 1997). An adaptive system, as described in earlier sections of this paper, is essentially a platform that uses automated processes, usually algorithmic and data-driven, to adjust and tailor the learning process, based on the student's preferences and performance (Ennouamani and Mahani, 2017). Such a system dynamically adapts factors such as content, pace, and difficulty level to optimise outcomes. An adaptable system, on the other hand, is a more flexible environment that allows learners to take higher levels of active control in personalising their learning experience (Ruiz et al., 2008). These systems give students the opportunity to make choices (about, for example, content and learning methods) that match their individual learning style. More specifically, some of the key differences include:

1. Personalisation: An adaptive system uses advanced AI and machine learning techniques to collate information about the learner and uses this information to automatically adjust aspects of the learning process such as content and pace. An adaptable system gives learners the autonomy to customise their own learning experiences, allowing them to choose resources and approaches that suit their preferences.

2. Decision-making: In an adaptive system the decision-making process is highly automated, algorithmically analysing data to make real-time adjustments to the learning process. Little direct input is needed from the student. An adaptable system requires the learner to actively participate in decision-making, allowing them to take responsibility for activities such as the topics they want to explore and the type of assessments that suit them best.

3. Feedback: Adaptive systems gather data continually from learner-interaction and use this data to enhance the learning experience dynamically and automatically. An adaptable system relies on feedback provided by the students themselves.

In short, adaptive learner systems use data-driven automation to dynamically adjust the learning experience to suit learner needs, while adaptable learner systems give learners a level of control which allows them to make their own decisions and personalise their own learning journey (Peter et al., 2010).

There are, clearly, merits to both approaches. On the one hand, giving learners control (adaptable systems), by allowing them to ask questions, request changes in content, alter the pace of learning, log misconceptions and so on, can stimulate interest, encourage progress, and help to prevent dropout (Rumetshofer and Wöß, 2003). On the other hand, however, it may be that learners do not need, or even want, continuous control at all times. Learners who are new to a subject, for example, may lack confidence that they are able to make optimal choices. Such learners may welcome some level of automated error prevention, or system-generated guidance (Gerard et al., 2015)

Striking a balance between these two approaches is not straightforward, as the needs and learning styles of individual learners varies greatly (Ahmed et al., 2013). However, in the field of adaptive systems, there has been a gradual shift in focus from attempts to design fully automated adaptive system that can assume full teaching responsibility, to systems that also accommodate learners in making choices which suit their preferences (Kay, 2001). Yet the implementation of a significant level of automation is both desirable and necessary, if powerful and effective e-diagnostics are to be employed to aid the learning process. It is this level of adaptivity which is the focus of this study, as the central hypothesis of the research is that the ability to identify the missing skills and knowledge that lay behind a learner's mistakes is key to designing an online learning system that is capable of supporting the learner with dynamically generated remedial pathways.

Despite this focus, the model described in this research is dynamic. This is to say that it changes its position on the adaptive-adaptable spectrum [Oppermann and Rasher, 1997) as the learning process progresses. Initially, the system lies towards the adaptive end of the spectrum, but as the learner interacts with the system, it becomes more adaptive, in the sense that it evaluates the learner's ability to solve a problem. With further interaction, the system collects enough data to diagnose any missing knowledge and skills that are causing an inability to solve problems. This process allows the system to make clear suggestions concerning what the student should learn. At this point the system can 'regress' to a more adaptable mode, giving the learner some freedom to make decisions such as the order of activities (though still restricted to system-recommended content).

3.3 Limitations of the student model

As has been discussed in previous sections, the "student model", in the context of education, refers to the representation of a learner’s knowledge, skills and learning progress, for application in educational technology, adaptive learning systems and personalised learning platforms. By aiming to understand each individual student's capabilities, and to deliver educational content appropriate to these capabilities, they are powerful and valuable concepts. Coffield et al, (2004) argued that making learning styles relevant to a variety of domains would consume huge financial and human resources over a long period of time and it can be questioned by research funding in this sector. Like any model in other areas of research and development, the student model has some significant limitations. (Laurillard, 1988; Beck and Chang, 2007; Beck and Xiong, 2013).

1. Limited representations and errors: Student models use data collected from a student's interactions with instructional content and assessments. This means that they might not capture all aspects of a learner’s skills, knowledge and learning preferences, leading to an incomplete representation of the learner’s capabilities. Further, the dependency on collected data means that, if this data is inaccurate or incomplete, the model's assumptions and recommendations may be flawed.

2. Poor holistic development: The frequent focus on quantitative metrics, such as test scores, means that some student models may overlook qualitative aspects of learning, such as creative ability, critical judgement, and social skills, which are key to holistic development.

3. Over-focus on cognitive factors: There is a tendency for student models to focus on cognitive aspects of learning, and to neglect (non-cognitive) factors such as motivation and emotional well-being. These can play an important role in learning outcomes.

4. Subjectivity: The interpretation of learner data as a basis for making analysis about their understanding is a major challenge for technology. While this is improving, due

to advances in machine learning and AI, it remains imperfect, and lacks the contextual and situational understanding that human educator possesses.

5. Ethical and privacy considerations: There are several ethical concerns related to personalised learning. Excessive personalisation might, for example, result in learners being exposed only to information that aligns with existing beliefs, thus hindering exposure to wider and more diverse perspectives. A related concern is the issue of privacy. Because student models rely on collecting and storing personal data, this can raise problems of data security and misuse.

6. Human bias: Another potential limitation in student models is that, ultimately, human beings are responsible for the development of the domain models. This carries the possibility of introducing human biases.

3.4 Summary

This chapter has discussed the topic of student models, and related concepts, in the context of education, with a particular focus on how they have informed and inspired the current research project. The purpose of this research is to design and develop an e-diagnostic system that can identify the likely causes of learners' mistakes when they solve a linear equation. The development of such a system requires the creation of an online learning platform that has the ability to (a) analyse a learner's solution approach, (b) identify methodological errors, (c) suggest a remedial pathway and then (d) perform a retest, to gauge whether the process has been effective. To achieve this, it is necessary to implement some widely used AI techniques and a range of modelling approaches. As a result, Section 3.3 of this chapter opens with a discussion of current user modelling techniques, which are ways of creating representations of individual learners within a technical framework. The chapter then proceeds to examine a specific form of user model, called a student model, which is at the heart of an adaptive system, and which is a representation of an individual learner's knowledge, skills, preferences, and learning progress. Subsequent sections of the chapter discuss the various techniques and challenges involved in developing a student model with the analytic and interpretive abilities that are required for the design of an e-diagnostic system, which is the aim of this research. These techniques, which include the adoption of a constructivist (learner-centric) approach, and the use of overlay models, are discussed in detail. The chapter then proceeds to a comparison of adaptable versus adaptive systems and discusses why a mixture of both approaches is required for a successful interactive e-diagnostic model. The chapter concludes with a description of the key limitations of the student model.

Chapter 4 will describe the design and implementation process, including a detailed analysis of the functional and content requirements of the proposed system, and a full description of the techniques employed to deliver meaningful learner interaction that can act as the basis for the e-diagnostic process. The prototyping process is also described in depth.

Chapter 4: System Design and Implementation

In Chapter 3, different types of adaptive technologies and user modelling, their particular characteristics and limitations and the challenges inherent in their implementation were both reviewed and discussed. Catering to lifelong learners' learner-directed learning and their development of meta-cognitive skills, for example, setting learning goals, knowing what material to select, assessing the learning process, the development of troubleshooting skills, and the revision of learning goals according to progress made, are areas about which there has been a growing interest in recent times. Furthermore, learners' active involvement in the process of constructing their personal understanding of the subject matter, along with their active integration of prior knowledge and experiences into the assimilation of new information (Driscoll and Burner, 2005). However, the question about to what extent learners can determine what to learn based on their own points of weakness, has not yet been solved. Most of the learner-directed models and adaptive models are only determining the level of learner in the domain, then based on that they suggest, identify what the individual learner should study more. None of the previous models are able to discover what the specific part in the domain is where the learner has problems.

An alternative approach to the design and development of adaptive model will be discussed and presented in the following chapters. Learners have the freedom to choose the type of relationship with other learners and with the teacher. In addition, the intrinsic benefit of online learning lies in its ability to empower learners with the autonomy to choose the most suitable physical learning environment that aligns with their individual requirements (Sung and Mayer, 2012). This thesis’ interest is in the concept of breaking down the domain into its smallest elements by determining the necessary skills and knowledge that the learner should cover in order to be able to pass the domain assessment and understand the domain to mastery level. Furthermore, the thesis' interest is then to evaluate the learner level in each of the skills and knowledge, and to improve them by suggesting a direct remedial path to each missing skill or gap in knowledge. This concept intends to help the learner to save time and effort by knowing exactly what he or she needs to learn in order to cover the domain. The e-diagnostic assessment can determine the weak points of the learner in the domain. It intends to help the learner and guide them in any learner-directed model. It may help them to save time and effort by pointing out the most exact missing piece of knowledge or missing skill that they need in order to understand the domain and pass through the assessment.

4.1 Introduction

This chapter is about the designing and the implementation of the e-diagnostic system that has been used in this thesis. The e-diagnostic system intends to specify the missing skills and gaps in knowledge that may cause learner errors. More details about how such a system will be designed and implemented is discussed in the following sections. Section 4.2 describes the background of different types of adaptive systems that have been used in the past to evaluate learner level. Section 4.3 illustrates the e-diagnostic system and how it works - depicting the concept behind it. Because this system is novel, it was necessary to build it from scratch using a prototype technique as there was no similar system to simulate it. This led to the first prototype and all its versions being sacrificed just to learn how such a system can be designed and implemented. The pros and cons of the first prototype are then identified, together with what the system should contain, how the interface should interact with the user, and whether such a system really can find the missing skills and missing pieces of knowledge. Those aspects will be discussed in Section 4.4, and Section 4.5 will discuss the second prototype that was used to test the concept behind this thesis in the real world. So Section 4.5 describes how it is designed, what the differences are between the second and the first prototype, the model's functional, domain knowledge, and in addition, how it works in the real world. This chapter will conclude with a summary in Section 4.6.

4.2 Background

This research focuses on how to narrow the possible reasons behind a learner's errors to the most closely related missing fundamental pieces of knowledge and skills. By focusing on those missing pieces of knowledge and skills, the amount of learning will be reduced. This intends to satisfy all learners as they know what to learn exactly instead of learning a big part of the domain. This piece of research also explored different methods of student modelling and the development of a student model which is appropriate to be used in an adaptive educational system that is web based (Barker and Lee, 2010). This model and the other models will be used to create the e-diagnostic system that will be utilised in this research. The e-diagnostic system will be supported with a learning system in order to give the learner a specific learning about the missing skills or knowledge. It should be noted that, in the real world, the learning system can be much wider than the one which is used in this research. Kolb's Experiential Learning Theory (ELT) (Kolb, 1984) was covered extensively in Chapter 2. Its description included the experiential learning cycle with its four distinct stages of learning, which are as follows: Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AE). At the very core of this theory is the perspective that learning is a comprehensive cognitive process, and that learning is grounded on real-world experience through the dialectic interaction between the learner and the environment. Learners thus make progress by means of a learning cycle. This learning cycle shows them the action of observing and experiencing knowledge to reflecting upon those actions. The cycle then, in turn, leads to the formation of concepts, and the hands-on application of knowledge. This learning cycle is, therefore, an ongoing process of learning. The learning cycle, together with its iterative process, is illustrated below in Figure 4.1.

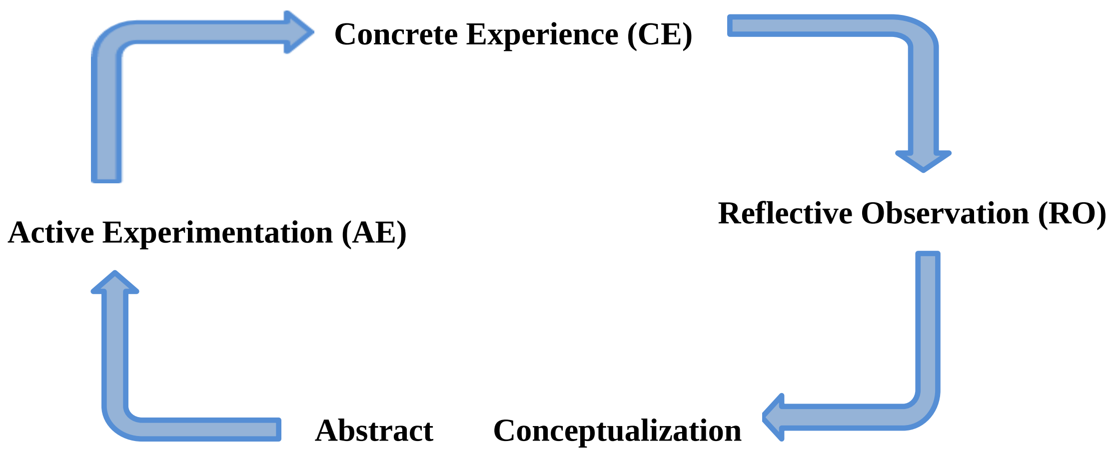

Figure 4. 1: Kolb's learning cycle stages

As a constructive theory of learning, missing a crucial piece of knowledge or skill in any stage of Kolb's learning cycle stages may result in a long delay in the process of learning. Learners may need to seek why he or she can't reach the mastery level in the domain, what to learn, and how to improve their level in the domain. This research will use the diagnostic system to help the learner to directly learn what they miss without searching the domain to know what they miss. Many previous systems have been created to focus on learning level with the support of an intelligent tutoring system (ITS). Yet none of them have been designed to find out the exact missing knowledge or skills that cause learner errors. With regard to intelligent tutoring systems (ITS), researchers have previously tested several systems. With the intention of making use of artificial intelligence (AI) in the field of technical training, a program called Microcomputer Intelligence for Technical Training (MITT) was created (Johnson et al., 1989). Furthermore, Hwang put forward a system that was able to detect students' on-line behaviour (Hwang, 1998), and in 1999 a multi-agent systems (MAS) approach was developed to discover if it could be utilised to construct an interactive ITS (Giraffa et al., 1999). In 2000, an intelligent agent that could direct students to complete on-line course material was also presented. This agent was capable of assisting students to study the concept of the topics and navigating them with their particular level of knowledge (Ozdemir and Alpaslan, 2000). The view of Pugliesi and Rezende (1999) is that, in the development of ITS, the relationship between education and computer science becomes absolutely central. There has, moreover, been research undertaken and published which had the intention of approaching the issue of students adopting a strategy of memorizing answers rather than actually working those answers out, which was the aim of the questions (Fanet et al., 1996). With this in mind, Wainer and Dorans put forward an approach that reduced the time period of an exam, and still managed to maintain the levels of accuracy (Wainer and Dorans, 2000). Following on from this research, similar approaches have been suggested by Lilley and colleagues, (2004). When operating in a standard classroom presentation, teachers certainly are responsible to give advice to their students regarding their mistakes and also about misconceptions in solving equations. Indeed Hwang (2003) shows that this becomes increasingly difficult as class sizes increase.

It can be argued that, as a result of ITS's high-speed improvement, the use of computer systems and the internet in the field of education is increasingly beneficial to learners. Moreover, a computer-based diagnostic system named ITES, a system suggested by Hus, Tu, Yeh, Chu, and Hwang in 1997, can, therefore, be seen as an approach of great interest in its relation to these ideas.

This system originated from the CORAL (Cooperative Remotely Accessible Learning), (Sun and Chou, cited in Hwang, 2003), and the project's end goal, reported there, was to put into practice an intelligent tutoring environment on a computer network. So ITES's main strategy is linking the relation between new and previous concepts which are learned during a learner's interaction with a tutoring system, and this system was able to produce a conceptual map (McAleese, 1994). Furthermore, with regard to this ITES system, Hwang has created a tree diagram demonstrating the key concepts that were required to be learned (see Figure 4.2) (Hwang, 2003).

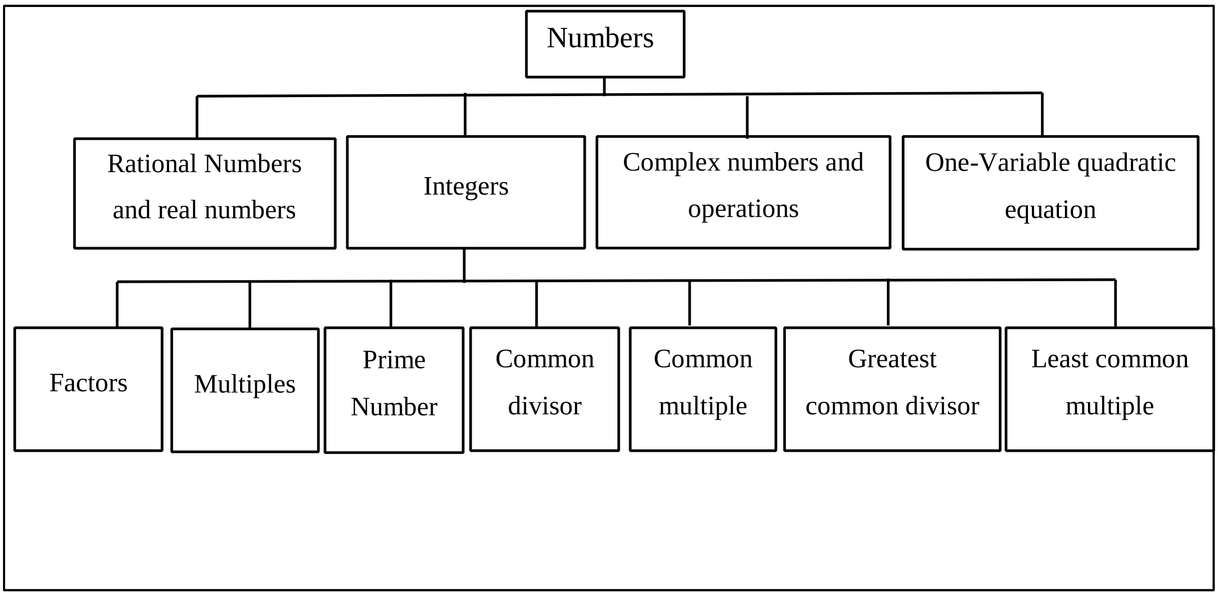

Figure 4. 1: Tree structure for "Numbers"

The strength of the required concepts is presented in the hierarchy above. With each concept being assigned a value and a related prior concept, the researcher is facilitated to determine what percentage of understanding of each concept an individual student has. Additionally, this system was able to make suggestions about what further study was necessary in relation to these missing concepts. However, it must be noted that due to the fact that it did not consider multi-misconceptions, human errors, unlisted concepts or other factors, this approach may not be able to provide accurate reasons for all classes of student errors. There is another system, called ELM-ART, that was put forward by Weber and Brusilovsky, in 2001, which is an intelligent interactive educational system which aims to provide support to learning programming in Lisp. ELM-ART delivers all course material online, with this material based on an adaptive interactive textbook. ELM-ART offers individualized diagnosis of student solutions, adaptive navigation support, course sequencing, and support for example-based problem-solving, using a mixture of an episodic student model and an overlay model (Weber and Brusilovsky, 2001). This is characterised as another intelligent example of Adaptive and Intelligent Web-based Educational Systems (AIWBES), and it utilises another approach of building a model of the goals, preferences, and knowledge of each student. This model is used throughout any interaction with the student in order to adapt to the particular needs of that individual student (Brusilovsky and Peylo, 2003). It is clear that none of the above systems search for the deep reason for learner errors. Mostly they adapt to the needs of learners by measuring learner level in the domain regardless of the reason behind this level.

The next section will describe the concept of the current system and how it is different to the previous pieces of research.

4.3 The concept of the current E-Diagnostic system

In the previous section, much of the existing research work has been mentioned. However, none of them were designed to find out the most suspected reason behind a learner error. The concept of the current e-diagnostic system is to break down the domain into its smallest elements, such as knowledge and skill elements that the student should understand in order to reach the mastery level in the domain. In the current system, the linear equation domain is used to demonstrate the concept and to test the possibility of such a system being able to determine both learner errors and the reason that caused them, then retest them after the remedial path has been given. The system uses an algorithm to determine from the student input where exactly errors lie. This information is saved in the form of a student model. More details about this will be discussed in the next section. With the help of the current research concept, learners intend to be able to make their decision about what to learn and when as they will know what they miss exactly from the domain. The next section will talk more about the first prototype of the current research system, how this system works, what algorithms and models have been used and what the result of testing it is.

4.4 The first prototype of the E-Diagnostic system

In the previous section, the concept of the current research has been discussed. To test this concept, an e-diagnostic system needs to be designed and implemented in order to test the ability of a computer-based test (CBT) to discover the missing skills and knowledge that lead to learner errors. The type of this test should be diagnostic. To approve the concept of this research, a remedial path should be designed too. This is to give the learner the missing knowledge or skills, then to retest them to see if they will be able to pass the test after they learn the missing knowledge or skills. In summary, the system consists of three applications, which cooperate to evaluate the learner.

1. The e-diagnostic system: To test the learners and find the missing knowledge or skills.
2. The e-learning system: To give the learners a remedial path about their missing knowledge or skills.
3. E-test: To test the learners on the missing knowledge or skills. If they reach the mastery level in the missing knowledge or skills, then retest them again in the domain.

This section will describe the first prototype of the system. This prototype was designed to study the possibility of the idea and to evaluate the usability. Since this is a novel system, it is not possible to find a previous system similar to it. Therefore, it was necessary to make a prototype just to test the idea and then discard this prototype, and then make another better prototype, called the final prototype, to test it in the real world. The goal of the first prototype is to know the possibility of applying the idea - i.e. can a computer-based test designed make a deep analysis of learner answers to find the missing knowledge or skills - and to know how the system should be, and how to create it, what model should we use, how the interface should be etc. For this purpose, the first prototype was only an e-diagnostic system without the other parts; the e-learning and e-test. This section will cover the domain, background about the models, the algorithms that have been used in this prototype directly or with some modification, the design of the prototype, the versions of the prototype and the pros and cons of each version, the evaluation of the system, and will summarise the result of testing the first prototype and the recommendation to make the second prototype.

4.4.1 The domain

As mentioned in Section 4.3, a linear equation domain has been used to test the concept of this project. Since a linear equation has many steps to be solved, the system will have more chances to analyse a student's answer to find the problem. A linear equation is not very complicated like a quadratic equation or other domains, so the system will, therefore, need to be complicated and will need a long time to be implemented. Also, it is not as easy as a simple algebra equation so the learner may solve it in one step. However, this concept can be applied to most domains as will be discussed at the end of this research. In order to develop the system, it is necessary to have a detailed understanding of how to solve simple linear equations. This will recall the background from Chapter 1. In summary, “An equation is a statement indicating that two algebraic expressions are equal. A linear equation with one variable, x, is an equation that can be written in the general form ax+b=0, where a and b are real numbers and a≠0“(Flat World Knowledge, 2015). Chapter 1 discussed how to solve a linear equation and mentioned the categorisation that was chosen in this research for the linear equations:

Category 1: ax + b = d

Category 2: ax + b = cx + d

Category 3: n (ax +b) = m (cx + d)

This section will focus more on the critical issues of the system and why it is difficult to implement such a system that can analyse learner answers step by step and find the reason behind learner errors. Many people find solving a simple equation a not very difficult task, but when it comes to finding out why certain students cannot solve a particular equation, one has an extremely difficult task on one's hands. The difficulty stems from two factors, firstly from the fact that there are a variety of methods by which a student can solve a particular equation, and secondly, the variety of errors that may occur in these stages. The problem can be made more complicated to determine by the presence of hidden steps. These hidden steps are those stages when a student is solving a problem that occurs in the student’s head and, therefore, does not show up during input. A strategy of some previous research into this area has been to avoid these hidden steps by ensuring the user describes their answer step-by-step by using either pre-set lists of steps, or through the use of limited input options (Hwang et al., 2008). The prototype presented here, due to the fact that it provides users free text input rather than a set sequence of steps (although it still permits hidden steps to be analysed albeit with some limitations), is certainly an improvement on this method. By requiring the user to enter their answer with a minimum of two steps, and a maximum of six steps for an equation of category (1), this improvement is achieved. It usually takes between three and five steps to solve non-trivial simple linear equations. A whole range of problems may result in some errors, and errors may be caused by a misconception of knowledge or skills that is required for solving equations. Given below are some examples of common errors, together with how these errors were dealt with:

Consider the following incorrect solution:

$4x + 3 = 5$

$4x = 6$

$x = 2$

In this example, producing the number 6 in the second stage of the solution is probably caused by two possibilities.

Firstly, this could occur by moving number 3 to the other side with the same sign and making an error in addition ($4x = 5+3$) then ($4x=6$).

Secondly, this could occur by moving the number 3 to the other side with a negative sign and making an error in subtraction ($4x = 5-3$) then ($4x=6$).

These two possibilities refer to problems related either to a lack of user skills in addition or subtraction, and a lack of user understanding about moving numbers from one side of the equation to the other.

However, it can be shown that there are other possibilities. The user, for example, might not have actually made any of the errors outlined above, the error may simply be a typing error, i.e. there may have been a very simple human error. The prototype will not handle this type of error. Indeed, it is assumed that these types of errors can be ignored because they are unlikely to be repeated consistently.

There may be occasions when the user makes an error while the system is going through its equation solving procedure. The system should be able to recognise the mistake as a human error in this case, rather than an error due to any lack of knowledge or skill, and, therefore, not try to further analyse the mistake. The current prototype system does not include this option, but including this option will be considered in later prototypes.

The number 2 can be produced in various ways, in the last step of the above equation. For example, by moving the number 4 to the other side and subtracting it from 6

4x = 6

x = 6-4 (=2)

or dividing both the sides by 4 and there being an error in division

4x = 6

4x/4 = 6/4 (=2)

or by the operation being reversed and dividing 6 by 4, with there being an error in division also.

4x = 6

4x/4 = 4/6 (=2)

These possibilities may each refer to different misconceptions in skills or knowledge, misconceptions which the system must analyse and classify.

Another situation leading to errors made by a user is given in the following example. Consider the following incorrect solution:

3x + 4 = 9

3x = 9 - 4

x = 3 – 4/3

x = 1

There are many possibilities here for errors being made, for example:

The user may erroneously calculate 4/3 in stage 3, making it 1 instead of 1.33, and then follow this with another error in subtraction.

3-1 = 1

The user may make an error in the result 4/3 in stage 3, making it 2 instead of 1.33, but the final calculation is correct 3-2=1

The user may get the correct result of 4/3 = 1.33, but then make an error in subtraction 3-1.33 =1

So, it is clear from the examples given above, that there is difficulty in determining what the reasons are for user/student errors when they are set the task of solving relatively straightforward linear equations. The previous cases are designed by the researchers with the help of some references (Gov.uk, 2013; Anton, 1994).

The intention in the current study was to design the system to be able to simulate the steps taken by the teacher in their analysis to determine the reasons behind their student's error. This will be described in detail in Section (4.4.8). The section will address the difficulties in implementation, along with other issues in detail. However, at this point, one must recall from Chapter 1 the various types of errors that users may make, as well as how the system should respond to these types of errors. Although some of these errors are not related, it is still highly beneficial to consider them during the design process. It is possible to face all of the following errors during assessment: Bluffing errors, guessing errors, sampling errors, and personal partiality errors. The system should be ready to deal with them in the real world, but for this prototype they will be ignored as the goal of this prototype is not concerned with them. Some of them will be considered in the final prototype. To analyse the learner's answer with regard to all these difficulties and considering the variety of error types, at this point the models and the algorithm that has been used for this prototype must be discussed. The next section will describe the main algorithm and the models that have been used to achieve the goal of this prototype.

4.4.2 Algorithms and modules

In Chapter 3, some models were mentioned as they have been used in previous pieces of research and have been found to be profitable in most adaptive systems. In the current system, those models will be considered and redesigned to face the difficulties of the goals of this prototype. However, it is necessary to talk about the main algorithm before talking about the models and the modules in the current prototype. Figure 4.3. illustrates the targeted process in this research, which is a part of Browns' learning process chart, as mentioned in Chapter 1.

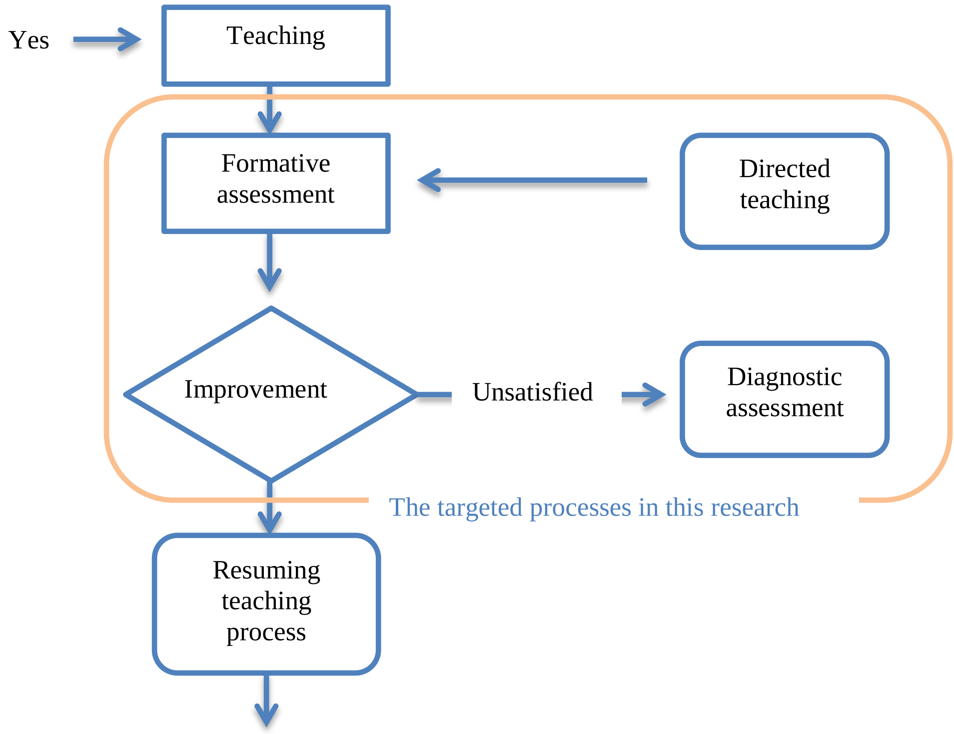

Figure 4.3: The targeted process in this research

It is clear from the chart that this research is targeting the diagnostic phase in the learning process. The main idea was to combine different models to produce an e-diagnostic system that can help teachers to evaluate learners, and help them if they misunderstand any part of the domain. This task is very difficult to do manually and individually in large classrooms. But with the help of the suggested system it intends to be much easier and faster. In the next figure, there is an illustration of the first prototype system algorithm design, which should be able to find learner errors and the reason behind them.

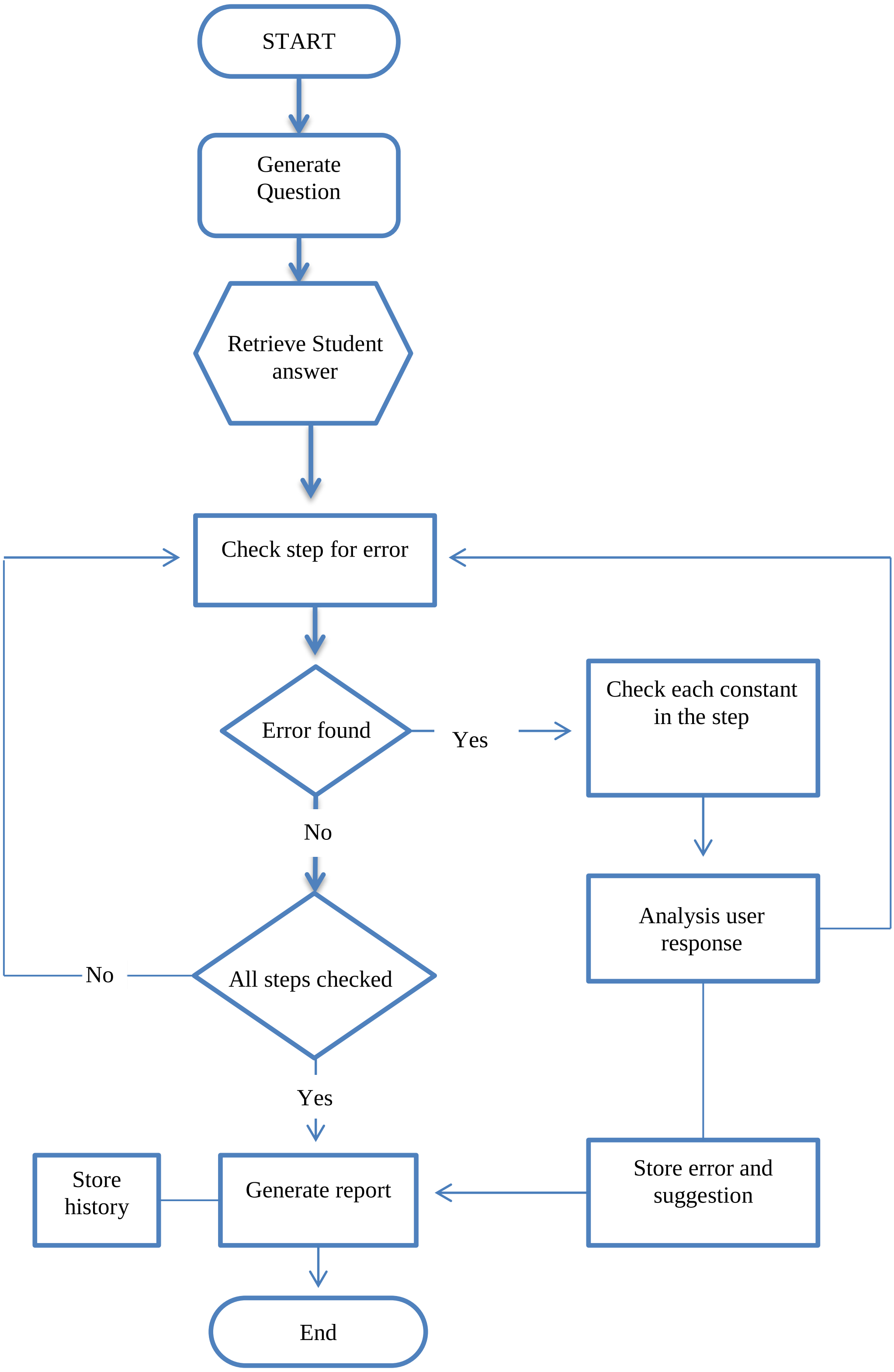

Figure 4.4: First prototype system algorithm design

There have been many modifications to the current system algorithm, with these modifications based on the stages of the various prototype versions that were used while developing the final prototype system. The following basic algorithm is employed in the current version of the prototype:

1- Generating question
2- Step checking
3- Generating questions about each error in the step
4- Analysing user response
5- Generate report

The algorithm of the current system is illustrated in the above diagram, with each of the stages in the algorithm representing a specific task. The function of each of these stages is outlined in the next paragraph, through a description of the methods and modules used.

Here are the main processes of the modules developed in the system.

1- Generating question:
The method name of this stage is 'GenerateLinearEquation'. This was designed to method generate an equation dynamically using random numbers to vary the operands. The correct answer to the equation is also generated here and will be saved for later use.

2- Step checking:
This method name is 'LoopinBoxesTocheck'. This method runs through the user input and checks all the steps entered by the user, determining those with errors. This method is termed 'CheckSteps'.

3- Generating questions about each error in each of the steps: These questions are presented to the user in order to determine the cause of any error.
The method name of this stage is 'Analysis'. This method generates questions related to each operand in all the steps identified with errors. The method is designed to determine how the user produced the error by analysing the previous steps in the entry. The information collected here is stored in a hash table to be used later.

4- Analysing user response:

   Many methods are used in analysing user response to the questions posed in the previous stage. One of the important methods is ‘GetError’. This method discovers the type of error the user made. Based on the type of error identified, the system records the error, produces notes and makes and records suggestions for the user. The method is termed ‘Suggestions'.

5- Generate report:

   This stage presents the output from all previous stages (and more). Most of the above methods save their results in hash tables and strings allowing full details of the errors to be recorded, then used in the report and saved to the system. The method ‘OrderErrorByID’ orders the notes and suggestions in the report.

4.4.3 Technical requirements

The system needs to be developed to work online to be easy to access from anywhere and to meet the needs of the targeted participants who will test it. It will be tested by random students and experts from the University of Hertfordshire. Because it is only a prototype, it will have a simple login method, a simple interface, and will be accessible from any computer using the Chrome browser as recommended. The system should work with any internet connection speed with its light design and the fact that it doesn't use any heavy Flash components, which may cause a delay with a low-speed connection. The system will be on a simple database and a site with a domain which will be accessible from anywhere.

4.4.4 Functional requirements

As a part of functional requirements, the system needs to provide the users with these abilities:

- Start and end anytime
- Skip the entire section
- Skip any part during the test
- Free input text box to allow users to input their answer instead of selecting it.

It also needs to have the following functionalities to:

- Save user input for reporting and analysing purpose.
- Evaluate learner's competency at the current domain and pre-requirements.
- Provide a report for the user to know their level after using the system.

The main idea for functional requirements is that the system should allow maximum flexibility for users to input their answer without any hint, by giving them choices or options to select the answer. This will help to know all possible errors and the important needs to implement such a system.

4.4.5 Interaction design requirements

This section is about the interaction design that the system should have. As this is only a prototype, it may not concentrate on the interaction design, but the interaction design will be focused on more in the final system. Interaction design can be defined as the dynamic and intricate interplay between a system and its users, encompassing a comprehensive understanding of their behaviours, responses, and the contextual factors that shape their interactions (Smith et al., 2022). Taken from Tognazzini (2003) are the principles of interaction design listed below. These are used as a guide for the interaction design requirements for the prototype and will be used more fully in the final system.

4.4.5.1 Effective use of visual elements:

Whenever possible, one should use engaging visual elements. Visual elements that engage learners to further explore should be used by the prototype. Tractinsky et al., (2000) explicate the aesthetic-usability effect, as articulated by Kurosu, positing that users' perception of heightened aesthetic appeal in designs engenders the belief that said designs possess greater ease of use, irrespective of their objective usability. Furthermore, it has been claimed that aesthetic designs are more effective at creating positive attitudes in users, as well as increasing people's tolerance of design problems. This becomes particularly important in stressful environments, where fatigue increases and cognitive performance is reduced

(Norman, 2002). This prototype, therefore, tries to use an aesthetic design; one that has the appearance of being easy to use and, thus, helps to create positive attitudes towards both learning and system acceptance in its users. Simplicity is a crucial factor in this prototype as the goal is just to test the idea. The final prototype will be more attractive.

4.4.5.2 The importance of consistency

Lidwell et al., (2021) posit that the construct of consistency in design comprises four discrete dimensions, namely, aesthetic consistency, functional consistency, internal consistency, and external consistency, all of which collectively enhance the overall user experience and foster a sense of coherence. This will be interpreted by the final prototype as having a recognizable input interface that appears consistently across all questions, while this prototype will be only a simple interface. Functional consistency means consistency of meaning and action. When there is functional consistency, usability and learnability are improved, due to the fact that users can learn to expect the action that follows the interaction (for example, clicking the “home” button always takes users to the home page). This prototype will, therefore, keep the function of all buttons the same on all pages. Because this is only a small prototype, it will not have a lot of buttons. The final prototype may have more buttons with the same functionality on each page and the same of this prototype. Internal consistency is defined as consistency with the system's other elements. In this prototype, internal consistency relates to the pages' look-and-feel, the amount of content, and that the material is presented for each question and for each learning concept in a way that is consistent. External consistency means that there is a requirement for there to be consistency with other elements in the environment (for example, the observation of common design standards by an independent system). Once again, as this is a small prototype, it may not have a lot of pages and options which need to be consistent with other elements. However, in the final prototype, more consistency will be applied as it will have more pages and more options for learning and testing.

4.4.5.3 User interfaces exploration

Human errors should be kept in mind when creating a design that aims to encourage learners to explore. Lidwell et al., (2021) explain that forgiveness in design assists in the prevention of errors and the minimisation of negative impacts. Furthermore, this forgiveness in design will, in turn, lead to users being willing to learn and use the design. This prototype will, therefore, encourage the user by always having a way out or back to the home page, and by always having a way to start over or to skip. This is due to this prototype's main goal being to discover what such a system will need, by permitting users to test the system, and then by allowing users to give their feedback. Additionally, this prototype indicates to users where they are and where they need to go. In order to achieve this, the section the user is currently in is highlighted, and the interface which is used permits users to skip to different questions. In the final prototype there may be some limitations with regard to this skipping, which must be implemented at certain points (i.e. evaluating skills level), and this will be described in the final prototype chapter.

4.4.5.4 The significance of scaffolding in learning process

The term scaffolding refers to the support, which is given during the learning process, support which is customised to the user's needs. This support intends to assist users in achieving their particular learning goals. This support is designed to change gradually as learners turn more competent in their tasks, (Wood et al., 1976). The facilitation of an incremental mastery of concept is the idea behind scaffolding. Users are thus enabled to learn to internalise the information and so develop themselves to become self-directed, self-regulated learners. It should be noted that the scaffolding may not have a clear impact in this prototype as it will be only testing learner level, but in the final prototype, scaffolding will be integrated into the key study skills. Each of these key study skills is associated with one of the various learning activities. As learners progress through each concept's learning activities, each key study skill will become progressively more advanced.

4.4.5.5 Learnability of the user interface

The user interface design selections heavily impact learning curves of tools. Roldán-Álvarez et al., (2016). This perspective on what makes good design suggests that what is necessary is to work with and build on the ability of human beings to relate to and to intuitively understand, without the requirement of learning a new principle or metaphor every time an individual uses a particular system. The design of this prototype will be very simple which will allow the user to reuse the system and move through questions with no need of learning new methods to deal with the system. This concept will be considered in the final prototype too.

4.4.5.6 Visibility in navigation

Johnson and Smith (2018) stated that in environments characterized by high levels of stress, the capacity to engender a sense of familiarity assumes heightened importance, given the escalating impact of fatigue and subsequent decline in cognitive performance. In turn, learners are less able to recognise solutions when they have to recall the solutions from memory. This principle of visibility ensures that the system is more usable, and it also permits the user to better control the system. The prototype designed in this study intends to reduce navigation to a minimum and makes sure that the labelling uses clear and natural language. This prototype may have more options than the final prototype as the goal of this prototype is to study user needs and find out what options such a system should have.

4.4.6 Requirements of the Content

The prototype must include domain-knowledge learning material in the introductory linear equation. Specifically, one unit of linear equation with one variable needs to be redeveloped so that it fits with the interface of the prototype. In this prototype, the level of the equation should be easy as the main goal is to study the system requirement itself. However, the final prototype will have more levels as will be described later. Additionally content should be designed in such a way that users are facilitated to start and stop at any particular time. The content should be of a type that targets introductory linear equations in plain English for grade 9.

4.4.7 The Golden Circle

Johnson (2022), addressed that the Golden Circle model, drawing inspiration from the concept of the Golden Ratio, offers individuals a comprehensive framework to gain insight into the fundamental motivations underpinning their actions and decisions. This viewpoint aligns with Sinek's perspective on the pivotal importance of comprehending the "why" in order to proficiently communicate and inspire others. The Golden Circle is a model that assists individuals to understand why we do what we do (Sinek, 2009). The Golden Circle begins with the question: “Why”. So, to give clarity of purpose with regard to why this prototype is being created, the Golden Circle has been used due to the fact that it is an explanation that begins from the inside out. The Golden Circle is made up of three distinct parts: Why, How, and What (see Figure 4.5).

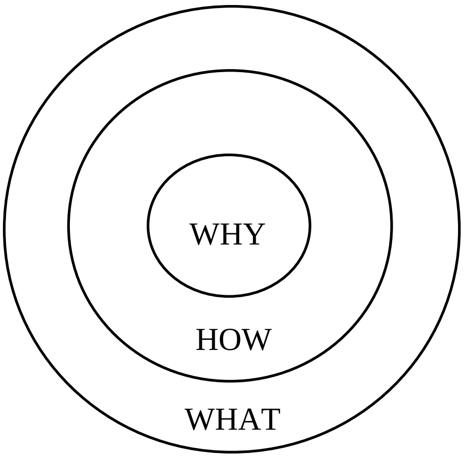

Figure 4.5: Sinek’s (2009) Golden Circle

How these three parts are broken down could be explained as follows:

WHAT - What are you trying to do? The function of this part is to describe the product/system/service that one has the intention of building/providing.

HOW - How can you do that? What tools/techniques are needed so that you can achieve what you do?

WHY - Why are you doing it? What is your purpose/cause/belief?

For the purpose of designing this prototype, this can be adapted, so that the three parts in the Golden Circle can be explained as follows:

WHAT

- To test the possibility of applying the research concept
- To study the best design and options that should be applied to such a system
- To study the feedback that users will give so that they can be considered in the final prototype

HOW

- Designing a prototype
- Testing it by users and experts
- Retrieving the feedback from them
- Analysing system data and studying the feedback

WHY

While this research has a new idea, it was difficult to find a similar system to compare and study the pros and cons of a previous system. This resulted in the need of implementing an initial prototype to study the idea itself, and the pros and cons of the prototype, to help in designing and implementing the final prototype that will be tested in the real world. The final prototype intends to support the instructional design community by providing the system with the most critical issues that learners have in the domain. This will support what is known as "design science". According to Chen and Chang (2022), the application of design science in the realm of education plays a pivotal role in facilitating students' acquisition of efficacious learning strategies, fostering the development of a positive self-concept, and ultimately augmenting their overall academic achievement.

4.4.8 Prototype implementation versions

An iterative prototyping method was used in order to develop the system. Once an idea of the requirements was obtained from consideration of the research aims and literature, early-stage prototypes were developed, tested, and modified. In this way, the prototype system was improved in each version both in terms of basic usability and the achievement of the research aims. The iterative prototyping cycle went through many iterations in order to incorporate new ideas with regard to both usability and the basic functioning of the system. Each version was tested by the researcher and the supervision team. During the design stage of the project, there were many concerns about how the system would be able to determine the exact mistakes and errors that users made, as described earlier. Errors could be generated in many ways and different classes of error could lead to the same solution to the equation. The biggest challenge was to discover the errors when there were hidden steps in the student's solution. Understanding these and working out how they related to errors was a major challenge. In the following section a brief description of the major iteration versions is provided:

4.4.8.1 Version 1:

This was the first version; the main idea behind this version is to develop a naïve system just to go through the steps and see what problems and errors in knowledge and skills may be faced during implementation of the prototype. All these problems and errors in knowledge and skills have been considered in the next version. Figure 4.6 illustrates the UI of version 1.

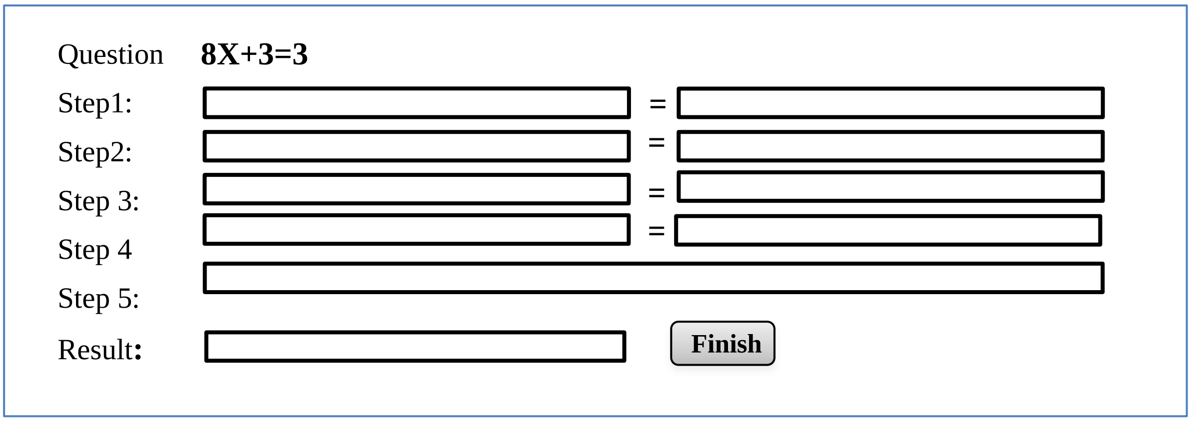

Figure 4.6: The UI of Version 1

4.4.8.2 Version 2:

In this version, the system was ready to work and get some results. It was modified with an internal simple error model which allowed it to discover many types of error, such as moving a constant from one side to the other or making mistakes in calculation. It has some limitations such as complex errors in the same step or if the user made a math operation for the whole equation, for example: if the user adds a number to both sides of the equation or multiplies both sides by a number. This will change the numbers in the previous step which will confuse the system about whether the student put wrong numbers in the answer boxes by mistake or because the equation's numbers have been changed by a math operation applied to the whole equation. It was a simple design which did not cover all expected errors, but it was the core idea of version 3. Figure 4.7 illustrates the UI of version 2.

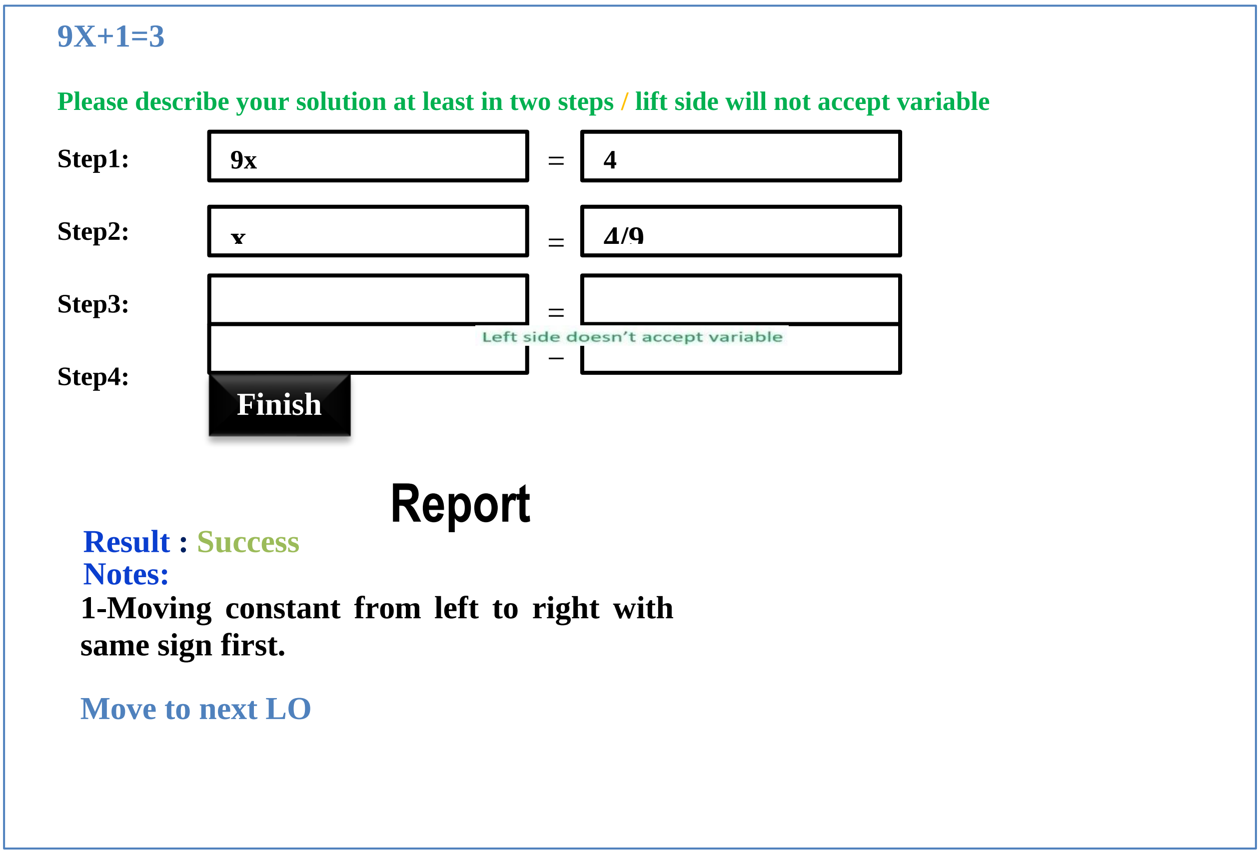

Figure 4.7: UI of Version 2

4.4.8.3 Version 3:

It was quite a good system; it was able to expect the error in a simple way and create a good report about student’s mistakes. It was designed to solve the limitations in version 2. It was able to go back with a student's answer in previous steps until it found the error, then it modified to go back to two hidden steps only, and if it couldn’t find the real error, then the system would consider it an error in student’s skill to solve the equation in the right way. In some cases like the following:

3x = 5/4+9

3x=10

The current version was not able to deal with a fraction operating with another number. In this case the system will not be sure if the mistake happened in the division or in the addition. This problem takes the prototype to other higher requirements where the system should be able to check each number individually and check if the numbers in each step have been changed by a math operation or not. In fact the system was quite good enough to find student errors if they used the system without tricks. To make the system stronger and capable of dealing with users abusing or tricking, a new idea came into being, as shown in version 4. Figure 4.8 illustrates the UI of version 3.

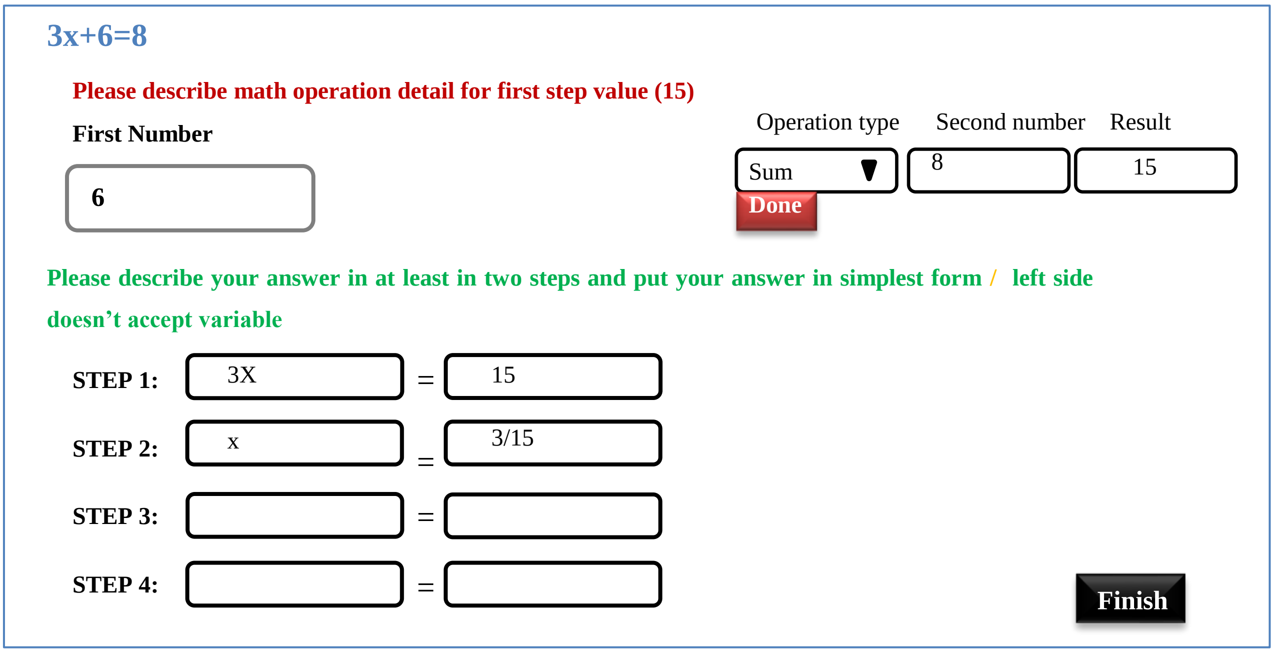

Figure 4.8: UI of Version 3

4.4.8.4 Version 4:

This version was developed to solve the weaknesses of version 3. In this version it was found that it is very important to know the hidden steps before the step that has the error. So the system supported with extra inputs to allow the user to enter the hidden steps but then another problem appeared. The user can put unlimited hidden steps with many numbers as a result of a variety of math operations, which may put the system in an endless circle. This system stopped soon after the first implementation without any extra subversion. Figure 4.9 illustrates the UI of the version 4.

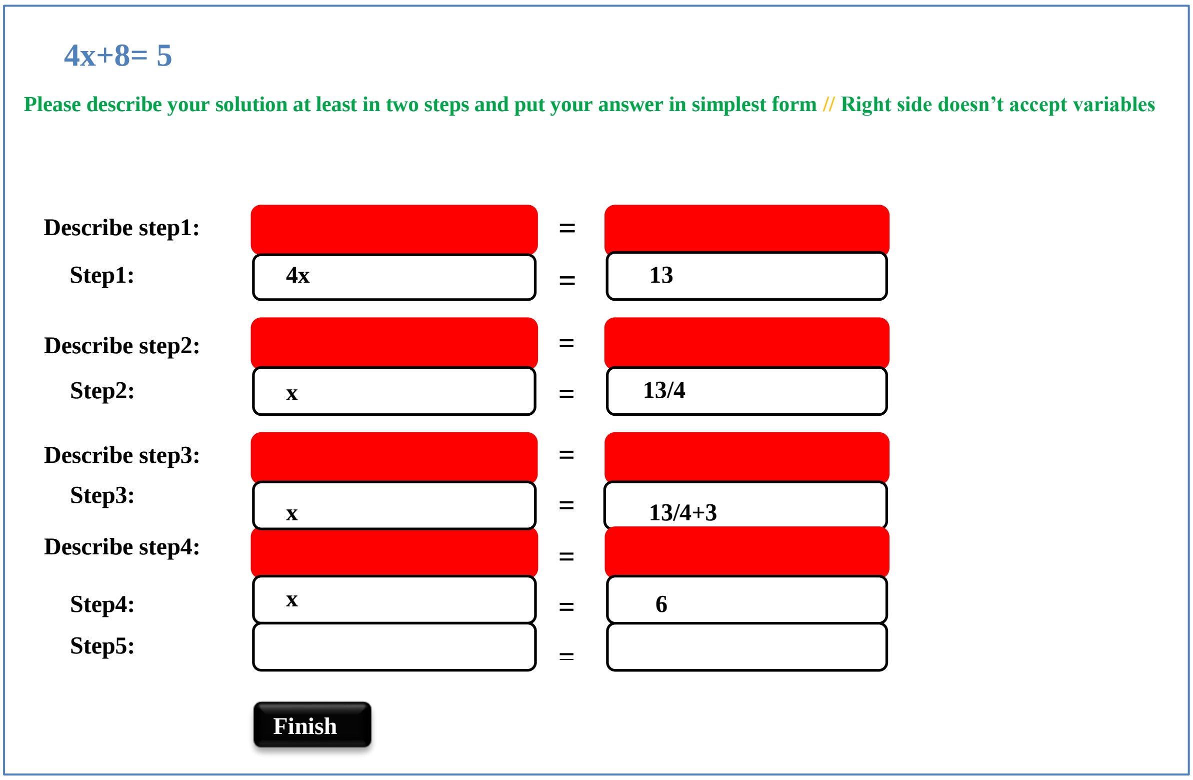

Figure 4.9: UI of Version 4

4.4.8.5 Version 5:

Many ideas were tested to solve the failure that happened in version 4. Finally an idea came on the scene that gave a hope of success. This idea was based on testing each number in each error in each step, by using what the author called 'Steps Wizard', the system was able to determine exactly what happened to each number and how each number was obtained. This allowed the system to know what the missing knowledge and skills are.

In this version the system will prompt the Steps Wizard in each step that has an error. In the wizard, the system will start by asking the user if any math operation has been done on the whole equation or not. If yes, then the system will consider it a missing skill. If not, then the system will start to ask the user about each number and how it was generated.

During the testing of version 5, there was a problem with moving the factor of the variable 'X' to the other side (e.g.: 5x+2=0 it becomes x+2=5). To work out this problem, it was important to give the student the possibility to deal with x and its factor individually. For this, version 5.1 was implemented, which has a button to break down the 5x to 5 and x, so the user can select any one of them to make the operation to show the system what happened in the last step or in any hidden steps. But that idea wasn't successful; by giving the user the ability to separate the X from his factor, users were given a big chance to make many mistakes, such as making addition or multiplication to the X alone or to its factor alone. This will lead to many unnecessary analyses and to wasting user time by going through many steps of detection. In fact this error could easily be assigned to a general misunderstanding of the right sequence to solve equation Cat.1. This is what was included in version 6.

The version was good and able to discover most of the errors with good efficiency, but was a little bit difficult and complicated, specifically for first time users. Figure 4.10 illustrates the UI of version 5.

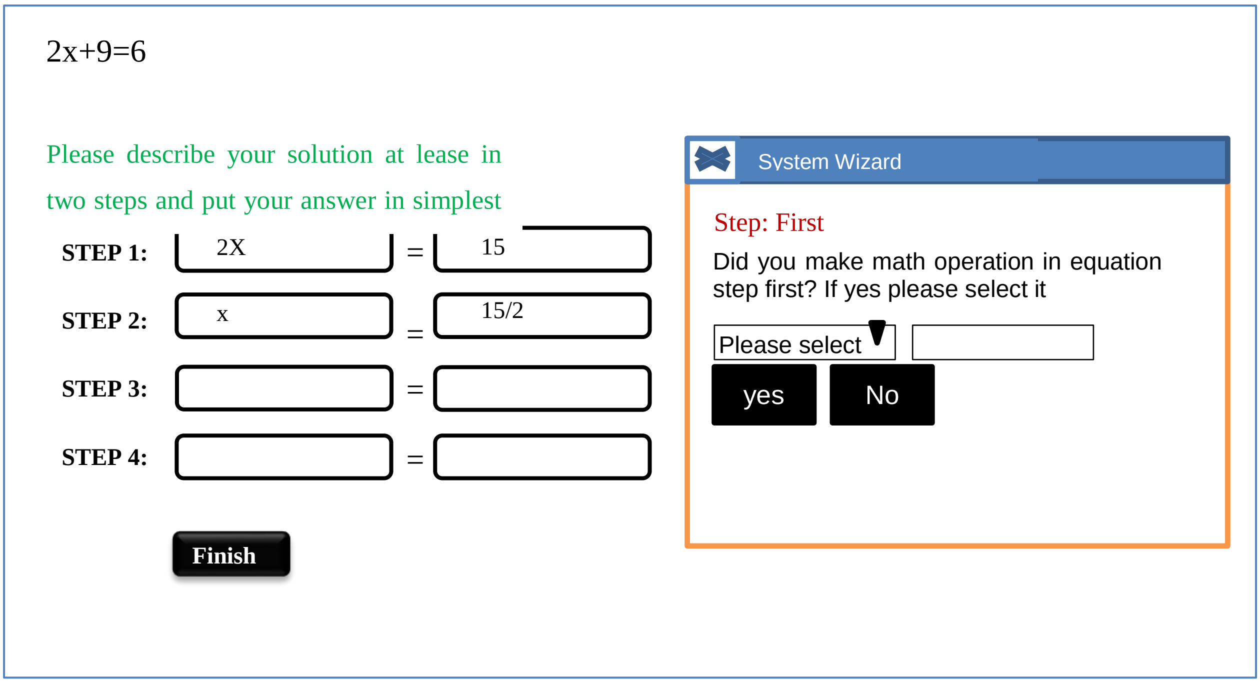

Figure 4.10: UI of Version 5

4.4.8.6 Version 6:

This version was an attempt to improve the usability of version 5. Figure 4.11 illustrates the improvement in the UI of version 6. It was decided at this point, as the basic functionality of the system was working well, to subject the system to expert evaluation. It would be vitally important to make the system understandable to all users. The researcher and supervisors were too close to the system and fresh insight was needed. This led to the development of the 7th iteration, ready for expert evaluation in a pilot study.

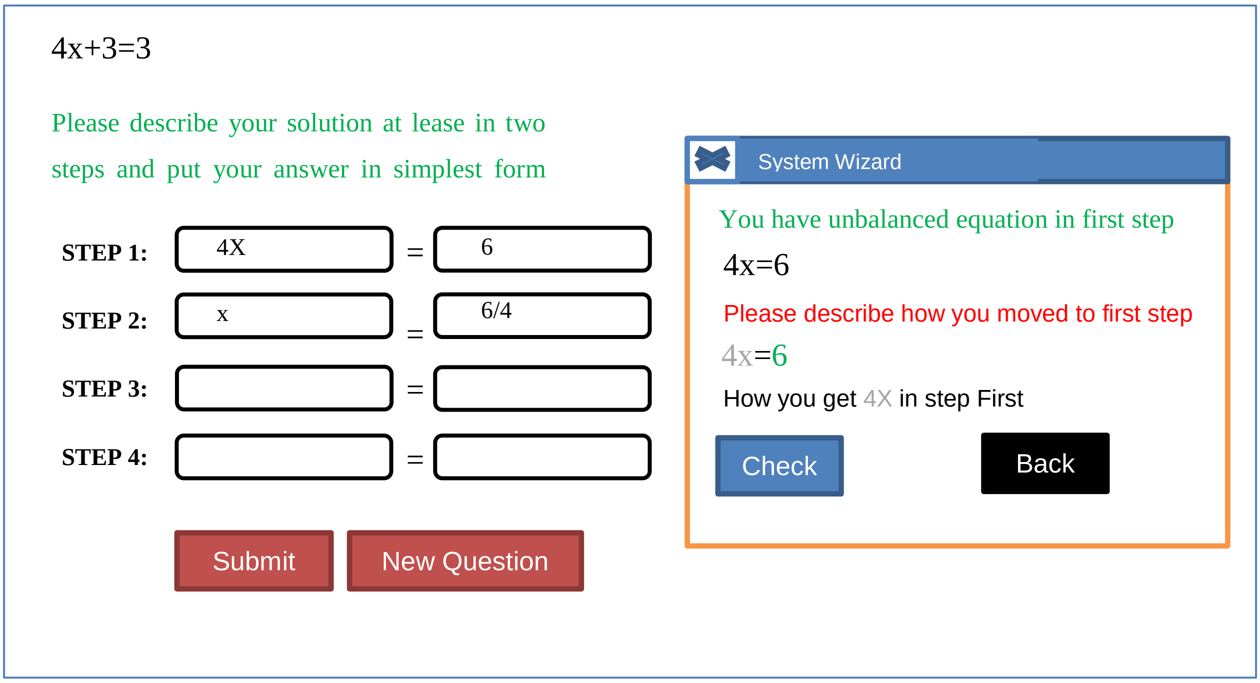

Figure 4.11: UI of Version 6

4.4.8.7 Version 7:

This is the final version of the first prototype and is ready to be tested. This version avoids the uncomfortable UI by using fewer colours, with better and clearer instructions. Individual fractions checking is provided too. As this is the proposed version to be tested, the system suggestions have been implemented to redirect users to further testing based on the missing skills and knowledge. Figure 4.12 illustrates the UI of the version 7.

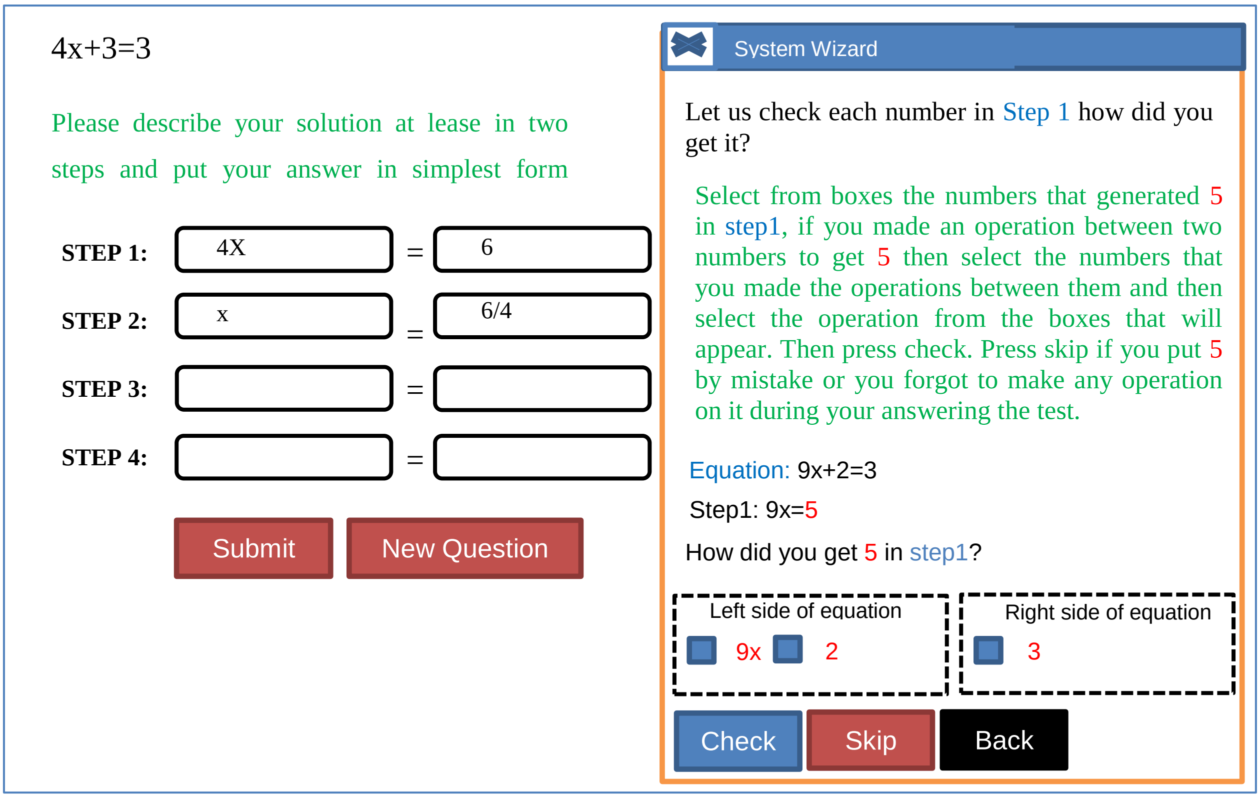

Figure 4.12: UI of Version 7

In summary, during the implementation of the above versions, each version comes with many system bugs and programming difficulties. While moving from one version to the next version, the bugs were fixed, and the programming issues were solved.

4.5 The pilot study of the first prototype

This section describes a pilot study intended to test the usability and functioning of the system with a small group of computer science experts. Issues identified in this study will be corrected in the final version of the prototype that will be used to undertake a full-scale study. It was also important to test the method employed in the study as well as the instruments of the study, such as instructions and questionnaire.

4.5.1 Pilot system

The pilot system was developed to present participants with seven simple linear equations that needed to be solved. The evaluator was asked to follow a set of instructions in order to solve equations correctly, make specific errors and use the 'Steps Wizard'. Participants were then required to fill in a questionnaire relating to the functionality of the system and its usability. The questionnaire and instructions are shown in Appendix (3). Ethical approval for the study was obtained prior to the study and this is shown in Appendix (4). In the following section details of the study are provided.

4.5.2 Methods

A functioning prototype system (version 7) was implemented as described in the above section, then published on the internet. In this way evaluators were able to use the system at convenient times and as often as they liked.

4.5.3 Study design

The design of the study was based upon Nielsen's heuristic method (Nielsen, 1994), and was simplified and modified for use in this context. In Nielsen's approach, a small team of expert evaluators are used to locate the most common usability errors inherent in an application. The experts were also teachers in a numerate discipline. Information about the basic functionality of the system could also be obtained.

4.5.4 Selection of participants

The evaluation was done voluntarily by six usability experts who were staff from the School of Computer Science, University of Hertfordshire. They were selected based on their knowledge of human-computer interaction and their computer science background. Nielsen (1994) suggests that six participants are sufficient in this stage to locate most of the common errors in an interface. The supervision team contacted the experts to obtain their approval and agreement to take part. All participants were assured that once the data had been collected it would be anonymised. Further induction emails about the evaluation instructions and questionnaire were sent to the participants explaining the procedure, providing links to the software, and explaining the ethics information and safeguards. An Ethical Approval was granted. A copy of the ethical approval is attached in Appendix (4).

4.5.5 Data collection

Once the survey had been completed, participants emailed the researcher their completed questionnaires. Questionnaires were copied into a folder on a computer and anonymised. emails were then deleted. A copy of the survey is shown in Appendix (٣)

4.5.6 Data analysis

Data analysis will involve the recording and reflection on comments related to the system. In summary this will include:

1- The opinions of participants related to the functioning of the system in response to correct solutions to equations and errors.
2- The opinions of participants related to the system design, font size, colours, etc. For more details please refer to the survey questionnaire in Appendix (٣).
3- The opinions of participants related to the system's clarity of instructions.
4- The opinions of participants related to the approach employed in the study.

The returned questionnaires have provided useful information for the future study. Most participants considered the idea to be a good approach to solving the problem of errors in equations. In general, the system functioned well and robustly, providing correct responses to both correct and incorrect input. Errors were located and classified without problem. There were, however, some issues with the usability and especially the understandability of the 'Steps Wizard'. This test gave a clear idea about the possibility of making such a system. The deep details of this prototype and its programming code will be ignored in this research as the result of this study shows the importance of redesigning the system with a better, more usable system. The task now is about redesigning the system with an easier interface. But at the same time, it should have better functionality. The system this time should be a full system. That means it should have all parts of the programming: log in, question generating, remedial path, skills test, and lessons, all these parts should be included in the final prototype. The next section will describe the final prototype in detail. It will cover all the aspects as it will be the prototype that is used for the pilot study of the research.

4.6 The final prototype

4.6.1 Introduction

The previous section described the first prototype and all the improvement stages that happened during testing and while improving the first prototype. The result of the testing was great, it gave a clear image about the system and how it should be, and what models should be used to find user errors made while solving linear equations. It gave a great deal of inspiration to build the final prototype. Most of the expert users agreed about the efficiency of the system and the benefits of using such a system. Although they complained about the usability of the interface, more complaints were received about the Steps Wizard as it was a little bit complicated to deal with it for the first time. Some of them agreed that difficulty was reduced after many attempts to use the system. The wizard has many options to choose from which was a little confusing when it was used for the first time.

In this section the full details about the final prototype will be described. How it works, what models have been used, what is the difference between the first prototype and the final prototype, what data it has been collected on, why it is more advanced, and how it solved most of the first prototype's issues.

4.6.2 Background and characteristics of the final prototype

To establish a well-designed system that can find learner errors, then determine the reason behind it, it was important to study similar systems to the current research system. However, it is rare to find similar systems to the current research system. The Flexilevel test is one of the similar ideas to that system and was first put forward by Lord (1971) with its format being a paper-based test. Customising the test difficulty level to an individual test-taker's proficiency level was one of its aims (Pyper et al., 2010). This Flexilevel test (Lord, 1980) provides a basis for a “minimalist adaptive test” (Wainer, 2000) and applies fixed branching techniques to select the particular items which will need to be administered during a subsequent test. A branching algorithm is utilised that presents items based on whether or not an item has been answered correctly by a test-taker. The potential benefits of a Computerised Adaptive Test (CAT) approach are offered by this Flexilevel test. This means that there are less resource issues which are typically associated with more traditional forms of CAT (Lord, 1980; De Ayala et al., 1990). In their research into this subject, De Ayala et al., (1990) showed that this Flexilevel approach can be just as effective as the IRT approach. In particular, it provides assessment while at the same time makes the experience of assessment personalised for test-takers without the higher resource requirements which characterise other IRT-based CAT techniques. Furthermore, a pilot study which was undertaken by Lilley and Pyper (2009) found that the attitudes of students towards this Flexilevel approach, given in a formative assessment context, was positive.

The algorithm used in a Flexilevel test is of less complexity than those which are used in traditional CATs applications with their basis in Item Response Theory (IRT). (Pyper et al., 2014). The test starts with a medium difficulty item. If the item is answered correctly by the test-taker, the next most difficult item is then presented. If the item is answered incorrectly by the test-taker, the next easiest item available is then presented to them. This continues either until the test duration is reached or until no more items are available for selection. Past researchers have considered the Flexilevel test as a method of giving an adaptive test without expensive computing equipment being required (Pyper and Lilley, 2010). The Flexilevel may well have been successful in estimating learner level, however, it was still not able to find the reason behind this level. The present research is concerned with discovering why a learner is at this level.

Another model presented in 2004 about student knowledge diagnosis based on a technique (Guzmán and Conejo, 2002) by which multiple topics are assessed through the use of content-balanced CATs. The fact that they are capable of adapting instruction to student needs is certainly one of the most important characteristics of Intelligent Tutoring Systems (ITSs). In order to achieve this, the ITS must know the state of the particular student's knowledge with accuracy. Testing is one of the most common solutions for student diagnosis, and testing's major advantages are both the fact that it can be utilised in a few different domains and that its implementation is relatively simple. Due to the fact that, in any given test, when assessment is being performed on more than one content area, only one estimation of student knowledge for all content areas can be provided by the test. Furthermore, in tests which contain these multiple topics, there can be no guarantee of the balance of the content. This model could be applied as a student knowledge diagnosis engine in ITS. An example of this would be, when instruction starts, using pretesting to initialize the student model; while instruction is happening, updating the student model; and/or when instruction has finished, a global snapshot of the state of knowledge being provided. However, domain models are capable of being structured on the basis of subjects, and these subjects can be divided into various topics. A topic is defined as a distinct concept about which student knowledge can be assessed. These topics can also be broken down further into other topics. Thus a hierarchy is formed, with the teacher having the power to decide on the degree of granularity. In this hierarchy, a unique concept or a set of concepts that are indivisible from the perspective of assessment, are represented by leaf nodes. For the purposes of diagnosis, one could extend this domain model through the addition of new layers which would include two different kinds of components: items and test specifications. Figure 4.13 illustrates this extended model (Guzmán and Conejo, 2004).

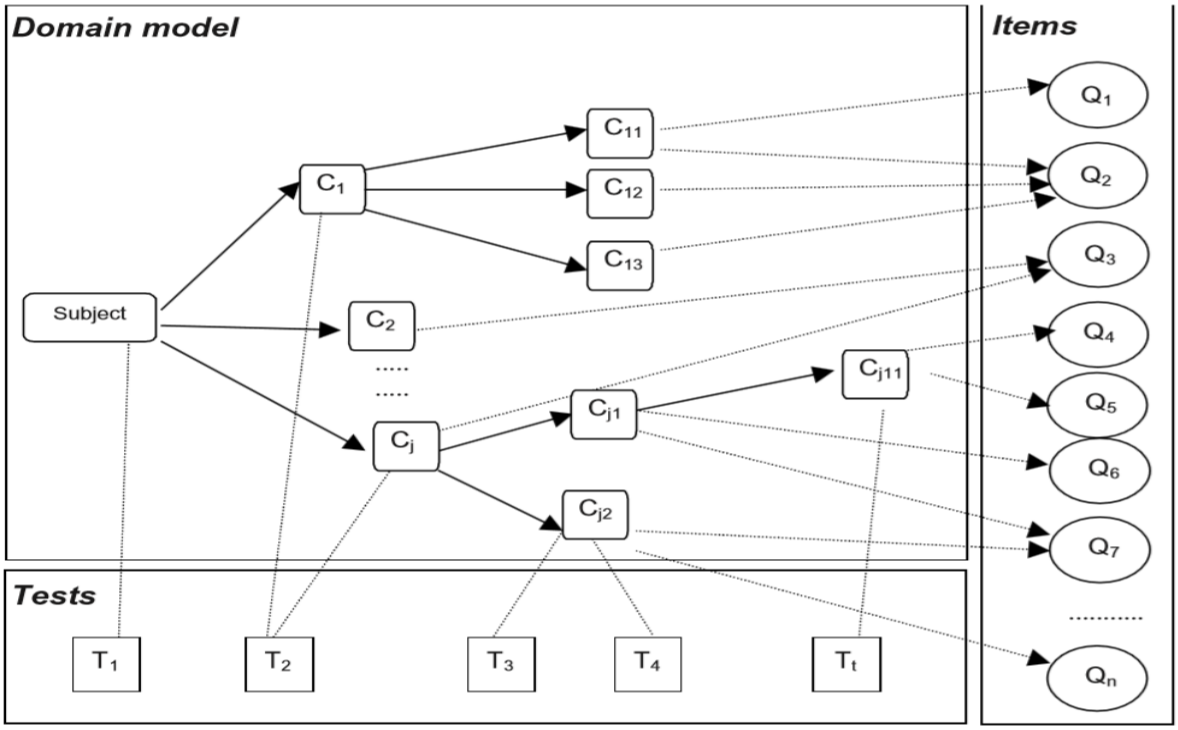

Figure 4.13: A domain model extended for diagnosis

Assessment of multiple topics through content-balanced tests is permitted by this model. Beyond this, there are other approaches which have presented content-balanced adaptive testing, for example the CBAT-2 algorithm (Huang, 1996). This model may be successful in estimating learner level, but it still can't determine the reason behind this level, what a learner is missing in terms of knowledge and skills. However, the current research aim is to find a new system which can determine learners' missing knowledge and skills.

The following will discuss the technical requirements of the final prototype. Functional requirements will be discussed in Section 4.6.4, while Section 4.6.5 will describe the interaction design requirements. To establish a good understanding of the domain that will be covered by the final prototype, a brief of the content requirement and the domain will be discussed in Section 4.6.6. Section 4.6.7 will describe the algorithm and the models which have been used in the final prototype. Finally, in Section 4.6.8, a summary about the difference between the first prototype and the final prototype will be discussed, and a description of the advantages of the final prototype will be given.

4.6.3 Technical requirements of the final prototype

The prototype will be designed in three parts.

1. Domain evaluation (e-diagnostic system)
2. Skills and knowledge learning
3. Skills and knowledge testing

All these three parts together will be called the system. In fact, the domain evaluation is presenting the final prototype (e-diagnostic system). The other two parts are supporting tools only. They help the learner to understand the missing knowledge and skills and they help to assess the learner in the particular skills or knowledge that is missing. However, this research will focus only on the first part. The other two parts are just tools to help so they will be designed and implemented in a simple way, just for demonstration and for experimental purposes. The system will be online and have a login page to distinguish between users' answers. The system will be designed for web application. It should be accessed via a web browser on a PC. The system will be compatible with Chrome and Explorer. However, there will be a recommendation to use Chrome as it will be tested on Chrome during the implementation.

4.6.4 Functional requirements

The functional requirements of the system will provide the learner with the following abilities:

1. Start and end anytime
2. Skip at any stages of answering the questions
3. Skip the entire section (not applicable on testing)
4. Choice of one or multiple learning activities to learn the missing skills
5. Avoid learning activities when the learner understands his or her mistake
6. Learners can test themselves in any missing skills and knowledge
7. Recording learner answers, time, and learning activities
8. Recording learner improvement in knowledge and skills
9. Providing learners with a report about their achievements

The designing of the functional requirements intends to give the learners maximum flexibility during their interaction with the system. However, the system has some limitations in its flexibility to evaluate learners' level of knowledge and skills. The learners have freedom to learn the missing skills or knowledge by using the provided lessons, but it will be mandatory to take the skills and knowledge tests to pass the level required and to be able to go back to the domain evaluation system.

4.6.5 The interaction design requirements

Refer to the definition of interaction design in Section 4.4.5 (Smith et al., 2022) and its principles. This section will not repeat the description of the interaction design and its principles; however, this section will describe the aspect of the final prototype regarding those principles.

4.6.5.1 Effective use of visual elements:

The system presents a clear visual element, simple colour, wide white space, clear font, and an animated input method to lead the user to focus on the targeted input box. Figure 4.14 illustrates the UI of the final system.

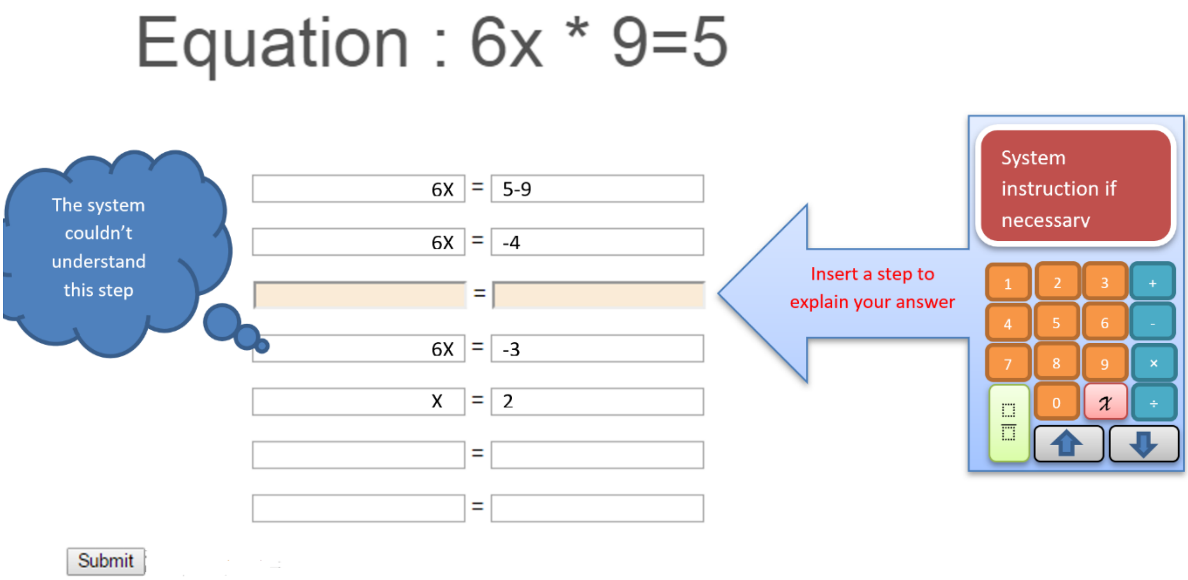

Figure 4.14: System UI

The figure above shows the UI design of the domain evaluating system. This design has a simple colour giving an impression of an attractive and colourful UI. It has animated elements to lead the user's focus to the input stage. The keys panel moves up/down when the user input her or his answer. The blue cloud appears when the system needs more declaration from the user. The beige colour text box appears between two lines of steps, when the system needs to see an extra step of the answer. This interaction between the user and the system, with the help of animated elements and colour changing concerning the steps, intends to help the user to deal with the system with minimum training needs. The key panel provides the necessary input numbers and the “x” letter to make it easy for users with laptops to find the numbers and letters. A fraction symbol is also provided to allow users to input fractions easily without the need of an extra input method to find the fraction. The viability of the necessary input number and the symbols in an appropriate visual intends to give the user free time to think about the answer instead of thinking about how to input the answer to the system.

4.6.5.2 The importance of consistency

The system will respect the style and appearance of consistency listed in Section 4.4.5 (Lidwell et al., 2003) in many aspects: questions pages, answering methods, and key panel. The question and answer will be on the same page for all questions, only the values will be changed for each question. The key panel has the same sort of number for any mobile phone as it’s the common numbering method that users may face during their lives. The other buttons will remain in the same place and will have the same functionality in all questions during the tests. The system will follow Microsoft design, as it is commonly used in schools, in most of the pages' menus in order to maintain the external consistency.

4.6.5.3 User interfaces exploration

With regards to that which was (Lidwell et al., 2003) described in Section 4.4.5, the design will have a validation module to prevent users from inputting wrong letters or unrecognised characters in the text box provided. This will help to reduce human errors and the need for a back button or undo. The system provides the users an open text box to input their answer with freedom. They can put anything they want as an answer, with a limitation on the letters and numbers related to the answer. This intends to give the user the feeling of freedom during answering but at the same time, it prevents human errors. That means anything will be entered by the user and the system validation will not stop, and it should be analysable by the system.

4.6.5.4 The significance of scaffolding in learning process

According to Anderson et al., (2023), support in learning environments is customized to assist users in attaining their individualized learning objectives. As learners enhance their competence in tasks, the design of support is intended to undergo a gradual and progressive evolution. The system will build up the learner level step by step. In each step, the system will realise what the learner's missing skills are and enhance it by giving the learner lessons in the missing skills. The system will be able to build a clear student model to give the right response to learner inputs. Recording all the learner's skill levels will allow the learner to stop and start at any time. However, there will be a slight restriction that will not allow the user to go back to the domain evaluation unless he or she passes the required level of the skills. This limitation is compatible with the goal of this prototype, as it is a diagnostic tool more than a learning model which should have more flexibility.

4.6.5.5 Learnability of the user interface

For learnability, designers might concentrate on how users carry out their tasks with ease (Rafique et al., 2012) and some might think of ways to decrease the load on a user's computer in order to enable faster completion of web applications (Seffah et al., 2006). It will allow the user to deal with the system faster every time they use it. The system will have the same interface for all tests and the same navigation buttons on all pages. This will allow users to use the system without any need of instruction when they come back to reuse it.

4.6.5.6 Visibility in navigation

To support navigation in this system and based on the work of Norman (1990), as mentioned in Section 4.4.5, the design of the system has minimum navigation options. Most user actions will be done on the same page. The animated elements will guide the user through the answer to help them to know what is next without reading a guideline or asking an instructor. Reducing buttons with clear labelling will support the visible navigation principle.

4.6.6 The content requirement and the domain

For the purpose of testing the system, the domain should be redesigned to support this purpose. The chosen domain is a linear equation (i.e. 3x+5=9). To find the missing pieces of knowledge and missing skills of a learner, a table of domain learning objectives has been set. This table is designed for the testing purpose only. The designed based on (Gov.uk, 2013;

Anton, 1994) with modification by the researcher. For a real-world system, it could vary. Table 4.1 lists the learning objectives that learners should know to be able to solve a linear equation.

Student No.	Learning objectives	Statuses
1	Student should be able to follow the sequence of solving linear equation Cat. 3	Current
2	Student should be able to move a variable or constant from one side to other of equation with the right sign.	Current
3	Student should know that addition or subtraction cannot be applied between a variable and a constant.	Prerequisite
4	Student should be able to open brackets.	Prerequisite
5	Student should apply the operations in the right order	Prerequisite
6	Student should be able to apply addition on variables.	Prerequisite
7	Student should be able to apply subtraction on variables.	Prerequisite
8	Student should be able to apply division of variables by a constant	Current
9	Student should be able to apply multiplication on variables and constant	Prerequisite
10	Student should be able to apply addition on two constants.	Prerequisite
11	Student should be able to apply multiplication on two constants.	Prerequisite
12	Student should be able to apply division on two constants	Prerequisite
13	Student should be able to apply subtraction on two constants.	Prerequisite
14	Student should be able to apply division on a constant multiplied by bracket.	Prerequisite

Table 4.1: Learning objectives

Some of those learning objectives have been learned in previous years, whereas others are covered by the current domain. To make it easy and acceptable for most schools, the domain is designed to have four levels of difficulty and three categories. Those categories describe the complexity of the equation as follows:

Cat.1: $ax + b = d$

Cat.2: $ax + b = cx + d$

Cat.3: $n (ax +b) = m (cx + d)$

The letter "X" presents the variable, and the other letters present the constants. The categories of the equations designed are based on the number of skills and pieces of knowledge required, where the levels are determined based on the value of the constant. This categorising and levelling of the equation are only for testing purposes. Other methods to determine the difficulty of questions are discussed in more detail (Irvine and Kyllonen, 2002). Table 4.2 shows the difficulty levels of the equations.

Level	Description
1	All numbers are integers. Numbers in (* & /) will be between 1-5 Numbers in (+ &-) will be between 1-9
2	All numbers are integers. Numbers in (* & /) will be between 6-9 Numbers in (+ &-) will be between 10-99
3	Numbers are mixed integers and fractions. Numbers in (* & /) will be between 1-5 Numbers in (+ &-) will be between 1-9
4	Numbers are mixed integers and fractions. Numbers in (* & /) will be between 6-9 Numbers in (+ &-) will be between 10-99

Table 4.2: The difficulty levels of the equations

4.6.7 Algorithm and the models

This section describes the algorithms and models which have been used in the domain evaluating system. To describe that, a brief of how the system works should be addressed.

4.6.7.1 How the system works

The main goal of the system is to recognise the missing knowledge or skills that may lead to learner error when they answer a linear equation. To achieve this, there are many ways. For example, to give the learner a short test in all the learning objectives that she or he should know in order to be able to solve a linear equation. However, this way may find the missing skills or knowledge but still, in some cases, it could not have an answer if the learner passes all those tests but is still unable to solve the linear equation. Yet, this idea may take a long time and the learner may feel bored by having a repetition every time to many tests even if he or she knows the answers.

The current system intends to find the missing skills or knowledge by analysing the learner's answer step by step to find out where the misconception is. To apply this idea the system needs to take the learner’s answer without any hint (i.e. multiple choice, link, true or false, etc.). The system will support that by giving the user an open list of text boxes to allow the user to fill in her or his answer step by step as they want. The text box has some input limitation to avoid the users entering any letter or character that is not related to solving linear equations. The system will analyse the user’s answer step by step. In case the user moved from one step to another step, but the system couldn’t understand how he or she did that, the system will present a blank text box between those steps, then ask the user to fill in how he or she moved from the first step to the second step. The beige text box in Figure 4.15 illustrates the extra text box that allows the user to insert a step between two steps when the system can’t understand how the user moved from one step to the other one.

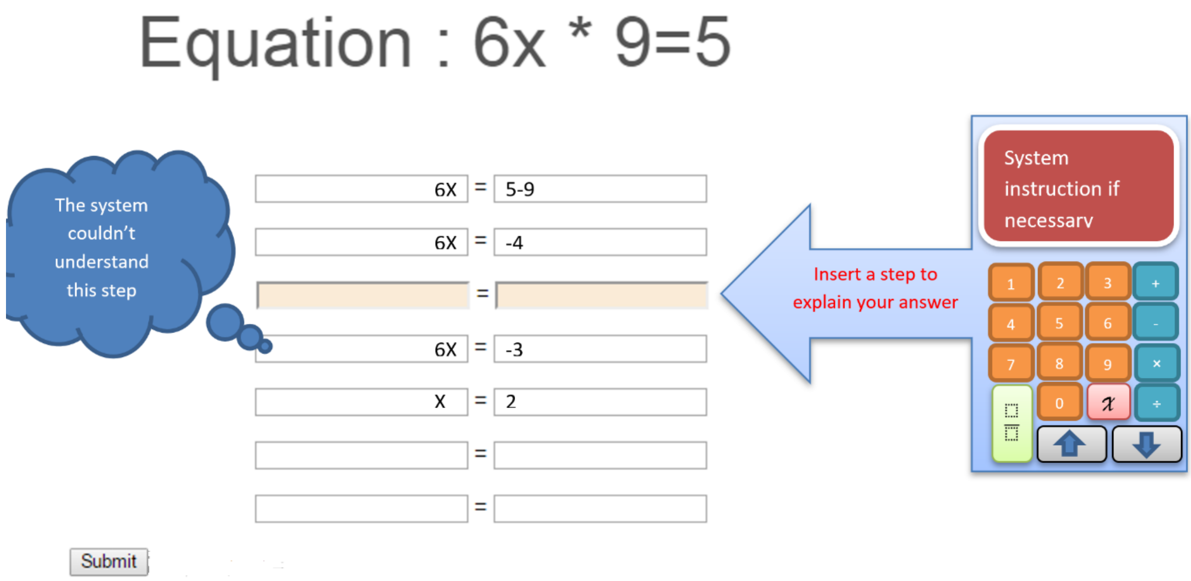

Figure 4.15: The extra step

If the system still needs more explanation between the new step and the step before it or after it, the system will present another beige box to allow the user to input one extra step. After two extra steps the system will analyse the answer by using another model to guess the missing skills. This model will be described later. If the system is successful in determining the missing knowledge and skills, then it will be much easier to direct the learner to the specific and direct remedial path. Learners will have freedom of choice to learn about the missing skills and knowledge through the system or by using any other open sources. The key stage is to pass an e-diagnostic provided by the system, especially about each missing piece of knowledge or missing skills. If the learner achieved the mastery level in all missing pieces of knowledge or missing skills, then he or she will be allowed to go back to the domain assessment.

To understand how the system works, an outline of the required skills and knowledge is presented in the following example:

4.6.7.2 The required skills and knowledge:

1- The right sequence of solving Cat.1 linear equation
    a. Move constant to the right side
    b. Move variables to the left side
    c. Calculate the right side and the left side to have this form: ax=b
    d. Isolate x by dividing both sides by (a)
    e. Simplify the answer to its simplest form
2- When moving a number from one side to the other the sign must be reversed
3- All calculation between numbers: +, -, *, /
4- All calculation between fractions
5- All calculation between fractions and numbers
6- Calculation between variables
7- Calculation between variables and constant
8- Simplifying fractions

The following list presents the common mistakes made by students:

1- Moving a number from one side to another with the same sign
2- Mistake in calculation
3- Mistake in simplifying
4- Increase or decrease the equation values as unnecessary steps
5- Multiply by factor of x instead of divide
6- Using factor of x in addition or subtraction without the x
7- Apply math operation to one side only
8- Wrong operations of signs
9- Adding a constant to a variable

Calculation error and error in simplifying a fraction could happen in any step. However, the system should deal with all error scenarios. The following example shows the standard answer:

3x+5=7

3x=7-5

3x=2

3x=2/3 division sign

x=2/3 as a fraction

While learners are answering, they may make different mistakes. Mistakes can be made in many steps too. Table 4.3 shows the common mistake scenarios.

Error Type	One error	Two errors	Note
Scenario 1			
Moving a number from one side to another with the same sign Addition error	3x+5=7 3x=7+5 3x=12 3x=12/3 x=4	3x+5=7 3x=7+5 3x=13 x=13/3 x=13/3	
Scenario 2			
Multiply by factor of X instead of divide Multiplication error	3x+5=7 3x=7-5 3x=2 x=2*3 x=6	3x+5=7 3x=7-5 3x=2 x=2*3 x=8	
Scenario 3			
Increase the equation values as unnecessary steps Move constant with same sign	3x+5+4=7+4 3x+9=11 x+3=11/3 x=11/3-3 x=2/3	3x+5+4=7+4 3x+9=11 x+3=11/3 x=11/3+3 x=20/3	In this scenario the student will need extra skill about subtracting a number from fraction, he will not need it if he follows the standard procedure
Scenario 4			

Add constant with variable Error in addition	3x+5=7 8x=7 x=7/8	3x+5=7 9x=7 x=7/9	
Scenario 5			
Decrease the values of the equation as unnecessary steps Error in subtraction	3x+5=7 3x+5-2=7-2 3x+3=5 x+1=5/3 x=5/3-1 x=2/3	3x+5=7 3x+5-2=7-2 3x+3=5 x+1=5/3 x=5/3-1 x=4/3	In this scenario the student will need extra skill about subtracting a number from fraction, he will not need it if he follows the standard procedure
Scenario 6			
Apply math operation to one side only Error in division	3x+5=7 x+5/3=7 x=7-5/3 x=16/3	3x+5=7 x+2=7 x=7-2 x=5	As he thought 5/3=2
Scenario 7			
Using factor of x in calculation without the x	3x+5=7 x=7-5-3 x=-1		
Another example With Error in Addition	3x+5=7 x+5+3=7 x+8=7 x=7-8 x=-1	3x+5=7 x+5+3=7 x+9=7 x=7-9 x=-2	
Scenario 8			
Mixing Errors Increase + moving with same sign	3x+5=7 3x+3+2=7 3x+3=7+2		

	$3x+3=9$ $x+1=3$ $x=3-1$ $x=2$		
Plus, Error in addition	$3x+5=7$ $3x+3+2=7$ $3x+3=7+2$ $3x+3=10$ $3x=7$ $x=7/3$		
Break down + apply on one side only	$3x+5=7$ $3x+3+2=5+2$ $x+1+2/3=5/3+2/3$ $x+1+2/3=5/3+2/3$ $x=5/3-2/3-1$ $x=0$		
Increase + apply on one side only	$3x+5=7$ $3x+3+2=5+2$ $3x+3=5$ $x+1=5/3$ $x=5/3-1$ $x=2/3$		
Back multiplication. Forgot to apply multiplication to one number	$3x+5=7$ $3x+3+2=5+2$ $3x+3=5$ $x+1=5/3$ $x=5/3-1$ $3x=5-3$ $3x=2$ $x=2/3$	$3x+5=7$ $3x+3+2=5+2$ $3x+3=5$ $x+1=5/3$ $x=5/3-1$ $3x=5-1$ $3x=4$ $x=4/3$	

Table 4.3: Errors Scenarios

All these scenarios will be analysed. Some hidden steps and more errors in calculation and fraction simplifying may occur in any step. The previous lists of skills required and common mistakes scenarios came from different references (Gov.uk, 2013; Anton, 1994) with some modification by the researcher to be compatible with research needs. The system should be able to act with all these errors. To achieve that, the system uses many methods and modules:

1- Context Check:

This method will check the context of all steps of the answer. It will give warning to the user if the answer is not understandable by the system, for example: if there is a strange letter such as A, Y, @ or duplication in signs (++, ==, -+, */), this will work as a validation for the answer, so the user cannot submit the answer until she or he fixes any mistakes.

2- Equation Balance:

This method will check if the balance of the equation still remains between steps, this method will also check if the equation values on both sides increased or decreased even if the balance is still stable. If this happens it will trigger another method (Extra Steps).

3- Extra Steps:

This method will check if this increment or decrement is relevant to the answer or just an extra step. If it is not relevant, then it will be considered as an error because students should answer in the right sequence.

4- Duplicate Step:

This method will check if there are any steps duplicated exactly. This method will give warning to the user if any are found. It will work as a validation too.

5- Terms Change:

Sometimes the user moves from one step to another step with the same balance but with different terms. This method will check the terms and compare them with the previous step. If this change helps to reduce steps, then it is acceptable. If not, then the system will consider it as an extra step.

6- Possible Error:

This method works if the balance is changed. It will compare the terms and try to find a possible error. These errors will be matched with the expected errors listed above. If any match, then the method will return the number of the expected error. If none match, then it will be considered as an unexpected error. This will happen if the terms changed in a logical way which the system can understand. If the terms changed in a strange way with no logical change, then the system will ask for more clarification from the user by asking them to insert more steps between the current step and the previous step. Each time the user will add steps the system will apply most of the methods again; the system will ask the user to add more steps if it still cannot find a logical change. If the steps count reaches the maximum (i.e.12 steps for Cat. 2) then the system will consider that the user entered random answers (more details about the system reaction for random answers will be discussed later).

4.6.7.3 System reactions:

The goal of this system is to find out the missing skills or knowledge. The lack of knowledge or skill can be determined by the skills and knowledge evaluation tools. To determine the missing knowledge or skill, the system follows two algorithms designed to cover the current system and more options. Those options will not be applied in this research, but they may be implemented in future work. The two algorithms are covering two stages. Figure 4.16 illustrates the algorithm of Stage One. For full scale, refer to Appendix (12).

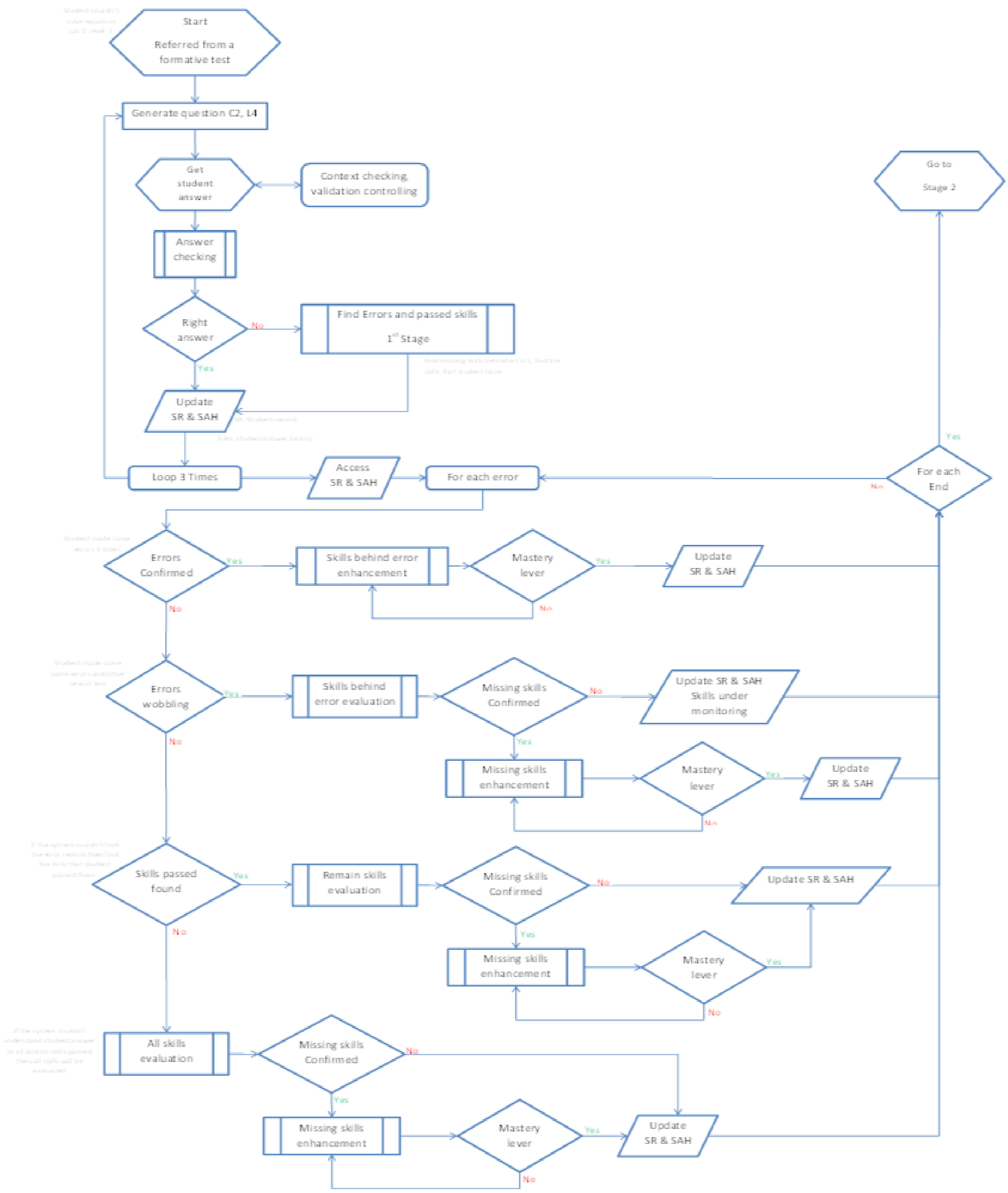

Figure 4.16 Stage One algorithm (Fore full scale copy see Appendix(12))

Stage One is about finding the possible missing skills or knowledge. This is done by giving the learners three equations. If the learner makes mistakes in one skill three times, the system will consider them missing this skill. The system will take them directly to a lesson about this skill, then keep testing them until they reach the mastery level in this skill. Mastery level in the real-world program can be adjusted. When the learners reach the mastery level in the missing skill, then they can go to Stage Two. If the learners make mistakes in a skill only one or two times out of three, that means they may know or may not know that skill. The system will take the learners to the skill evaluation tool to test the learners' levels in that skill. If the learners' level is not matching the mastery level, then the system will take the learners to a lesson, then keep testing the learners until they reach the mastery level. When the learners achieve the mastery level, they will be directed to Stage Two. In case the system couldn't find out the missing skill, then the system will find the skills that have been passed by the learners. After that, for example, if the learners' answer shows that he or she knows the first five skills out of thirteen, then the system will test the learner in the remaining seven skills, then will give them lessons about any missing skills, then test them until the mastery level. The learner will then be directed to Stage Two. In the experiments done in this research, there was no such case reported, as will be described in Section 5 which concerns the experiment's result, but the system was designed to be ready to deal with this case. In general, those cases and steps will be applied for each error as shown in the algorithm above. However, in Stage One, the system intends to find out all the errors and the missing skills behind these errors, but there is a possibility for the learner in the real world to make mistakes even if she or he passed stage one after learning all their missing skills. This is why Stage Two has been designed.

Stage Two is designed to confirm that the learner is ready to solve any equation of the domain. For this purpose, Stage Two will have four cases:

Case One:

The learner will have one equation. If the learner is successful in solving it in the right way, the learner profile will be updated, and the experiment will be ended. The result will be reported that the learner had some missing skills and she or he has learned the missing skill. The learner is now ready to solve any equation from the domain.

Case Two:

The learner made a mistake. In this case the system will check the steps. If the error is not defined, then a step by step system assessment needs to be used. There will need to be supervision by a teacher.

Case Three:

In Case Two, if the error is defined, then the system will check if this error was not discovered in Stage One, then the system will loop the learner in lessons and test the skill until she or he gets to the mastery level. The system may take the learner to the same process as Stage One. Teacher supervision will be required.

Case Four:

In Case Three, if the error has been discovered in stage one and the learner passes the mastery level, the system will give an indicator to the learner about the error. If the learner figures out her or his mistake and corrects it, the system will update the learner profile and report a possibility of cognitive load. If the learner couldn’t fix the error after the indicator, the system will give the learner a hint about the skill. If the learner fixes the error, then the system will update the learner profile and report that the learner needs more practice in that skill. If the learner couldn’t fix the error after the hint, the system will report that one to one tutoring is needed.

However, to achieve the purpose of this system with regard to the goals of this research, only Case One is covered by this research. The other three cases are just a suggestion for the full system that can be implemented and tested in future work. Figure 4.17 shows the algorithm behind Stage Two. The red line shows the part that is covered by this research. For full scale, refer to Appendix (13).

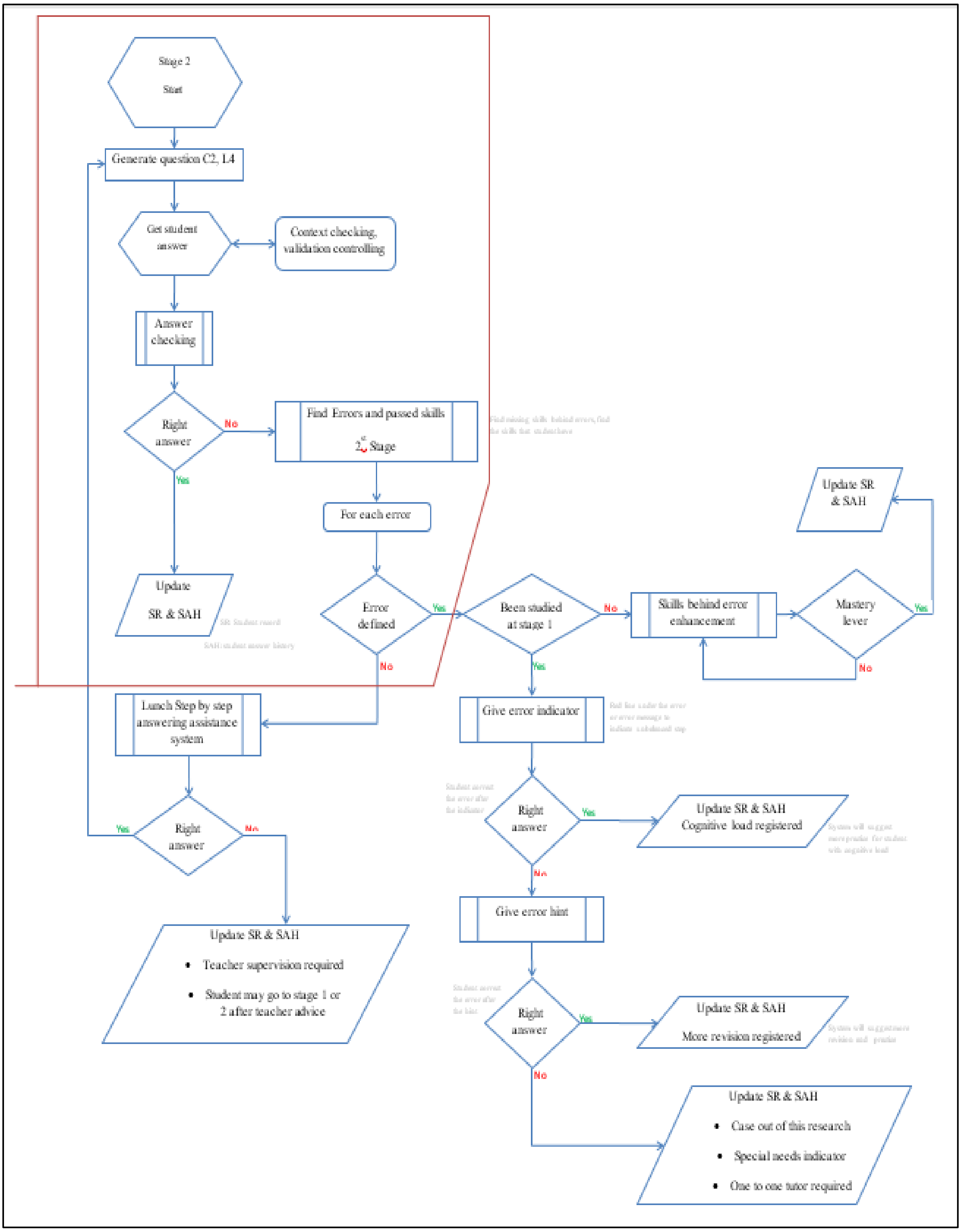

Figure 4.17 Stage Two (For full scale copy see appindex (13))

The system can be expanded in many aspects to be used in the real world, but for the purpose of this research it has been implemented in this way to save the time and effort of programming and testing. The limitation of the time that can be obtained from schools to allow a real testing of this system in school is not long and it is not easy to obtain it. The test and evaluation of this system needs to be done fast and short as most schools refuse to spare their students for a long time to test this system. More details about what experiments have been performed at school will be addressed in Section 5.

The system was provided with more scenarios to be compatible with the research aims. It can be worked on a normal scenario, which will present three equations to the learner, or a time measurement scenario, which will test the learners in all skills before starting to give them equations. This scenario will be used in an experiment as will be described in Chapter 5.

The next section will summarise the differences between the first prototype and the final system and examine what the advantages of the final system are.

4.6.8 Summary

The difference between the first prototype and the final system can be summarised as follows:

1. The first prototype was just a diagnostic tool, whereas the final prototype was supported with the remedial path tool and the skill evaluator tool.
2. The first prototype has a cooperative model to retrieve user opinion about the user answer, whereas the final prototype supported with full automotive step by step analysis.
3. The first prototype has a difficult wizard to retrieve the user reaction about each step. This wizard comes with many buttons and options to be selected by the user, whereas the final prototype has only one page with an open text box to allow the user to input their answer with only one button.
4. The first prototype was only able to analyse a learner answer if there was enough information, whereas the final prototype has a model to analyse a learner answer by considering the known skills to analyse the remaining skills.
5. The first prototype has only one scenario, whereas the final prototype has different scenarios.

The final prototype has many advantages, which are summarised in the following list:

1. Simple interface.
2. Only one submit button, no option to confuse the learner.
3. Attractive interface.
4. Animated interface to support the learner to use the system.
5. The system can deal with different cases as shown in Section 4.5.7
6. The system will not stop if it can't find the missing skill. It will evaluate the skills that were not passed.
7. The system can help the learner to know what they miss; this will help them to choose what they learn.

In summary, the final prototype is ready to be used in a real school. It can test the learner in different levels and categories of equations. It can be tested in different scenarios. Most of these features were extracted from the long testing of the first prototype and all its versions. The support of all the models from previous research that are discussed in the literature review section such as: student model, overlay model, domain model, etc., gave this prototype the capability to deal with most learners' answers and to extract the missing skills. In a real-world program this system can be designed and implemented in more options and in different modes and scenarios.

The next chapter will discuss the use of the final prototype in the current research experiments. It will illustrate the experiments that were done using this system, the goal of each experiment, how it was done, and what the result was. A full statistical analysis of the retrieved data from the system will be addressed.

Chapter 5: Experimental Design and Result

5.1 Introduction

The previous chapter detailed two different prototypes with their versions. The first prototype was made to test the general idea of the system and to know how such a system should be built, what are the interface requirements, what are the functional and non-functional requirements that should be considered during implementation of such a system, and what algorithms and models should be used to implement the final system. The final system will be used to test the research questions. The final system has been used in five different experiments. Each experiment has its own characteristics, requirements, procedure, and research questions covering the area.

The experiments were done based on different methodologies. The following paragraphs will describe the most common methodologies used in this research. In each experiment, sections will refer to one or more of these methodologies that were used in the experiment.

5.1.1 Quantitative and qualitative

Quantitative and qualitative are known broadly as methods to collect and analyse data in research. However, using one of these methods may not reflect the research result in many cases where data can be more complicated or have a mix between numerical and nonnumerical data. The quantitative method focuses more on numerical data, where the survey has scores which reflect the study results. While the qualitative method focuses and understands principles, thoughts, opinions, etc., when the study is related to understanding other dimensions of the study more than a variable. The qualitative approach is a better variant. In the current research, the data came from different experiments. Each experiment has its own type of data based on the aims of the experiment. This variety of data cannot be obtained and analysed by using an individual method. It needs to use both methods in terms of obtaining and analysing the current research experiments' data. This need triggered the importance of using a mixed methods methodology.

5.1.2 Mixed methods

The definition of mixed methods changed by passing time and by the purpose of the study. Bazeley (2006) refers to mixed methods when there is integration between methods. In case there is a use of methods in parallel or not integrated, then it will be named a multimethod approach. Johnson (2006) states that when researchers have quantitative and qualitative methods combined or mixed into a single study or set of related studies, that will be a mixed methods methodology. There are many other definitions by most leaders in this science, mostly about mixing the qualitative and quantitative methods to study the research data from different angles. However, going deep into the science of mixed methods is not related to the current research. The mixed methods methodology has been chosen to be used in this research experiment to cover the numerical and nonnumerical data that is expected to be the result of these experiments. The blending of both quantitative and qualitative methods allows this study to explore the research questions in-depth and contextually from multiple points of view (Johnson and Onwuegbuzie, 2004). A way through which mixed methods studies might be differentiated and one of the crucial decision points is the point at which elements of qualitative and quantitative methods are integrated together: either they will be at the point of interpretation, in the design of the question, at data analysis, data collection, or some combination of these (Caracelli and Greene, 1993; Creswell, 2003). Mostly, when qualitative and quantitative components of a study are considered in relation to each other mainly as conclusions are being drawn, the integration of methods happens mainly at the point of the final interpretation for the study (Bryman, 2006; Greene et al., 1989). Secondly, what are effective strategies for integration at different stages of the research process? For example, Bazeley (2006) has carefully examined how to integrate qualitative and quantitative data using data analysis software. Teddlie and Tashakkori (2006) and Tashakkori and Teddlie (2010) discussed the process of making meta inferences (that are based on the integration of qualitative and quantitative strands in research studies). On the other hand, few have argued for total separation of the quantitative and qualitative components of a multimethod study, with integration considered authentic only at the point of final interpretation (e.g., Morse, 2003; Sale et al., 2002). Caracelli and Greene (1993) identified four integrative strategies for mixed methods analysis:

- Extreme case analysis: The residuals or outliers divulged by one analysis are explored using alternative methods or data.

- Typology development: A classification of categories or concepts developed from one set of data is implemented on another.
- Data transformation: One form of data is converted into another for further analysis.
- Data consolidation to create new variables for use in further analysis: The mixed methods research purpose, which is most often served by integration of analyses, is initiation, that is, to be challenging and bring fresh perspectives through contradiction and (intended or unintended) discovery of paradox (Caracelli and Greene, 1993; Greene et al., 1989; Rossman and Wilson, 1985).

Finally, mixed methods were used in most of the current research experiments because it is a comprehensive technique to address the research questions. However, in some experiments, a quantitative approach has been used individually when the expected result is numerical only. The nature of the current research experiments results in numerical data most of the time, but these numerical data need to be supported by participant opinions, attitudes, and preferences. That is the goal of integrating the qualitative approach with the quantitative. There are also many other types of expected nonnumerical data that can be extracted from the system record itself. The system (prototype) will be used in all the experiments in different ways. The system records student answers and how they react to the system in some experiments. This record can show how the system succeeded in responding to learner errors and discovered the mistakes that were made by the learners during the experiment. This type of data will give a clear image about the system ability without any involvement of learner opinions as will be described in the experiments sections.

The next sections will cover five different experiments. All of them use the final prototype of the e-diagnostic system that has been described in Chapter 4. As mentioned in Chapter 4, the system has four levels of difficulty and three categories. Each experiment will follow a certain category and will have a certain level of difficulty. The level that will be most used is level 3 as it is the recommended level by schools' teachers. Level 4 may be difficult and will need longer time during the test. For the same reason, all experiments will use category 2 as the teachers' recommendation too. All of these experiments were done in Saudi Arabia, in Dammam city. The difference between the experiments will be clear in the sequence. The system supports three types of sequences. The first sequence is the standard sequence which will be used to test the concept of the current research. It starts by giving the learner three equations, then retrieves the learner's answer for each equation. The system will find errors, make the analysis, and update the data. The second sequence is based on giving the learner a direct error indicator during the solving of equation. This will allow her or him to correct the answer before submitting the final answer. The error will be registered in the data even if the learner corrects her or his answer. Then the system will work the same way as sequence one. The third sequence works in the opposite way to sequence one. The system will give the learner one equation, then it will test the learner in all knowledge and skills related to the domain. If the learner has any weaknesses in any knowledge or skills, the system will take him/her to improvement tools to enhance the weaknesses until the learner reaches the mastery level in all missing skills and knowledge, then the system will take him/her to the second and third equations. The system then will follow the standard procedure that is mentioned in Chapter 4. The following experiments followed different sequences based on the experiment's goals. The next sections will describe the first experiment in detail. It is about the usability of the system. Section 5.3 will be about the second experiment. It is about the reaction of the system when learners make a mistake. In the second experiment the learner will be asked to make an error intentionally to test the system reaction. Functionality Evaluation will be covered in Section 5.4 which will be the third experiment. In this experiment, learners will be tested to find their missing skills and knowledge. The third experiment covers the main goal of the current research. The fourth experiment is about teachers' opinions about the system. It will be covered by Section 5.5. The last experiment will be discussed in Section 5.6. It will compare the time consumed between sequence one and three. The summary of all the experiments will be in Section 5.7.

5.2 First experiment: Usability Evaluation

5.2.1 Introduction

Chapter 4 described the first prototype that was designed to test the idea of the current research. The prototype was able to break down the domain to the smallest elements, then determine which of these elements are missing from learner knowledge or skills. However, its user interface was difficult as was mentioned in Chapter 4. Although it was difficult, it opened the way to establish the final prototype which has been used in this experiment. The final prototype was designed and implemented to have all the features and options to help in testing the research questions. It has many options, levels, categories, and sequences as was described earlier. It was designed after studying all the feedback and problems that the first prototype faced. However, it's still a piece of software and it needs to be tested and evaluated before applying it to evaluate the current research questions. In this section, the usability evaluation of the final prototype will be described. This experiment has many goals:

- To find any bugs or programming issues.
- To retrieve the users' feedback and fulfil the final prototype before using it to test the current research questions.
- To check the necessary time that learners will need to use the system as this experiment will be done by similar learner ages.
- To give a chance to the teachers to test the system in the real world before they supervise the other experiments which will examine the current research questions.

This experiment will use the final prototype which will be called, in this research, the e-diagnostic system. It will use category 2 and level 3 as it is recommended by the schools' teachers. They believe that level 4 will be difficult and will take a long time to finish the test. However, from a research point of view, it is not necessary to use level 4 as level 3 is enough to test the usability of the system. The experiment will follow Sequence 1 as it is the major sequence to test the idea of the research. The other sequences will be used to answer the other research questions as will be described in Chapter 6. In fact, all the sequences use the same interface with the same programming modules. There is a little difference in the module that controls the sequences only. This will make the test of the usability of one of the sequences valid for all of them.

5.2.2 Method

This experiment involved fifty volunteer students, aged fifteen to seventeen, male and female. All of them were from the International Schools Group. It is an international school where the language of instruction is in English. The students were at high school level. The idea of using the high school level instead of the intermediate level, where they currently study the domain, is to have less problems with the domain and more ability to give feedback. In addition, they are more controllable and understanding which will help to finish the experiment on time with less noise and mess. As they all got the test together at the same time, using high school level students matches the goal of the usability evaluation test more than using intermediate level students. The approval from the Ministry of Education in Saudi Arabia was granted to apply this research in the international schools in Dammam- Saudi Arabia for this experiment and the other experiments. Appendix (5) shows a copy of the approval letter. The experiment was anonymised, no student data were recorded. The goal of the experiment was to retrieve users' opinion about the usability of the system and to give a chance to the teachers to become familiar with the system as they will supervise the other experiments. There was no need to record learners' answers as their answers will not be connected to the research, as they are from a level higher than the current research domain. The users faced three equations and they had a chance to test the skills test tools and skills enhancement tools. Learners were then asked to fill in a survey containing their opinion about the usability of the system and any other notes they would like to add.

5.2.3 Methodology

The choice of methodology comes based on the type of data that will come out of the experiment and goal of the experiment as mentioned in Section 5.1. For this experiment, mixed methods were used in order to be compatible with the numeric data and the nonnumeric data that came from the survey. In addition, other nonnumeric data came from teachers' interviews after the experiment. The survey contained a lot of numerical data about the user interface, user opinion about how easy the system was to use, and the clearing of the instructions, and other information about usability, all recorded as scores which will be used with the quantitative analysis. It also contains general notes from the users which will be presented in a qualitative method. In the end of this section, a brief description about the result of this data will be illustrated.

5.2.4 Participants recruitment

It is a hard task to deal with a huge number of students at the same time. But because of the limitation of the time that was given by the school management to avoid interrupting the school activities, it was very important to plan this experiment in advance with the full engagement of the school management. It was started by getting the verbal acceptance from the school management to apply the experiments in the school using their students and their teachers to supervise the students. After that, and based on Saudi government rules, it was necessary to obtain an approval from the Ministry of Education in Dammam City to apply the research experiments in International Schools Group and any other international school, as they teach in English and so, are compatible with the system's language. After obtaining the approval from the Ministry of Education, a hard copy was sent to the school management. They started to recommend some mathematics teachers from high school and intermediate school to the researcher, as per what the researcher had requested. There were other volunteer teachers from subjects not related to mathematics, in order to help control the big group of students. In total there were thirteen teachers. The system was presented to the volunteer teachers so they would be able to support the students during the test. Since this was a high school where most students were under eighteen, the teachers explained the experiment to the students in different classes. As this is a private school, each class had only a certain number of students which was less than twenty-five. For this experiment, the teachers together with the school management mixed three classes from different levels of high school to find fifty volunteer students ages from fifteen to seventeen, male and female. The teachers explained to the students about the experiment and their right to quit at any time. They were also informed that they were voluntarily coming to the experiment, and that it was an anonymising experiment, with no effect on their score in mathematics or in any other subject.

5.2.5 Procedure

After obtaining the teachers approval to help in this experiment, the teachers were given a full demonstration about the system and about how to deal with students' questions. They were asked to take notes about students' performance during the test and students' questions and concerns. This preparation was done before the time of the experiment. The thirteen teachers were from the field of mathematics and subjects other than mathematics, so they were divided into small groups. Each group had at least one mathematics teacher and another teacher from another subject. The mathematics teachers would help in case of any problem with mathematics and would be with the other teachers to help in controlling the students, to take notes about their performance, and to help them in any problem with the system as they trained. They were also asked to take students notes and to record concerns if they had any. The day of the experiment was the second day after the teachers' training was given. It was recommended by the management of the school to not have a long gap between the teachers' training day and the day of the experiment in order to avoid any of the teachers forgetting what they had learned. The day of experiment started by gathering all the volunteer students in a big area, which was two computer labs joined together. The experiment started with:

1- Explaining the experiment goals and procedure
2- Demonstrating the system to participants
3- Discussing the possible queries from participants
4- Giving the survey forms to the participants
5- Giving a username and password paper to each student.

The experiment took two hours, starting with thirty minutes for the demonstration and the experiment goals. There followed ten minutes for instructions, then students started to use the system and answer the equations by logging on to the website that contained the experiment. The students used the system for sixty minutes, the time included their questions and the solving of their problems by the teachers. After the sixty minutes, students were asked to fill in the survey in the last twenty minutes. The survey was collected from them at the end of the experiments, and they were thanked by their teachers. Teachers passed on the researcher's appreciation to all the participants. After the students returned to their classes, a short interview with the teachers was done in twenty minutes. They gave their opinions about the experiment, the system, students’ performance, and students' opinions about the system. Some issues faced by some teachers regarding the usage of the system were discussed too.

5.2.6 Results

The result of this experiment has two parts: the qualitative data and the quantitative information. The quantitative data came from the surveys. It contains scores about many usability points, such as user interface, user experience, and user preferences. The following table illustrates the summary of the survey scores of forty-two students who successfully used the system and reached the end of the system, then filled in the survey. There were eight students who either didn’t finish on time or stopped using the system, or they didn’t fill in the survey.

Q. N	Survey Question	Mean	SD
1	The font size was suitable for this application	4.50	0.80
2	The font colour was suitable	4.43	0.94
3	The font type was suitable	4.55	0.74
4	Text was easy to read	4.69	0.81
5	The application was easy to use	3.55	1.11
6	Information on the screen was clear and well explained	4.14	0.98
7	The language used was suitable for students between the ages of 13 and 15	4.74	0.54
8	Errors related to using or interacting with the system were rarely made	3.24	1.28
9	Knowing what to do next was never a problem	3.62	1.46
10	When mistakes were made in the calculations, the procedure was easy to follow	3.50	1.40
11	Using the onscreen keypad makes it easy to input the answer	3.19	1.50
12	Using the onscreen keypad prevents mistyping	3.50	1.61
13	When entering fractions, it's preferred that the text box height is increased rather than having a bigger text box	3.88	1.42
14	Using the provided onscreen keypad is preferred rather than using my computer keyboard	2.05	1.32

Table 5.1: The mean and the standard deviation for the scores of the survey questions. (5 is high, 1 is low)

From the above table, the first four questions related to the appearance of the user interface. The average and the standard divination show a good result. Most participants gave high scores to the four first questions. This indicates that the appearance of the system is clear and easy to read. Table 5.2 below, shows the repetitions of the score for each question. The repetitions of the high score in the first four questions confirmed the satisfaction of the user about the appearance of the system.

Value	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q 10	Q 11	Q 12	Q 13	Q 14
1	0	0	0	1	1	1	0	4	6	5	6	6	1	22
2	1	3	0	0	6	1	0	9	4	3	7	6	3	6
3	5	4	6	3	15	8	2	11	7	7	10	5	9	7
4	8	7	7	3	9	13	7	9	8	15	6	6	6	4
5	28	28	29	35	11	19	33	9	17	11	12	18	21	3

Table 5.2: Score value repetitions

Questions 5, 6, and 7 are related to user experience about the system. Question number 5 is about how easy it is to use the application. The average was 3.55 out of 5. That shows a significant improvement in the interface from the first prototype, where the difficulty of the interface was the main reason to change it. Although, the 1.11 standard deviation of the score indicates that students' opinion about the difficulty of the system was slightly polarized, from Table 5.2 it's clear that most of the students gave 3 out of 5 to the difficulty of using the system where another eleven students gave a 5 score which means the system is easy to use. There are only seven students who think that the system is quite difficult to use. Additionally, the teachers' interview gave a positive opinion about how easy it is to use the system as will be described later in the qualitative section.

Questions 8, 9, and 10 are related to system reaction with users' behaviour. From Table 5.1 above, the averages of these three questions are about 3.5. This indicates that the system responds in a good way to most users' actions. This result is fine for a user who is using such a system for the first time. The standard deviation of about 1.4 illustrates some polarity in system reaction. However, Table 5.2 gives more details about the score values repetition. Most students gave a score of 3 and above to all three questions. It is also a good improvement from the first prototype, where most users complained about the difficulty of the interface and how to deal with it.

Questions 11, 12, 13, and 14 are about input methods and system reaction during input. A full-size keyboard could be the most effective input method. However, there are many characters and symbols that are difficult to find by using a full-size keyboard (He and Zhang, 2019). The user in the current research experiments will need to enter “x” as a variant and fraction. By using a full-size keyboard, it is possible to find the capital letter of “X” but to write a fraction it may need more advanced experience. The final prototype provides the user with an onscreen keypad. It contains all numbers, all operations symbols, the letter “X”, and a fraction input symbol. Figure 5.1 shows the onscreen keypad.

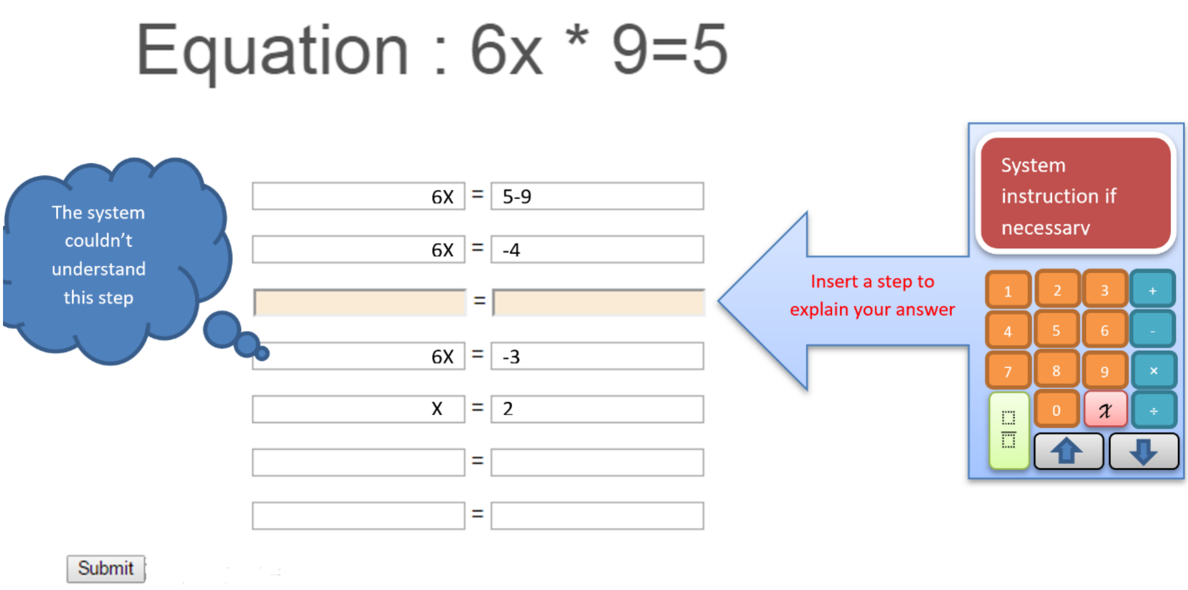

Figure 5.1: The onscreen keypad

The keypad moves up and down based on the user answer step. The arrow point is on the current step that the user should fill in. The blue cloud appears when the system needs more steps to explain the user's answer. The beige colour text box appears in between the two steps that needs more explanation to tell the system how the user moves from the step above to the step below. All these animations and the onscreen keypad are to help the user to have a good and correct interaction with the system. This will help to reduce wrong input. These ideas of an onscreen keypad and animations are to guide the users during their answer and can be redesigned based on the subject of the domain, as will be described in Chapter 6. The survey's result of these questions indicates an average of 3.5 regarding the use of the onscreen keypad, as shown in Table 5.1. However, the standard deviation of these questions shows some high polarity up to 1.6. This indicates that not all users like to use the onscreen keypad. Table 5.2 helps to understand users' opinion about the onscreen keypad. Most users gave a 5 score to the benefits and the ease of using the onscreen keypad, where the majority gave a score of 1 to the desire of using the onscreen keypad. Although there is variation of users' opinions about preferring the use of the onscreen keypad, the availability of such an option seems to be important in such a system. This claim has more support in the qualitative analysis, as will be described in the qualitative section later in this experiment section.

After a brief analysis of the quantitative data, the qualitative data is discussed here. The qualitative data describes nonnumeric information that was obtained from the students' notes, the teachers' notes, and the internal system reports and data that helps the researcher to improve the system in programming matters. The qualitative information may add some new ideas about the system or may support some quantitative data or may give more explanation about some quantitative results. One of the most important pieces of qualitative information that was obtained from the teachers and confirmed by the observation of students' answers, is that level 3 is the suitable level to be tested in the Functionality Experiment. This will be described in more detail in Section 5.4. Choosing this level was discussed with the teachers before the first experiment, the teachers confirmed it based on what they saw during the experiment based on the time that learners need to solve the test and how learners interact with the system. The last two questions in the survey were qualitative questions. Question 15 was about supporting the user answer to question 14 which was about using the onscreen keypad and how users like it or dislike it. The students' responses to this question can be summarised in the following points:

- Using the keyboard is faster and easier to input the answer.
- Users are more familiar with a normal keyboard.
- There were some bugs in using the onscreen keypad.
- The onscreen keypad makes it easier to input X and other mathematical signs and fraction symbols.
- It is a good idea to have the onscreen keypad as optional.

From students’ answers and the previous quantitative analysis, it seems to be recommended to have an onscreen keypad for mathematics or for any subject where users will be asked to insert special characters or symbols that are usually not easy to find on a normal keyboard.

The last question in the survey was a blank space to allow users to add any note they would like to add. The retrieved notes can be summarised by these points:

- It was easy to use the e-diagnostic system.
- Users have fun when they use the system.
- It is a new and good idea.
- Users like it when the system gives them the report about their errors.
- The system was accurate in determining student errors.
- At first it was hard to use the system, but it became easier when users got used to dealing with it.
- There were some bugs and misspelling in the system.

Although there were some bugs and some difficulties to deal with the system, as it is a new system for the students and varies from what they are used to using at their school, the general outcome from the experiment was good and gave the students a good experience which in general they liked. That can be observed from both qualitative and quantitative results and with the teachers’ opinions obtained after the experiment, which can be described in the following points:

1- There are some programming bugs that have been discovered and have been reported to the researcher.
2- Some participants got some queries in the beginning of the experiment, but that reduced in the middle of the experiment, and so on. Mostly the queries were about using the interface. Teachers observed that during the first equation answer there were some inquiries from some students. However, most of those students succeed in solving the next two equations without any problems.
3- Most participants become familiar with the system and were ready to undertake another experiment. That was the students’ feedback to the teachers after the experiment. Most students enjoyed the experiment and would like to have such a system for other subjects.

4- Confirming that level 3 of difficulty is the best level for the upcoming Functionality Experiment.

5- Participants achieved different stages in the system as follows:

   a. A group of students solved all equations with no errors at all. They have received a report with no errors. They were asked to wait until the end of the experiment to fill in the survey.
   b. Another group of students solved all equations with one error. They received a report with one error. Then they were redirected to the missing skill evaluation. Then they were redirected to the skills learning tool. After they learned about the missing skill, they were redirected to Stage Two where they solved Stage Two with no error. They received a report with one missing skill, missing skill enhancement successful, and passed Stage Two.
   c. Few students solved all equations with multiple errors. They received a report with multiple errors and were redirected to the missing skills evaluations. Then they were redirected to the skills learning tool. After they learned about all the missing skills, they were redirected to Stage Two where they solved Stage Two with no error. They received a report with multiple missing skills, missing skills enhancement successful. The students were redirected to Stage Two, and they passed.
   d. Two students solved all equations with multiple errors, received the report with multiple errors, moved to missing skills, learned about some of the missing skills, solved Stage Two with errors, and received the report with errors.
   e. One student solved all the equations with multiple errors, he received the report with multiple errors, then was redirected to the missing skills. He stopped working on the system as he didn't like it.
   f. One student solved some equations with multiple errors, then stopped using the system and filled in the survey randomly. (His survey was ignored).
   g. Five students got stuck in the beginning of the system, had no motivation to use the system, and they didn't fill in the survey.

6- The teachers confirmed that sixty minutes is a sufficient time for students to finish the current experiment and it will be an appropriate time for the Functionality Experiment.

The above information was retrieved by interviewing the teachers after the experiment. Although some students didn’t like to fill in the survey or to use the system, the teachers still felt that the system is good, and the problem was that those students were known to not actively participate even in the classroom. However, having this number of students may have helped in ignoring those students. Besides which, they had the right to quit the experiment at any time as they agreed at the beginning.

5.2.7 Summary

The goal of the first experiment was to evaluate the usability of the system to check if the system was ready to be tested on the real students who currently study the domain. The domain is about linear equations, which students study in their third year in intermediate school. More details about testing the functionality of the system will be discussed in the third experiment in Section 5.4. The first experiment resulted in many benefits to the researcher. It determined the right level to be used to test the system on the students who currently study the domain. There were many bugs and programming issues that appeared in this experiment. Some of them have been reported by students and teachers, while others were discovered by the researcher. This experiment will help to fix most of those bugs which will help the system to work better in the Functionality Experiment. The current experiments gave the researcher a good indicator of the accuracy of the system. Despite some bugs, the system was working well and had a good accuracy in determining a student's missing skills. Although the students’ level was higher than the system domain, there were still many students who made real mistakes during their answers, and they learned from their mistakes. However, this experiment doesn’t cover the analysis of students' answers as they don’t currently study the domain. The accuracy of the system in this experiment gave a good indication about the efficiency of the algorithm and the models used to program the system. This will help to answer the research questions about the using of models in such a system. More description will be given in Chapter 6. Finding bugs in the current experiments led to reprogramming some parts of the models to avoid any problems in the Functionality Experiment. It was necessary to make another experiment to test the system after fixing the bugs and to confirm the accuracy that was found in the first experiment. To achieve these goals, an additional experiment was prepared. The next section will describe the second experiment which was called “Intentional Error”.

5.3 Second experiment: Intentional Error

5.3.1 Introduction

The previous section was about the usability evaluation of the e-diagnostic system that will be used to test the current research idea. The above experiment results in a lot of benefits as described in Section 5.2. There were two of these benefits related to the current experiment. The first benefit was about the bugs that were found during the first experiment. It allowed the researcher to fix those bugs before the time of the functionality evaluation. This fixing resulted in changing of some programming codes which require another evaluation to check if the system is ready for the Functionality Experiment. The second benefit was about the accuracy of the system. Although the first experiment showed a high grade of accuracy, that accuracy was about the students' errors which happened during the experiment. There are still some possible errors not covered as none of the students made them. For this reason, it is necessary to test those errors intentionally. This is what this experiment is about. The goals of this experiment are to recheck the system after the bugs have been fixed and to check the other possible errors, which did not appear in the first experiment, and how the system will react to them. The experiment will use the same setting of the previous experiment, such as Category 2, Level 3, and Sequence 1.

5.3.2 Method

This experiment involved thirty-nine volunteer students aged fifteen to seventeen, male and female. All of them were from the International Schools Group. It is the same school where the first experiment was done and involved the same students. The reason for using the same school and the same students is to save time by having students with previous experience with the system. This will make it easier for them to deal with the system and reduce the chance of extra user errors that may waste the experiment time. It is also easier to do the experiment in the same school as they already have the approval from the Ministry of Education in Saudi Arabia to apply this research in this school. The experiment was anonymised, no student data was recorded. The goals of the experiment were to retrieve users' opinions about the usability of the system, after fixing the bugs, and to try extra errors that did not appear in the previous experiment. There was no need to record learners' answers as their answers will not be connected to the research, as they are from a level higher than the current research domain. The students went through the same experiment as the previous experiment except that in this experiment they have been asked to make some errors intentionally. More about the procedure of the experiment will be described in the procedure section.

5.3.3 Methodology

This experiment can be described as a second usability evaluation with intentional errors. For this reason, it will have both qualitative and quantitative data. For this experiment, mixed methods will be used to be compatible with the numeric data and the nonnumeric data. The survey will cover the intentional errors and how the system reacts to that error. This will be either an answer of yes, if the system discovers the error and advises the learner to the right missing skill, or a no, which will mean the system failed to discover the missing skill. That part of the survey presents the quantitative data of the survey. In addition, other nonnumeric data will come from the survey's open note. The students were asked to put any note about the system they can see on the survey. From these notes, the qualitative data will be obtained.

5.3.4 Participants recruitment

The current experiment will have a similar circumstance to the first experiment, based on the limitation of the time that was given by the school management to avoid interrupting the school schedule. The school management were pleased to allow the researcher to use their students and to let their teachers supervise the students for a second time. The approval from the Ministry of Education in Dammam City to apply the research experiments in the International Schools Group was still valid. The mathematics teachers who were involved in the first experiment were happy to help in the second experiment as they were all in the field of education and they felt that such a system is important to help them. In reality, teaching mathematics is a very difficult task where one to one teaching is required. Teachers normally don't have enough time to check all students individually as it takes a long time and effort. Such a system may help them in checking students' problems individually in an easy way. This gave them more motivation to help in this experiment and in the other experiments, as is described in the fourth experiment, which will be about the teachers' evaluation of the system, which will have more details in Section 5.5. The teachers recommended the good students who were active in the first experiment. They excluded some students who were negative in the first experiment. They invited the good students from the first experiment and asked them to participate in the second experiment. Thirty-nine students accepted to participate with the same rules and rights. Teachers explained to the students about the experiment and their right to quit at any time. They were also informed that they are voluntarily coming to the experiment, and it is an anonymised experiment with no effect on their score in mathematics or in any other subject.

5.3.5 Procedure

After obtaining the teachers approval to help in this experiment, the teachers got a full demonstration about the system and how to deal with students' questions. Teachers were familiar with the system as most of them were a part of the first experiment. The experiment started with:

1- Explaining the experiment goals and procedure
2- Discussing the difference between this experiment and the previous one
3- Giving the survey forms to the participants
4- Giving a username and password paper to each student.

The experiment took one hour, starting with fifteen minutes for the demonstration and the experiment goals. There were five minutes for instructions, then the students started to use the system and answer the equation by logging on to the website that contained the experiment. The students used the system for twenty minutes including their questions and the solving of their problems by the teachers. After forty minutes, students were asked to fill in the survey in the last twenty minutes. The survey was collected from the students at the end of the experiments. The survey contained the intentional error that students should make. Figure 5.2 contains examples of the survey form. Each survey has a different error request.

User ID: Student51 Exam ID: 2028, 2026

Please pretend that you don't know addition or subtraction

Answer all steps correctly but make a mistake in addition or subtraction.

Did the system suggest to you to evaluate your skills addition or subtraction?

Yes (✓) No( ) It found my error in the equation

User ID: Student 66 Exam ID: 2028

Please pretend that you don't know how to move number from one side to the other side.

Answer all steps correctly but move a number without changing the sign.

Did the system suggest to you to evaluate your skills in moving numbers to other side?

Yes (✓) No( ) I did addition mistakes and the system told me the problems

Figure 5.2 Example of the intentional error survey

5.3.6 Results

Section 5.3 detailed the second experiment. It was about intentional errors. Students were asked to make errors intentionally while they solved the equations. The goals of this experiment are to double check the usability of the system and to be sure about the readiness of the system to be used in the third experiment about the functionality of the system. In addition to the usability evaluation there were some errors that didn't appear in the first experiment which this experiment covered intentionally.

The results of this experiment focused on quantitative data about whether the system discovered the errors and gave the right advice to the students to learn about their missing skills. The data came by Boolean type. It is either “yes” which means the system gave the right suggestion about the missing skills, or “no” which means the system failed to give the right suggestion about the missing skills. However, students will still have a chance to provide any extra qualitative information which can be by writing a note about the system on the survey form. Thirty-five students gave “yes” after they intentionally made an error during their answer. Only four students gave “no” to the system. By reviewing their answers, it was clear they didn’t finish the test. They just put “no” in the form. This can happen for many reasons which are not related to the experiment goals. The qualitative information was null in the whole survey part, as there were no notes except in four surveys, but their notes were irrelative to the experiment goals. Although there is no qualitative data retrieved from the survey, the after-experiment discussion with the teachers confirmed that the experiment went smoothly despite those four students’ lack of interest as they didn't have motivation to complete the experiment. However, the teachers added a very important point regarding the experiment - the students answered the test with no problems and no questions. That indicated that they had become familiar with the system. Being familiar with the system just after their second use shows a satisfactory result regarding the usability of the system. This is a new system for them, not like the LMS (Learning Management System) that they use in their school. Yet they became familiar with it after their second use. This result will help to answer the research question about the usability of such a system, and Chapter 6 will have more details about that. Although the surveys and the teachers' results show a high level of efficiency of the system, there were still some bugs discovered by the researcher. No single software is known as 100 percent guaranteed bug-free (Peterson, 1996). Those bugs were non-functional bugs and have been fixed after the experiment.

5.4 Third experiment: Functionality Evaluation

5.4.1 Introduction

Section 5.2 detailed the experiment about the usability evaluation of the e-diagnostic system that will be used in the current research study. The experiment involved fifty volunteer students from the International Schools Group in Saudi Arabia. This experiment was followed by another Intentionally Error experiment where thirty-nine volunteer students participated. Full details about the experiment are described in Section 5.3. Both previous experiments were supervised by the same thirteen teachers from the school. Some of them were mathematics teachers who supported students in any mathematical issues. The rest of them were teachers of subjects other than mathematics. They helped the mathematics teachers in controlling the crowd of students and leading the students while they were answering the test as they were trained in how to deal with students' inquiries. The results of both experiments indicated a sufficient level of accuracy and learner satisfaction. The teachers' opinions were positive in terms of the usability and the efficiency of the system despite some bugs and the fact that some students were not motivated to finish the experiments, as was described in the previous sections. However, there were many benefits from the previous experiments which paved the way for the current experiment, which will evaluate the functionality of the system. The current experiment will follow Sequence 1 as it is the standard sequence which supports the research question about the possibility of applying the research idea. It will be Category 2 and Level 3 as they are recommended by the result of the first experiment.

The current experiment is about the functionality of the system. The system will be tested on real students from the domain level. In Saudi Arabia, linear equations with Category 2 is the domain of the third year at intermediate school. This makes the third-year students as targeted group of students for this experiment. The goal of this experiment is to test the ability of such a system to categorize the domain into small elements. Each of those elements is related to a learning objective from the current domain or from a previous study. Those learning objectives are designed to be specified to cover a certain skill or knowledge required to pass the learning objective. The system will analyse a student's answer step by step to find any error in his or her answer. The system will check the possible missing skill or knowledge that prevented the learner to approve her or his ability to pass the learning objective. When the system determines the missing skill or knowledge, the system will test the learner in this skill or knowledge. Then it will provide them a remedial path tool to learn about the missing skill or knowledge and keep the learner in this loop until the learner reaches the mastery level in this missing skill or knowledge. Then the system will retest the learner again in the domain to check the improvement. Learners may have one or more missing knowledge or skills. This experiment is designed to test the functionality of the system and this idea will help the learner to understand his or her weaknesses and to know what part of the domain they should learn to improve these weaknesses.

To approve the possibility of achieving the experiment goal, tests of Category 2 and Level 3 have been prepared. The tests will follow sequence 1, which is the standard sequence of the system. To evaluate the idea of the system, it was necessary to find real students who don’t know how to solve a linear equation. If the students know how to solve the linear equation, then it will be nearly impossible to evaluate the improvement of the students after using the system. For this reason, it was very important to test a large number of students and select only those who don’t know how to solve a linear equation. The plan was to test all volunteer students from the domain level using a conventional paper test in solving a linear equation. Then to choose those who fail in the test and send them to the computer lab to test them by using the e-diagnostic system, to see why they failed in solving the linear equation and how the system will help them. The conventional test will be done by the teachers as is described in the next section. Because of the short time that was available for the experiment, the teachers agreed to choose one learning objective to focus on. It is about moving a constant from one side to the other with the same sign. This learning objective needs an easy skill which can be learned in a short time, and it is a very common mistake that students may have made based on the teachers’ recommendation. The experiment has some challenges: how to find the students who don’t know how to solve a linear equation, how to control them if they are many, does the school have a large number of students who don’t know how to solve a linear equation, and if yes, will their weaknesses be in the targeted learning objective that has been chosen by the teachers. All these questions will be answered in the next few sections about the method and participant recruitment.

5.4.2 Method

This experiment involved fifty students aged 14 to 16 years, male and female, from the third year of intermediate schools in Saudi Arabia. Those students were selected after failing a conventional test about a linear equation. To collect enough students, two schools were involved in this experiment - The International Schools Group and the Dhahran School. Both schools are in Dammam City, and they are international schools following an English mode of instruction. More details about recruitment of the students will be given in the next section. The students were asked to use an online system to solve linear equations, then to follow the system instruction. At the end of the experiment they were asked to fill in a survey. The approval from the Ministry of Education was still valid to be used in both the schools. The experiment was anonymised, and no student data was recorded. Student answers were recorded in order to be analysed so as to find the ability of the system to determine the missing skills and knowledge from the targeted learning objective, and from any other learning objective, as they will not be targeted because they will need a long time to reach Stage Two of the system. Reaching Stage Two means the learner must learn the missing skill or knowledge and reach the mastery level, only then will the learner be allowed to go to Stage Two. Although these learning objectives will not be targeted in this experiment, as they need a long time, the answers will be recorded in order to have a full analysis which will help to evaluate the ability of the system to find a variety of errors and determine the missing skills or knowledge. For this purpose, it is not necessary that the learner finish the whole experiment and go to Stage Two. However, only students with moving constants and variables from side to side will be asked to finish the experiment until Stage Two. This strategy will save teachers time so they can focus on the learners who are missing the targeted learning objective. It will reduce the time that students are away from their class and reduce any issues arising with the school management.

5.4.3 Participants recruitment

Fifty students aged 14 to 16, male and female (students who are currently studying the domain). They are from two schools in Dammam City in Saudi Arabia. The International Schools Group has only ninety-two students in total who are in level three of the intermediate school. The conventional test shows that forty-three students failed to solve the linear equation. Only twenty-nine students answered the equation with clear steps. Some of the students used calculators and others just put the final answer so there was a chance that they had cheated. However, those students were excluded from the experiment as they didn't show enough interest to be involved in the experiment. Because of the small number of students who are both ready to participate in the experiment and failed in solving a linear equation, it was important to involve another school. Dhahran School gave the approval to apply the experiment in the school. It is an international school teaching in English and Arabic. The conventional test was applied to seventy-six volunteer students from the school. They were in their third year at the intermediate school where they currently study the domain of linear equations. The result of the conventional test of a linear equation came with twenty-one students making mistakes while answering this test. This made the total number of the students for both schools: fifty students. The teachers in Dhahran School had training before the experiment, so that they would be able to apply the test. All the students from both schools were recruited voluntarily by their teachers after they finished the conventional test of a linear equation. Students from both schools were from the same level of study, which made sure that the samples from both schools were similar. However, to reduce the chances of cheating, the conventional test had two forms, with each form containing an equation with different numbers. Figure 5.3 shows samples of the conventional test forms.

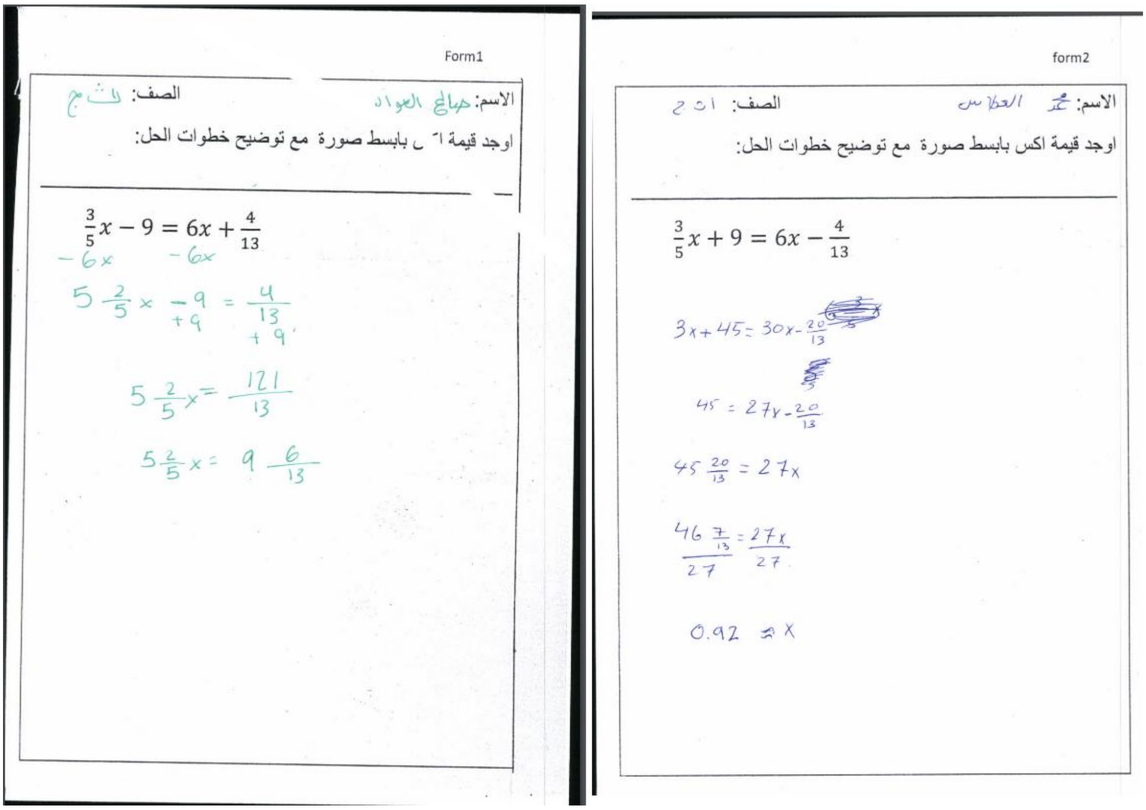

Figure 5.3 Samples of test forms

There were twelve volunteer teachers from Dhahran School who helped in controlling the students and applying the test to their students. Four of them were from a mathematics background and the rest of them were from different subjects. The teachers were recruited voluntarily by the school management. There were thirteen teachers from the International Schools Group who participated in the previous experiment and were also involved in this experiment.

5.4.4 Methodology

This section will describe the choice of the methodology for the third experiment. This experiment intends to evaluate the functionality of the e-diagnostic system. It will discover whether or not the system will succeed in finding the missing skill or knowledge behind the students' mistakes made while solving a linear equation. Then the ability of the system in enhancing the students by teaching them the missing skills or knowledge. Then the system will re-evaluate them to find out if they succeed in solving the linear equation. The main goal of this experiment is to evaluate the ability of the system to discover the missing skills and knowledge of a learner, then suggest the most relevant remedial path. The results of this experiment will help to answer other research questions too. More details about this will be described in Chapter 6. Because of the variety of results that are expected from this experiment, there will also be a variety of data that is expected to come out of this experiment. This data will be retrieved from the students’ surveys, teachers' interviews after the experiment, and analysis of students’ answers that will be recorded in the system. This variety of information is mixed between numeric data, such as that which will come from the survey, and nonnumeric data which will come from the teachers’ discussion and the analysis of the recorded students' answers. The choice of methodology of this experiment needed to be capable of dealing with numeric and nonnumeric data. In this case mixed methods will be the proper choice so as to have a full analysis of the quantitative and qualitative data, as has been described in the introduction section.

5.4.5 Procedure

After obtaining the teachers' approval, from the second school (Dhahran School), to help in this experiment, the teachers were given a full demonstration about the system and how to deal with students’ questions. They were asked to take notes about students’ questions during the test and students’ performance plus what they were concerned about. This preparation was done some days before the experiment. Twelve teachers were taken from mathematics department and from subjects other than mathematics. The teachers from the other school (International Schools Group) were already trained as they had tested the system in the previous experiment. The experiment was done in both schools separately. Each school handled their students and applied the experiment on their students by following the same procedure. The procedure of the experiment was given to the teachers to follow during the experiment. It started by division of the students into small groups. Each group had at least one mathematics teacher and another subject teacher. The mathematics teachers’ duty was to help in case of any problem with mathematics, and to be with the other teachers to help in controlling the students, to take notes about their performance, and to help them with any problem with the system, as they had been trained. They were also asked to record any students’ notes and concerns if there were any. The day of the experiment started off by gathering all the volunteer students in a computer lab. The experiment started with an explanation of the experiment goals and the procedure, which was given to the students in the first ten minutes. Following that, the students received twenty minutes' training about how to use the system with the help of their teachers. After that the students received the survey form that they will need to fill in after the test, so that they were made aware about what they should consider during their use of the system. They were also given a slip of paper which contained the username and password for each student. The students were asked to start using the system by opening a webpage: www.globalhint.com then logging in using their username and password. The test was prepared based on username. Each username was assigned to a preset test. The students were asked to finish the test in sixty minutes. After the sixty minutes were up, they could fill in the survey. This rule helps to give the students a chance to answer the test without rushing. If they were asked to fill in the survey directly after the test, some students may rush to finish and go to play out of the class. The survey was collected from them at the end of the experiment, and they were thanked by their teachers for their participation in the experiment. The teachers passed on the researcher's appreciation to all participants. After the test, there was a short discussion between the teachers and the researcher for twenty minutes. They gave their opinions about the experiment, the system, the students’ performance, and students' opinions about the system. Although some of the teachers from Dhahran School faced a little difficulty in answering students' inquiries about using the system, the experiment went smoothly.

5.4.6 Results

This section is about the results of the third experiment. The experiment was about the functionality of the e-diagnostic system in determining the missing skill behind a student's mistake made while solving a linear equation. The introduction of this chapter described the qualitative and quantitative research methodology. It also covered the mixed methods approach that uses both qualitative and quantitative methods. This experiment used the mixed methods approach, as was described in the previous section. Choosing mixed methods will help to cover the variety of data that is expected to come out of this experiment. In the beginning, quantitative data will be described, as this will be retrieved first. The quantitative data came from the survey that students filled in after the experiment. The survey consists of seven questions. The first six questions present the quantitative data. Each question has a rating from 1 to 5, where 1 means low value and where 5 means high value. The seventh question was an open question where students can write their opinion about the system or make any note they want to write. The seventh question presents qualitative data. There will be more qualitative data from the teachers' discussion after the test, and from the students' answer analysis, as will be detailed later in this section about the qualitative data. The seven questions were as follows:

1- The system found my exact error every time.
2- The system gave me the right suggestion about my missing skills.
3- The system improved my missing skills.
4- It is not boring to use such a system.
5- When the system couldn't find my error, it tests the skills that caused the error quickly without testing many skills.
6- After using the system, proficiency at solving equations was reached.
7- Please write any suggestion that you have, to improve the system.

A sample of the survey can be found in Appendix (6). Table 5.3 below shows the numeric results of the experiment's survey.

s	Question	Mean	SD
1	The system found my exact error every time	3.41	1.75
2	The system gave me the right suggestion about my missing skills	3.39	1.76
3	The system improved my missing skills	3.24	1.61
4	It is not boring to use such a system	3.39	1.44
5	When the system couldn't find my error, it tested the skills that caused the error fast without testing many skills	3.11	1.65
6	After using the system, proficiency in solving equations was reached	3.41	1.51

Table 5.3: Mean and standard deviation of the survey result

The above table shows the mean and standard deviation of each question. The means of all questions are above 3, which means that in general there is a positive opinion about the system. However, having standard deviation above 1 in all questions indicates a polarity in the result. The following table will give more details about the score repetition for each question.

Value	Q1	Q2	Q3	Q4	Q5	Q6
1	0	0	0	1	1	1
2	1	3	0	0	6	1
3	5	4	6	3	15	8
4	8	7	7	3	9	13
5	28	28	29	35	11	19

Table 5.4: Score repetition

From the table shown above, it is clear that the deviation in the result concentrates around the value 5 in the first four questions, whereas they spread between 3 and 5 in question 5 and 6. To understand the students' opinion about the system based on the survey results, it is necessary to study each question and its result.

First question: The system found my exact error every time.

The goal of this question is to find out whether the system will succeed in finding the students' errors in each question or not. This question will help to evaluate the functionality of the system. The system is designed to check students' answers step by step. If the system found any error in any step, then it will record that error and try to find the missing skill or knowledge that caused the error. This question is related to the first part that is related to finding the errors. The survey result for this question shows an average of 3.41 out of 5, which indicates a high level of efficiency of the system to find the student's error that led to a wrong final answer. The error can be in one step or more, or it can be more than one error in the same step. However, the average of 3.41 has a polarity as is shown in the standard deviation value of 1.75, which indicates a moderate level of polarity, as is shown in Table

5.3. Although there is this moderate level of polarity, Table 5.4 shows twenty-eight out of forty-two repetition of value 5, which indicates a high number of students agreed about the ability of the system to find their errors. However, there are still eight students out of forty-two who gave 4 out of 5 as a rating of the ability of the system to find their errors every time. Another six students gave 3 and below for the question. There are different reasons that explain why those students didn’t give a full score of 5. More details about those possible reasons will be discussed in Chapter 6, in the discussion section.

Second question: The system gave me the right suggestion about my missing skills.

This question is about the second phase of the system. After the system succeeds in determining the steps where the students made an error and the type of the error, the system will then suggest to the students the possible missing skills or knowledge that may have led to these errors. However, this suggestion can be confirmed in the third phase of the system, which will test the missing skill or knowledge that is suggested by the system. If the students fail in the test, then the system will confirm the students’ level in the missing skill and knowledge. After that, the system will direct the students to the tools that can enhance the missing skill or knowledge. The survey result of this question had an outcome with an average of 3.49 out of 5. It has a standard deviation of 1.76, which indicates polarity too in the answer to this question. Although there is this polarity, Table 5.4 determines this polarity to the positive side, with twenty-eight students giving 5 out of 5 as a rating for the ability of the system to give the right suggestion to them after discovering their errors. More analysis of this polarity will be discussed in Chapter 6. There are eleven students who gave 3 and above out of 5 for this question. This indicates a high level of satisfaction from the students' point of view, about the accuracy of the system in providing the right suggestion about the missing skills or knowledge. This high level of accuracy will help to answer some of the research questions about the use of mixed models in such a system, and how it will be beneficial to use mixed models in designing e-diagnostic systems, as will be detailed more in Chapter 6.

Third Question: The system improved my missing skills.

This question doesn’t have a direct link to the research questions. It is about the tools that enhance students' missing skills or knowledge. Those tools are designed and implemented in the system just to help the learners to understand the missing skills and knowledge in a simple way to check the system prototype. However, in a real system, the enhancement tools should be an advanced e-learning system with multiple teaching options to match individuality of the students. Although the tools are not related to the research questions, it is still important to evaluate the functionality of the system. Those tools are intended to be able to teach the learners about their weaknesses, and missing skills or knowledge. By helping learners to learn the missing skills or knowledge, the system will be able to evaluate the learner's improvement after using the system, which will be helpful to answer some of the research questions, as will be described in Chapter 6. The survey result for this question came out with an average of 3.24 out of 5 and a standard deviation of 1.61. Having a high standard deviation in most questions, as is shown in Table 5.3, indicates polarity. However, this phenomenon of polarity will be discussed in a deep analysis in Chapter 6, with more details about students' survey answers, to check if the polarity is related to the finishing of the test or is just different opinions. This deep analysis will be covered in Chapter 6. However, Table 5.4 clarifies that the polarity is to a positive rating. Twenty-nine students gave 5 out of 5 to this question which indicates that the system was able to improve their misconception.

Fourth question: It is not boring to use such a system.

Using an e-learning system can be a boring activity. The design and the interaction between users and the system may reduce the possibility of it being perceived as a boring activity. However, this point is not directly related to the research's main concept. This question will help to evaluate the improvement of the prototype, from the first prototype to the final prototype, as the first one was rated negatively by the users in terms of its usability. That prototype had a solid interface where there was no animation or graphics. The final prototype has an interface with graphics and animation that helps to improve the enjoyment of using it. This question may help to answer some of the research questions, as will be described in Chapter 6. The result of this question was an average of 3.39 with a standard deviation of 1.44. However, the polarity of this result came equally between rating 3 and 5 by fourteen students for each rating. Table 5.4 illustrates this distribution of the result. The result indicates a high level of improvement in comparison with the first prototype. This result will be confirmed by the qualitative result as will be shown in the qualitative analysis later in this chapter.

Fifth question: When the system couldn’t find my error, it tests the skills that caused the error quickly without testing many skills.

It is a very critical point when the system fails to discover the error that a student has made while answering the test. The system will not be able to suggest the right tools to the learner to study in terms of improving the missing skills or knowledge. It will result in a failure in the whole system to do what it is intended to do. So, the goal of the system will not be achieved. Therefore, a special model was implemented to deal with this situation. This model will guess the missing skills and knowledge by isolating the skills that were passed in the correct steps. It will then suggest evaluating the remaining skills and knowledge based on the remaining steps. It was very important to check the ability of the system to provide the right prediction which will be the closest to reality. The result of this point of the survey came out with 3.1 as an average, which indicates a high level of user satisfaction about the system in this case. The standard deviation of this point was 1.65, which is a moderate level of polarity. Table 5.4 shows that polarity is concentrated on rates 3 and 4. A total of twenty-five students gave a rating of 3 or 4 to this point. However, there were a moderate number of students who didn’t give any rating to this point as they may not have faced such a case during their answer. In Chapter 6, more details about the matching between students' answers and their rating in the survey will be given.

Sixth question: After using the system, proficiency in solving equations was reached

This is the most important question. It is a question about the holistic evaluation of using the system. This question will be supported with a lot of qualitative data, as will be described in the qualitative section. A holistic evaluation can’t be described in terms of a number. However, the numerical data about the evaluation of using such a system can be an indication of the user satisfaction of the system and the system result. Some students may enjoy using the system and they find it a good system, but they don’t feel that the system improved them with regard to solving linear equations. The usability of the system is important, but functionality is more important. This question will discover the students’ opinions about the functionality of the system, and whether it improves them in terms of solving linear equations or not. The result for this question came out with an average of 3.4 and a standard deviation of 1.5. Table 5.4 describes the standard deviation result as most students have positive feelings about the system in terms of it enhancing them in their ability to solve linear equations. Twenty-seven students rated this question at 4 and 5 whereas only seven students gave a rating of 3 and six students gave a rating below 3. The next section will give more qualitative results of the survey.

Seventh question: Please write any suggestion that you have, to improve the system.

This question presents the first part of the qualitative data of the survey. It is an open text box where students can write any notes about the system with freedom. They can write positive or negative thoughts about the system. They can write suggestions, or anything they want, with no limitation and no effect on them as the survey was anonymised. Some of the notes came as suggestions and others were about some bugs, and few were positive about the system. A summary of related notes is detailed below:

- There were some bugs that have been discovered regarding the usability from Dhahran School. They were non-functional bugs, so they didn't affect the experiment. For example: a problem with scrolling down, text disappeared when a fraction was entered. Those problems happened because the browser used in the Dhahran computer lab was an older version and there was some restriction in the browser options as they were restricted for security reasons. However, those problems didn't affect the test as they were solved by the lab teacher at the school.
- There were suggestions from some students about putting on a screen calculator, allowing decimals, and providing a skip button. Those suggestions may be applied in a full software or a commercial one, as preferences. But for this research, a calculator is not accepted as one of the goals is to check a student's ability in calculation. It is also not allowed to accept decimals as calculating the fraction is a part of the domain that should be tested. A skip button was in the first prototype as it was a pilot study, but in the final prototype students should follow the test sequence without skipping. This will help to evaluate the system in full functionality.
- One student suggested showing the error after each answer. This option is available in Sequence 2. However, based on the goal of the experiment, Sequence 1 was selected. But having this suggestion gives an indication about how this student interacted with

the system and that he reached this level of thinking to suggest such an idea. In fact, this student gave high ratings in all the questions which indicates that he or she enjoyed the system.

- Some students ask for more interaction and pictures after solving the equation in the right way. Those kinds of suggestions indicate a good feeling about using such a system.
- There are many positive notes about the system by many students such as: it is liked, it can find my error every time, it is good, and more, which gives an indication about the user satisfaction of using the system, and the fact that the functionality of the system is good. This qualitative data supports the result of the quantitative data that have been detailed in the previous section. However, there will be more qualitative data retrieved from the teachers' discussion after the test, and the students' answers which were recorded, as will be described later. The next section will discuss the outcome of the teachers' discussion after the test.

The second part of the qualitative data is the data that came from the teachers' discussion after the experiment. There was a twenty-minute discussion with the teachers in each school. The discussion can be summarised as follows:

- Some participants had queries about using the system in the beginning of the experiment, but the queries reduced in the middle of the experiment as they started becoming familiar with the system. This point confirmed a similar observation made in the usability test with the difference in the participant ages. Most participants become familiar with the system after the first equation. This indicates that even if the system's interface is new to the students, they still can learn it as with any other software.
- Some students took the test seriously while others did not. Students who took the test seriously enjoyed the system more than other students who didn't.
- Some students had the desire to finish the test until the end even when teachers asked them to discontinue as they didn't make mistakes in the targeted skill.
- Some students were happy when they learned from their mistake through the system, then solved the equation at Stage Two.

- It is necessary to apply this concept to all the domains. It will be helpful to the teachers to have a computer-based system that can solve students' misconceptions individually, where it is impossible for the teachers to do it.

The third part of the qualitative data is the data that came from the students' answers records. After analysing the students' answers records, there were eleven students who made an error in moving a constant from one side to the other with the same sign. This is the targeted error that this experiment is concerned with. It was recommended by the teachers as it is easy to teach the learners about the necessary skill behind it. The other errors may need a long time to teach the learner about the necessary skills or knowledge. Because of the limitation of the time available for the experiment, the teachers and the researcher agreed to focus only on the learners who will make an error in this skill. It is a common error, just as the teachers thought. For this reason, only students who move constants from one side to another with the same sign, were asked to go to Stage Two. The other students, with the other errors, have the freedom to go to Stage Two, or just exit the test based on the time available for them to finish the test. The analysis of students' answers reports shows that eight of the eleven students who made errors in moving constants from one side to the other side of the equation have moved to Stage Two, by taking the enhancement tools and reaching the mastery level in this skill which led them to move to Stage Two and answer the equation correctly. This is a very high level of goal achievement. The system succeeds in determining students' errors. Then it succeeds in providing the missing skill. Then it suggests the part of the domain that the students should learn about. After that, the system provided the right remedial path to help the students to learn about the missing skill. Then the system keeps evaluating students' level in this skill, until he or she reaches the mastery level in this skill and passes the equation in Stage Two. This is actually the main concept of the research. The result coming from this experiment indicates the good efficiency of the system. Chapter 6 will have more details about how these results help to answer the research questions. More data analysis will be covered in Chapter 6.

5.5 Fourth experiment: Teachers' Evaluation

5.5.1 Introduction

In Section 5.4, the functionality evaluation experiment of the e-diagnostic system has been detailed. The experiment shows positive thoughts about the system functionality by the students and by the teachers who supervised the experiment. Some notes came in the Functionality Experiment suggesting giving the learners an indication about their error after each equation. In fact, this option is available in Sequence 2. The system can be designed in many sequences to cover many cases. However, based on the current research goals and questions, only Sequences 1, 2, and 3 are implemented in the current research. More sequences can be implemented for future work as it will be described in Chapter 6. The difference between those sequences is described in the introduction of this chapter. Although the suggestion came from students, it was in the current research plan to evaluate such sequences. Such evaluations should be done by the teachers, as they can judge the use of such sequences and how the system will affect the improvement in diagnosing the learners. For this reason, the current experiment was prepared. There are other sequences that should be tested and compared, which will help to answer some of the research questions, as will be described in Chapter 6. It is about testing all the skills before giving the equations to the learner. It is likely to consume more time, but it was necessary to test it. However, to give the ability to the teachers to understand the difference between the three sequences, to see how they can be used, and to see which benefits can come from using these sequences, it was important to demonstrate the three sequences to the teachers and retrieve their opinions about the system and the three sequences. The experiment was on Level 3 and Category 2, as they have been used in all the other experiments. The experiment covered Sequences 1, 2, and 3. The goals of the experiment were:

- To evaluate the usability of the system from the teachers’ point of view.
- To evaluate the functionality of the system from the teachers’ point of view.
- To retrieve the teachers’ opinions about different sequences.
- To retrieve the teachers’ opinions, suggestions, and notes about the system.

5.5.2 Method

This experiment involved twenty volunteer teachers, male and female. Twelve were from the International Schools Group and eight were from Dhahran School. Most of the teachers were involved in the previous experiments. However, some of them weren't involved in any of the previous experiments, and some were involved in some of the experiments. It was recommended to have all the teachers who were involved in all the previous experiments, but that was very difficult because of the limitation of time and their availability. The experiment was anonymised, and no teachers' data were recorded. As some teachers didn't know about the system, and due to limitation of experiment time, there was a demonstration of the experiment rather than letting the individuals trying out the system. The experiment was a real demonstration of the e-diagnostic system using all three sequences. It was a demonstration given by using real tests with many users answering the test with the help of the teachers, trying different cases and sequences to see how the system would respond. At the end of the experiment there was a survey given to teachers to fill in. After that, a thirty-minute discussion between the teachers and the researcher was done. The discussion took place after the survey to avoid some teachers' opinions influencing other teachers' opinions.

5.5.3 Methodology

The current experiment is the fourth experiment which is specially designed to gain the teachers' opinions about the e-diagnostic system with all the sequences. The expected data from this experiment is a mix between numeric data and nonnumeric data. The survey consists of eleven questions. The first nine questions present the numeric data, while the other two questions cover the nonnumeric data. However, there is other nonnumeric data that will be retrieved from the teachers' discussion at the end of the experiment. Due to the nature of the data that comes out of this research, mixed methods were chosen. Mixed methods research intends to be able to analyse the numerical and nonnumerical data, as is described in the introduction of this chapter.

5.5.4 Participants recruitment

Participants were recruited, comprising twenty teachers, male and female, from mathematics and other subjects. It was based on the approval that was obtained from the International Schools Group and Dhahran School to involve their students and teachers in some experiments. The teachers from both schools were invited by the schools’ managements to participate voluntarily in this experiment. Those teachers mostly had experience of the system as they had participated in the previous experiments. Some of them didn't have any experience of the system, as they were not involved in any of the previous experiments. It was difficult to have all those teachers who participated in the previous experiments because of the school timetable and the availability of the teachers. In fact, some teachers agreed to participate in this experiment because they had heard about the system from their colleagues.

5.5.5 Procedure

After obtaining the teachers' acceptance to participate in this experiment, a computer lab was prepared to be used in the experiment in each school. The researcher visited the schools one after another, starting with the International Schools Group. The time was agreed upon with the school management where they were able to give their teachers free time to participate in this experiment. The experiment started with a twenty-minute introduction about the system and the three sequences. It took twenty minutes for the first sequence. The researcher opened the site of the experiment and used a pre-test with different users. The test trained the teachers in different ways to try different cases. This way was used to avoid spending a long time training the teachers, and to give them time to solve the test. After that, Sequence 2 was tested with the teachers in ten minutes. Then Sequence 3 in another ten minutes. Then the teachers were asked to fill in the consent forms and fill in the survey in fifteen minutes. Finally, at the end of the experiment, there was a twenty-minute discussion with the teachers. The same procedure was used in both schools.

5.5.6 Results

The experiment in the previous section was about the functionality of the e-diagnostic system. The results of that experiment came out with positive students’ attitude about the system. The teachers also gave positive opinions about the system in that experiment. However, the teachers weren't involved in all the sequences in the previous experiments. They also hadn't tried the system by themselves. They only trained on the system and how to answer students' questions. The current experiment will give them the chance to try the system by themselves and they will try all three sequences. This experiment will help to answer some of the research questions, as will be described in Chapter 6. The results of this experiment have different types of data. The quantitative data came from the first nine questions of the survey, and the qualitative data came from the last two questions of the survey and from the discussion at the end of the experiment. Table 5.5 illustrates the results of the quantitative part of the survey. There were only thirteen teachers who filled in the survey as some of them didn't like to fill it in as they were not interested in math and some of them left the experiment before the survey time as they were busy with schoolwork.

s	Question	Mean	SD
1	The system is working as expected	4.00	1.08
2	It is easy for the students to use the system.	4.85	0.38
3	Students rarely asked for support	2.15	2.12
4	The errors that were found by the system match the reality of the students' errors	4.62	1.12
5	Such a system can improve students' skills	5.00	0.00
6	It is important to use such a system in schools	4.46	0.78
7	It is important to apply this concept to other topics	4.62	0.65
8	The time consumption of the system was reasonable with the benefits	3.08	1.71

Table 5.5: Mean and standard deviation of the survey results

The data in the above table shows a high level of satisfaction about the system from the teachers' point of view, despite some questions having a low mean with a high standard deviation. In this experiment, the value (0) has a high repetition as it is indicating a null value of the survey result. It means the participant didn't fill in any value in this question. This can be because they didn't supervise the students' experiments, or because they didn't know the right answer to the question. In this experiment, there were some questions that got full marks in the survey's answers, which shows a full agreement by the teachers with zero standard deviation. However, there are still some other questions that have a moderate level of standard deviation, which indicates a polarity which is clarified by Table 5.6 below.

Value	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
0	0	0	6	0	0	0	0	0
1	1	0	0	1	0	0	0	4
2	0	0	0	0	0	0	0	1
3	1	0	1	0	0	2	1	2
4	7	2	5	1	0	3	3	2
5	4	11	1	11	13	8	9	4

Table 5.6: Score repetition

Table 5.6 above shows the explanation of the variation of standard deviation related to the survey results. There follows a description of each question and the average result, with an explanation of the polarity that is shown by the standard deviation value of each question.

First question: The system is working as expected.

This is a holistic evaluation question about the functionality of the system based on the teachers' point of view, which they obtained from the current experiment and their supervision of the previous experiments. The result of this question was an average of 4 out of 5, while the standard deviation was 1.08. This low standard deviation shows that the result focused around the average which is confirmed by Table 5.6. There is no high level of polarity in this result which indicates a high level of teachers' satisfaction about the functionality of the system. This result supports the result in the Functionality Experiment where students and teachers gave high ratings to the functionality of the system. This will help in answering some of the research questions, as will be described in Chapter 6.

Second Question: It is easy for the students to use the system.

This question is related to the teachers’ observations about students while they were attending the experiments. It can also be answered by the teachers’ opinions about students’ ability to use such a system. Because the schools are international schools, they used many systems during their teaching. Their students are used to dealing with computer-based learning systems. Although these programs are mostly LMS (Learning Management System), it still gives them the ability to deal with other systems, even if those systems are new. The result for this question is an average of 4.85 out of 5. The standard deviation is 0.38 which shows no polarity in this result. Most of the ratings came around the average. In fact, Table 5.6 shows that eleven teachers out of thirteen gave a rating of 5 to this question. This result shows a high level of teachers’ satisfaction about how easy it is for students to use the system. This result confirms the result of the previous experiments that was rated by students. Chapter 6 will describe this confirmation in detail.

Third question: Students rarely asked for support.

This question describes how the previous experiments went: were there many inquiries about the use of the system by the students? In fact, it is necessary to reconcile the answer to this question with the previous question. As is clear from Table 5.5, the results for this question came out with an average of 2.15, with a standard deviation of 2.12. This indicates a very high level of polarity. Table 5.6 explains the reason for this polarity. Table 5.6 shows that six out of thirteen students didn’t answer this question, which caused the polarity and reduced the average. By deducting those teachers who didn’t rate this question, the average will be 4 out of 5, and the standard deviation will be 0.58, which indicates non polarity in this result. With the new result, it is clear that students will not have difficulties using the system, despite some queries in the beginning of the previous experiments as shown in the previous experiments' results. The teachers' discussion confirmed this result too.

Fourth question: The errors that were found by the system match the reality of the students’ errors.

This question was similar to one in the Functionality Experiments. It is repeated here to take the answer from the teachers’ point of view in order to support the students’ answers. This question is about the ability of the system to determine students' errors precisely. In the Functionality Experiment, students gave a positive rating to this point. The goal of this question is to find out the teachers' point of view and whether they will confirm the students' opinions? The result of this experiment shows the average is 4.62 out of 5, and the standard deviation is 1.12. These results show a high level of positive feeling about the system accuracy and a low level of polarity. Table 5.6 interprets the standard deviation as eleven teachers out of thirteen gave a rating of 5 for this question.

Fifth question: Such a system can improve students' skills.

This question is about the importance of such a system. In fact, the teachers evaluate the importance of the system where the goal is to evaluate what is behind the system. It is the concept of this research to break down the domain to the smallest elements and evaluate them. The result for this question came with a full mark and zero standard deviation. All the thirteen teachers gave 5 out of 5 to the importance of such a system in improving students' skills. This result is supported by the qualitative results, as will be described in the qualitative results later in this chapter.

Sixth question: It is important to use such a system in schools.

The question is to retrieve teachers' opinions about the importance of using such a system in schools. This question is related to the importance of the future of this system and to the concept behind it. There are many computer systems used in schools. Some of these systems are not important to the teachers as much as they are important to the school management or for the reputation of the school. Teachers who were involved in this experiment gave an average of 4.46 out of 5 to this question, and the standard deviation was 0.78. This indicates a low level of polarity in the result. However, Table 5.6 shows that eight of the students gave 5 out 5, while only three students gave 4 out 5. This result indicates a high level of importance in using such a system in schools, based on the teachers' opinions. This result will be supported by the qualitative data as it will be shown later in this section.

Seventh question: It is important to apply this concept to other topics.

Here the teachers from other subjects also give their opinions to support the concept of the current research. In fact, talking about the system is referring to the concept behind it. The main idea of the system presents the concept of breaking down the domain to its learning objectives. This question is to retrieve teachers' opinions from other subjects and the point of view from the mathematics teachers about applying such a system to subjects other than mathematics. The result for this question came with 4.62 out of 5, and a standard deviation of 0.65. This result shows a positive opinion about applying such a system in other topics. Table 5.6 indicates that most teachers gave 5 out of 5, while only three teachers gave 3 out of 5 and one teacher gave 3 out 5. This result is supported by the qualitative data, as will be described later in this section.

Eighth question: The time consumption of the system is reasonable with the benefits.

This question is very important regarding the reasonability of using such a system in terms of time consumption. The teachers' opinions about the reasonability of using such a system varied. The average was 3.08 out of 5, and the standard deviation was 1.7, which indicates a polarity. Table 5.6 describes this polarity as an equal opinion between teachers. Four teachers agreed completely while another four teachers disagreed completely. The rest of them were around the average. This result shows different opinions from different teachers. The qualitative data will have more clarification about the reasons behind the variety of opinions.

Ninth question: Which sequence do you prefer?

This question is related to the teachers' opinions about the three different sequences of the system. In fact, such a system can be designed to have many sequences based on the goals of the system. The current research has only three sequences, as was described earlier in this chapter. After testing all three sequences, eight teachers chose the first sequence while five teachers chose the second sequence. The analysis of the qualitative data will give more details about the teachers' preferences. The next section is about the analysis of the qualitative data of the survey.

After analysing the quantitative data of the survey, it is the time to support the teachers' preferences through the qualitative data. The qualitative data analysis can be divided into three parts. Qualitative data came from the tenth question in the survey, qualitative data came from the eleventh question in the survey, and qualitative data came from the teachers' discussion after the experiment.

First: Qualitative data came from the tenth question in the survey. It is about the teachers' preferences with regard to the three sequences. Back in the quantitative data, there were eight teachers who preferred the first sequence. They supported their opinions by their notes in the tenth question. The summary of their notes can be given by these two points:

- “Because the goal is evaluation, so the first sequence is finest”

This point was mentioned by two teachers. They really understood the goal of the system. However, giving the learners’ hints during their answers may be used to evaluate learners’ level in advanced skills that are related to the missing skill. For example, if the student makes a mistake in division, it may be found in the next step's integer numbers, where the question was designed to test the student's ability in calculation with fractions. So by giving the student a hint to allow them to fix their error, it will lead them to have a fraction in the next step instead of an integer. This point will be covered more in the future work section of Chapter 6.

- “The child should be an independent learner”

This point was mentioned by three teachers. It is a good point of view. However, it may not be compatible with the goal of the system, as it is a diagnostic system. If the system is a learning system, then yes, it may be a good idea to have a direct indicator or hint while answering the test. More details will be given in the third part of the qualitative data section. The uses of Sequence 2 will be described in detail in Chapter 6.

There were five other teachers who selected Sequence 2 in question number 9. The summary of the reasons for why they preferred Sequence Two were as follows:

- When students solve the equation, he/she can know their mistakes
- This system will support them to enhance their skills

Second: Qualitative data came from the eleventh question in the survey. It was an open note where teachers could write any suggestion or notes to improve the system. The notes can be summarized by these two points:

- To design the system for all the mathematics subjects
- To design the system for all other subjects

Third: Qualitative data came from the discussion with the teachers after the experiment. The most important points can be summarized as follows:

1. Teachers agreed about the importance of such a system to help them to enhance learners' misconceptions about any part of the domain individually. A teacher doing that in a crowded classroom can be an impossible mission. If the misconceptions were from a prerequired domain, the situation will be more difficult as teachers cannot go back to teach fundamental skills and knowledge to the learners. This will need a lot of time and effort which is not available in the curriculum timetable. In the research field, classrooms can exceed thirty-five students. If the teacher needs to be with one student individually to reteach him or her a missing skill, they will need at least two minutes. If there are ten out of thirty-five students who need help that means the teacher will lose twenty minutes out of forty-five minutes that are available in the classroom. It will delay the curriculum timetable or may result in the students not finishing all the domain.
2. Teachers agreed about the importance of making such a system to cover the domain of mathematics and for other subjects. Some of them wondered how such a concept can be applied to other domains, such as philosophy, history, languages, and all those domains where they depend on learners' thoughts and opinions more than a solid domain like mathematics where it follows constant rules.
3. Teachers confirmed that the use of such a system can be difficult for the first time, however, learners quickly become familiar with the system after their first attempt. Teachers observed from the experiments they had supervised that learners started asking questions about the use of the system at the beginning of the first experiment they faced. Learners who attended more experiments didn't face any difficulty while they were using the system. Teachers in the research field schools used different systems of Management Learning System (MLS)
4. Teachers agreed that such a system can help to evaluate teachers too, by studying learners' levels in the previous domains. More details will be given on this in Chapter 6.
5. Some teachers have concerns about the feasibility of such deep analysis of students' answers and the cost to implement such a system with Sequences 1 or 2, when Sequence 3 can find all the learning weaknesses at the beginning of the test. Although it has the same features of Sequences 1 and 2, it may cost a similar amount to them

but the concept of testing all necessary skills can be done without going deep into analysing learners' answers steps. The argument was about the time consumed between Sequences 1 and 3. The next experiment was designed to compare the time consumed by using Sequences 1 and 3.

5.6 Fifth experiment: Time Consumed

5.6.1 Introduction

The previous section detailed the teachers' experiment. The teachers were given a full demonstration of the system. They tried the system by using three Sequences: 1, 2, and 3. The teachers' opinions were more toward Sequence 1. However, the difference in time consumption by using Sequence 1 and Sequence 3 was obvious. Some teachers argued about the feasibility of implementing Sequences 1 and 2, while Sequence 3 can improve learner skills before the test, as was mentioned in the previous section. To have a clear comparison between Sequences 1 and 3 in time consumption, this experiment was designed. How much time is consumed is an important factor in the learning process. The challenge is to make an e-learning system with effective time consumption to have the maximum profit from the technology (Koper, 2004). Long-time process and repetition of the learning process may lead to students feeling bored, or they may give up if they have to repeat the whole test of all skills every time they make mistakes. Although time consumption is an important factor of e-learning success, the students' opinions about the use of Sequences 1 and 2 can be a very important factor. This experiment has goals of testing how time consuming the system is, and gaining students' opinions of using Sequence 1 and 3 in terms of time consumption and process repetition. The experiment used Category 2 and Level 3 based on the teachers' recommendations. Sequences 1 and 3 will be used in this experiment in order to compare them.

5.6.2 Method

The current experiment involved ten students. They were asked to test Sequence 3 then Sequence 1. The students did the test individually and voluntarily based on their availability after their participation in the previous experiments. The experiment was done at the

International Schools Group. Here, the school management gave the researcher more opportunity and time to apply the required experiment than at the other school. Students used the same PC and the same username and password to test only the time consumption of each sequence. Due to the limitations of experiment time and students' availability, the test was set for six skills only, instead of thirteen. The purpose of the test was testing time consumption. This quick change in the prototype programming reduced the system's ability to calculate the time consumption of using the system in both sequences. The students were asked to input how much time was consumed manually in a given form. Appendix (7) shows the given forms that were delivered to the learner to input the time consumed by each sequence. Participants were asked to enter the system using a pre-set test with a pre-set username. As this is a modified prototype of the system, all participants were asked to use the same PCs, which were prepared for this purpose, the same username, and the same password. The learners came to this experiment after they finished the Functionality Experiment. The learners were asked to start with Sequence 3, then fill in the form. After that they were asked to go to Sequence 1, then fill in the form. The Appendix (7) shows the forms given to the learner to fill in after they tested Sequences 3 and 1. The main goal of this experiment was to measure the difference in time consumed between Sequences 3 and 1, to fulfil some teachers' concern about the feasibility of using such a system with all the effort needed to program the system in Sequence 1. This concern was addressed in the teachers' experiment because some of the teachers weren't sure about the feasibility of programming a system such as Sequence 1, which needs a big effort to program it. This is because it is based different models, with a lot of complications, necessary to allow the system to understand the learner's weaknesses, then give them the right remedial path. In contrast, teachers can use a straightforward system that can measure learners in all skills before giving them the test.

5.6.3 Methodology

The nature of this experiment determined the type of data collection. As it is a comparison between the times consumed by Sequence 3 vs Sequence 1, the outcome data will be numerical data, which will need to be analysed to find the difference in time consumption between Sequence 1 and Sequence 2. Based on that, a quantitative methodology will be used to illustrate the difference in time consumed by using the system in both sequences.

5.6.4 Participants Recruitment

Ten students from the International Schools Group (Intermediate level three), aged between thirteen to sixteen, male and female, voluntarily and randomly participated in the experiment after they finished the Functionality Experiment based on their availability.

5.6.5 Procedure

During the introduction of the Functionality Experiment, the learners were asked to participate in this short experiment voluntarily and randomly, based on their availability after the experiment. As the computer lab was busy with the Functionality Experiment, only ten PCs were prepared to be used for this experiment, with one username and password, because the system would not record the users' input, and they wrote this information manually on the paper form. Those ten PCs were available for the students who were ready to be involved in this experiment, after they had finished their Functionality Experiment. Most participants were from the learners who had finished the Functionality Experiment early. This experiment needed an average of forty minutes to finish it. Students who came to this experiment had an introduction to this experiment during the introduction of the Functionality Experiment. In addition, a short instruction was given to the learners individually upon their arrival at the PCs, by the teachers. Participants received the form to enter the time consumed during their answering of the test. Learners were asked to use the system with Sequences 1 and 3, and to fill in the form immediately after each answer so as to register the time. Those learners who came voluntarily had a high level of motivation to do that, otherwise they would not have come, as the other learners went to the playground after the Functionality Experiment. It can also show a high level of interest of the learners to use and interact with such a system. After the learners had finished the experiment, they passed the forms to the teachers. The next section will address the results of this experiment in detail.

5.6.6 Results

The goal of this experiment is to measure the difference in time consumed between Sequence 1 and Sequence 3. To achieve this goal, two tests have been set, the first test was done by using Sequence 1 and another test was done by using Sequence 3. The participants were asked to fill in a form with the time that they needed to solve each point of the first test, and they were given another form for the second test.

The time consumption of the first test (Sequence 1) shows a mean of 1٧:٠١, while the time consumption of the second test (Sequence 3) was 28:4٥, which indicates that using Sequence 1 is faster than Sequence 3 by more than forty percent. This difference is when testing six knowledge and skills only. Obviously the difference will be much more when testing all thirteen knowledge and skills. However, the concept of this research can be applied to more complicated domains, for example, quad equations, or even more complicated domains, where there will be many skills and knowledge that need to be tested. Sequence 1 is intended to be the right choice for most domains, and is much more feasible for the more complicated domains. This result was intended to satisfy the teachers' concern about the importance of using Sequence 1, with the easy availability of Sequence 3. Reducing study time is one of the most important factors that can lead to a successful online learning environment, as is mentioned in the introduction of this section. Table 5.7 below shows the time consumed by the Sequence 1 test.

Student	1	2	3	4	5	6	7	8	9	10
Time	17:06	18:05	16:05	16:04	15:01	19:06	17:08	19:01	18:01	15:06
Average		17:01								

Table 5.7: The time consumed by Sequence 1

For more details about the time consumed by the Sequence 1 test, please refer to Appendix (8) where the time consumed for each question and each skill is illustrated. Table 5.8 below shows the time consumed by the Sequence 3 test.

Student	1	2	3	4	5	6	7	8	9	10
Time	27:02	27:03	23:09	28:05	33:04	28:02	29:00	32:02	27:49	29:17
Average		28:45								

Table 5.8: The time consumed by Sequence 3

Appendix (9) illustrates more details about the time consumed for each of the six skills and the questions of the Sequence 3 test. The next section will summarise all the experiments done in this research.

5.6.7 Summary

This chapter addresses the five experiments that have been done in the current research study. The experiments were conducted in two schools in Saudi Arabia, in Dammam City. The schools' medium of instruction was in the English language, which was important so that the system would be easy to deal with by their students and teachers. An authorisation to conduct these experiments was granted from the Ministry of Education in Saudi Arabia. Participants were asked to voluntarily participate in the experiments based on their free time, which was given by the schools' management. All the experiments were done under teachers' supervision, after they were given the necessary training by the researcher. The experiments are summarised in the following sections.

The first experiment was about the usability evaluation of the prototype. As this is a new system that has never been implemented before, multiple prototyping versions were tested before the final prototype was made. These multi tests led to the final prototype that will be used later to prove the benefits of using an different models in an e-diagnostic system, with the concept of breaking down the knowledge and skills behind the domain, then testing them individually to find out the learners' weaknesses. This experiment was conducted to evaluate the usability of the final prototype before using it to evaluate the concept of this study in the real world. The experiment has different goals: to discover programming bugs, find issues, gain users' feedback, record the time consumed for each step, and to give teachers a real introduction to how the system works. The experiment was done with fifty volunteer students, aged fifteen to seventeen, male and female. All of them were from the International Schools Group. Forty-two students successfully finished the test of the prototype. The average score for the system interface appearance was 4.69 out of 5. The user experience rating average was 4.14 out of 5, which indicates a significant improvement on the final prototype when comparing it with the first prototype, as is mentioned earlier in Chapter 4. A score of 3.5 out of 5 was the average of the system reaction to the users. This indicates that the prototype is ready to be tested in the real world. The final quantitative result of this experiment was about user input preferences. The average score was 3.15 out of 5. This score helps in understanding learner preferences. However, it is intended to be a high enough score to apply the prototype in the real world. Overall, the previous qualitative result indicated the readiness of the system to be tested in the schools by using the targeted learners who currently study the domain. However, this experiment has qualitative data too. This data came from learners and teachers' opinions. The summary of this data can be listed in the following points:

- Level 3 is the suitable level to test the system.
- Some bugs were found and solved before the real-world test.
- Having the onscreen keyboard is helpful when inputting fractions and symbols.
- The difficulty of using such a system well, gradually reduced while learners were using the system, like any other new program.
- Learners like to use such a system, which will give them their errors directly after the test and teach them how they can correct it.
- Some programming bugs were found.

The second experiment was about intentional errors. This experiment was done after fixing all the bugs and programming errors which were discovered during the usability evaluation experiment. The need for this experiment came after the amendment happened to the prototype, to fix the bugs and programming errors. But as was found in the previous experiment, it is also necessary to test some student errors that did not happen during the previous experiments. In this experiment, students would be asked to make specific errors intentionally to retrieve the system's action to those types of errors. This experiment involved thirty-nine volunteer students from the International Schools Group. From the experiment results, it is shown that thirty-five students out of thirty-nine answered yes, that the system responds to their errors and right way. Only four students didn't finish the experiment. There were no notes from the students.

The third experiment was about the functionality evaluation. This is the experiment that can be considered as the main experiment of this research. This experiment would evaluate the concept of the research, to break down the domain into its smallest elements that a student needs so as to understand the domain - those elements can be called the skills and knowledge behind the domain. The system intends to be able to analyse learners' answers step by step and find the missing skills or knowledge from the current domain or from a pre-required domain. The system then provides the learner with the suitable remedial path. The experiment involved fifty students, male and female, from two different schools in Saudi Arabia. All the students were from the third year at the intermediate school, where they study the current domain. Due to the limitation of time given by the school's management, the experiment was set to be completed by those students who made errors about moving constants or variables from one side to the other side of an equation. This system will record all students' answers to be analysed to find the system's reaction to all of the errors. The students received a full demonstration about the system. They were also supervised by their teachers who had already been trained how to use the system and how to respond to learners' enquiries and notes. The result of this experiment came out with a variety of data from the experiment survey. The first six questions were about the system functionality and these questions are listed below:

1- The system found my exact error every time.
2- The system gave me the right suggestion about my missing skills.
3- The system improved my missing skills.
4- It is not boring to use such a system.
5- When the system couldn’t find my error, it tests the skills that caused the error quickly without testing many skills.
6- After using the system, proficiency in solving equations was reached.

The average score of these questions was 3.32 out of 5. However, the standard deviation shows polarity in the result. By reviewing the repetition table, it will be clear that this repetition is mainly in the 5 out of 5 score. This is because most students gave high scores in all of the questions. The last question in the survey was about students' suggestions or notes to improve the system. These notes and suggestions present the first part of the qualitative data from this experiment. The qualitative result shows some bugs in the system because of the browser version, and some limitations of the browser because of full school lab security. Those bugs were solved instantly by the lab technician. Other suggestions by the learners were to improve the system interface by adding a calculator, or to give the students their mistakes directly after each question, and there were some other suggestions too. There were also many positive opinions about the system. These suggestions and the positive opinions indicate that the learners enjoyed using the system and they were excited during the test. The second part of the qualitative data of this experiment came from the teachers' discussions after the experiment. The teachers' discussions came out with a very important observation. Learners at the beginning of the experiment have some queries, which are reduced in number during the experiment, which indicates that learners become familiar with using the system, gradually as they use the system. Another observation about the learners' feelings while they are using the system, was that most of them were excited to learn from the system about their mistakes. The teachers' opinion was positive to apply such a system for the other subjects. The third part of the qualitative data came from the experiment which was about the system analysis of the students' answers record. This analysis shows a high efficiency of the system in determining the learners' missing skills and giving the right suggestions about the right domain to learn.

The fourth experiment was about the teachers' evaluation of the prototype. It was very important for the teachers to test the prototype and the different sequences, and for the researcher to understand their opinions. This test will allow the teachers to understand the difference between the sequences, to determine which one would be suitable for the students and to meet the goal of the test. Twenty volunteers were involved in this experiment from two different schools. This experiment survey has eleven questions listed below:

1- The system works as expected.
2- It is easy for the student to use the system.
3- Students rarely asked for support.
4- The errors that are found by the system match the reality of the students’ errors.
5- Such a system can improve students’ skills.
6- It is important to use such a system in schools.
7- It is important to apply this concept to other topics.
8- The time consumed by the system is reasonable with the benefits.
9- Which sequence do you prefer?
10- Support your answer with reasons.
11- Please write any suggestion that you have to improve the system.

The first nine questions present the quantitative data while the last two questions retrieve the qualitative data. The results of this experiment can be divided into three parts. The first part is the quantitative data about the usability and the functionality of the system. This part is presented by questions number 1, 2, 3, and 4. The average score of these questions was 3.9 out of 5. This average indicates the improvement of the system. The second part of the results is presented by questions 5 to 8. Qualitative data came from these questions as an average 4.3 out of 5. Having this average indicates the high level of satisfaction of the teachers about such a system. The third part of the results came from questions 9, 10, and 11. These questions present qualitative data in the results. The data shows the high demand for using Sequence 1. However, there are some opinions about using Sequence 2. The data shows demand to design such a system for the whole of mathematics and for the other subjects. This demand is demonstrated by the teachers' interest in the system. However, there were some concerns about the feasibility of designing such a system in Sequence 1, which needs a lot of effort, whereas Sequence 3 can be implemented faster and easier. This concern raised the importance of doing the fifth experiment about time consumed between Sequence 1 and Sequence 3.

The fifth experiment was about the comparison of the time consumed between Sequence 1 and Sequence 3. This experiment involved ten students from the International Schools Group at Level 3. The students were asked to fill in a form to calculate the time consumed by them to pass each step and the system. The result of this experiment shows an average of 16:57 for Sequence 1, while the average of Sequence 3 was 28:46. This result supports the importance of Sequence 1, even if its cost is higher than Sequence 3.

The next chapter will discuss all of these results in more detail and connect these results to the research aims. The chapter will cover other topics about the reasons for undertaking this research.

Chapter 6: Discussion

6.1 Introduction

The previous chapters provided an overview of the research conducted in this study. Chapter 1 introduced the field of e-learning and the application of AI, covering various AI techniques used in e-learning environments and adaptive learning systems. It outlined the study's relevance, objectives, research questions, and background, offering a brief history of e-learning. Additionally, the chapter discussed the research framework and presented the outline for the rest of the thesis.

Chapter 2 reviewed the literature on e-learning and e-assessment, emphasizing the role of AI in adaptive learning and assessment systems. Key topics included adaptive learning approaches, education theories, learning styles, metacognition, and user experience.

Chapter 3 focused on existing learning systems and student modelling. It explored macro-adaptive instructional systems, intelligent tutoring systems, adaptive hypermedia systems, and adaptive educational hypermedia systems. The chapter also compared adaptive and adaptable approaches for enhancing learner control and discussed student modelling applications, particularly those based on verbal and visual skills.

Chapter 4 detailed the design and implementation of the current research system. It introduced the first prototype of the e-diagnostic system, described its evolution through seven versions, and then focused on the second prototype, which was used in the study's experiments.

Chapter 5 summarised the experiments designed to test the second prototype. These experiments explored the prototype's functionality, intentional errors, teacher evaluations, and time efficiency. The results were analysed to address the research questions.

This chapter will now discuss the key findings from the five experiments and how they contribute to answering the research questions, as well as the significance of this research.

6.2 Research purpose

The principal academic reason for this research has already been discussed (Chapter 1 Section 5). The current section, however, explains the reason from the researcher's personal perspective.

The story begins when the researcher was a teacher of math at elementary level, and who then became a supervisor who trained teachers to use computers in teaching. At this point, the researcher was focused on helping teachers maximise the benefits of using computers during the teaching process. This gave rise to a belief that computers' could be used not only to simply act as passive display tools, but to help with active tasks such as comparing learners' answers with standard answers, giving hints during the answering process, and a number of other useful support operations, quickly and precisely. These beliefs led the researcher to think beyond the (then) current teaching orthodoxy, and consider how to use computers could be used to simulate the teaching role. The question was: how can a computer support, and even add value to, the learning process? The idea was thus conceived that, by using computers to collect student feedback from the leaning process, it might be possible to evaluate the learner's understanding and provide advice on a personalised remedial path. This, the researcher decided, might be achieved by breaking down each learning objective into smaller elements of knowledge and skill. He therefore redesigned the objectives so that they could be measured easily by computer modelling, as described in Chapter 4. The first prototype described in this research was designed for this purpose. The next section will describe the research findings after using the prototype in the real world.

6.3 Discussion

6.3.1 Introduction

As was noted above (Section 5.1) five separate experiments were carried out (using the final prototype), in order to provide insights into the study's Research Questions (Section 1.3.3). A full description of the purpose, methodology and results of each individual experiment can be found in Section 5. Here we discuss the findings of the experiments, and their relevance to the aims of the research.

6.3.1.1 Experiment 1: Usability

While the overall aim of this experiment was to test the system's readiness for real-world use, it also had several specific objectives (Section 5.2.1). Full details of the methodology employed, and the results of the experiment are described in Section 5.2.

The findings of the experiment provided valuable insights. One of these was that users expressed a high level of satisfaction with the appearance of the UI (Table 5.1). While UI appearance is a basic point, it is also important, as a well-designed UI can improve user-acceptance of the usefulness of the software (Bourque and Fairley, 1999). As the UI of the initial prototype was perceived by users to have an overly complex UI, the revised (final) version was built in accordance with the recommendations of Ferreira et al. (2007), who argue that an effective UI should be straightforward and easy to navigate.

Improving the UI also led to an improved UX, as indicated by the results shown in Table 5.2, which show a high level of user satisfaction with the system's ability to help learners understand the reason(s) for their mistakes. As has been shown in several studies (e.g., Yakit and Ismailova, 2018); Harrati et al., 2016), a positive UX is crucial to the success of learning management systems, while Revythi and Tselios (2021) found that high satisfaction levels with the UX positively influences students' intention to use e-learning technology. If an LMS does not provide high usability, learners may focus their cognitive effort on understanding how to use the platform instead of learning the educational material (Ardito et al., 2006). This point was highlighted by the initial system developed in this research. In this first prototype, users spent a disproportionate amount of time trying to understand the system, despite receiving step-by-step support from the researcher. However, the final prototype addressed these issues with a simple, yet powerful, UI. This allowed learners to focus on the learning process itself.

The high level of UX satisfaction achieved by the final prototype also suggest that there is a significant benefit to using many models (see Chapter 4) to analyse users' answers. By integrating multiple models into the system, it was possible to implement an 'open response' approach, in which learners answer questions in their own way. This provides more detail to the system, and allows it to perform an analysis on a more individual basis. Traditional ‘closed’ test methods (such as fill-in-the-blanks, match two lists, true or false, etc.), in contrast, may not allow the student to provide sufficient detail in their response, thus leading to an inability of the system to discover the missing skills or knowledge.

Another important aspect of system usability is input method: is the UX higher with a ‘normal’ (physical) keyboard, or an on-screen keyboard? There seems to be no clear and definitive answer to this question, as each individual learner has their own preference - some prefer a normal keyboard, while others find an on-screen keyboard easier, especially when inputting symbols and fractions. However, the use of on-screen keyboards have been well-researched, and a number of key requirements of such input methods have emerged. Defined as an on-screen visual which allows users to select keys using (typically) a pointing device (Nganji, 2012), on-screen keyboards must have a clear layout (Lehikoinen et al., 2002), and allow the user to manipulate the pointer accurately enough to quickly locate and select a small area of the screen (Stephanidis, 2007). The same study (Stephanidis, 2007) found that on-screen keyboards often feature the QWERTY layout, despite the fact that new users can find this layout confusing. One way of addressing this is to use a simple alphabetical layout, although other users prefer a ‘clustering’ feature, in which frequently-used characters are grouped together. This can aid character identification and input speed. Overall, the optimum solution seems to be domain-dependent. In some domains, alphabetic sorting may be better than QWERTY sorting, while in other domains (such as math), users may prefer a shorter on-screen keyboard with special characters, such as symbols and fractions.

In the context of this research, it was found that it is sufficient to have an (optional) on-screen keyboard which includes the characters frequently used in the domain material, rather than a full on-screen keyboard. However, it can be seen from the results shown in Table 5.2, that, although many users appreciated the presence of the on-screen keyboard, they still prefer to use a physical keyboard.

6.3.2 Experiment 2: Intentional Errors

The findings of Experiment 1 were based on the system’s analysis of a defined set of mistakes typically made by users in solving a linear equation. However, other (relatively rare) mistakes are possible, which were not made by users in this experiment. The purpose of

Experiment 2 is to examine the system's treatment of such mistakes. To achieve this, learners were asked to make pre-designed errors, and the reaction of the system was recorded and analysed. A full description of the aims, methodology and results of the experiment is given in Section 5.3.

The results of the experiment showed that the system carried out an accurate analysis of the mistakes made by learners. As described in Section 5.3.6, almost 90% of the users confirmed that the system had correctly identified their error (four students failed to complete the experiment without giving a clear reason). Furthermore, the after-experiment discussion with the teachers, showed that learners generally liked the system.

Overall, the findings of Experiment 2 showed that the system was ready for a Functionality Test (Experiment 3), although a few (non-functional) bugs were identified (and fixed). Such an iterative processes for dealing with system bugs is inherent to conceptual designs such as the current system, as the options for drawing on pre-existing knowledge/systems are limited. This experiment offered useful insights for answering RQ2.

6.3.3 Experiment 3: System Functionality

This experiment is, essentially, at the core of this research, as it is designed to test the possibility of identifying the main factors in the learning process (of solving equations), as posed in RQ1. It is also designed to test aspects of the concept's real-world practicality, such as its accuracy, commercial appeal and user acceptance. A full description of the aims, methodology and results of the experiment is given in Section 5.4.

The experiment collected data using a mixed methodology (quantitative and qualitative). Tables showing this data are provided in the Appendices. From the quantitative data, it was clear that there was a significant improvement in the accuracy of the final prototype, compared with the initial version of the system, in terms of identifying learner errors and recommending a remedial pathway. This confirmed the system's potential to help learners develop their skills and knowledge, by breaking domains down to their smallest element and evaluating those elements individually. This improvement is likely to be a result of integrating multiple models, and confirmed the system's potential to help learners develop their skills and knowledge, by breaking domains down to their smallest element and evaluating those elements individually. This improvement is likely to be a result of integrating multiple models, as was demonstrated by Adisen and Barker (2007), who found that using AI models is profitable to learners and to the learning process.

The decision to integrate multiple models was based on a careful study of the history and development of student models. As e-learning has increasingly grown in popularity as a mode of education, various approaches are emerging, based on different models. These (student models) are systems that aim to understand and adapt to individual needs, and which have the unique ability to transform the learning process within educational institutions. They can be created to build personalised instructional materials, and to provide learning experiences based on the preferences and requirements of individual students. To achieve this, a set of rules is deployed, through algorithms, to make sure the system is open and flexible (Yakubov and Rasulova, 2021). Several studies have shown how a student model can be effectively implemented in fields such as mathematics/logic, linguistics, vision, and music. (Kelly and Tangney, 2006). In these studies, the user's mistakes were carefully observed in order to identify knowledge gaps and provide an appropriate remedial path.

One type of student model which is widely used is the Open Student Model (OSM). This uses external student representations in order to enable student learning diagnosis, knowledge awareness, student reflection and collaboration, and can be part of existing or new learning systems. OSMs work with creative methodologies and interactions based on evidence, such as the assessment of score reports. For these test score reports, OSMs gather data from an individual's assessment-based results, summative and formative, with recommendations to include stakeholder interactions, in order to support student learning and teacher instructions. Disclosure agreements between students and agents can guarantee privacy and data security, to enable students' control over acquired information, giving them different degrees of access, as well as enabling student interactions with OSM (Zapata-Rivera, 2021).

As the concept of the student model has evolved, it has begun to take into account various factors, such as learning styles, cognitive styles, knowledge levels and motivation, allowing educators to create 'adaptive' learning systems that significantly enhance students' learning outcomes. Although the concept of the adaptive learning system differs greatly from other learning techniques, and offers major benefits, it requires the input of experts if it is to work effectively (Hammad et al., 2018). However, they have been shown to be powerful teaching models. Adaptive e-learning with Moodle (LMS), for example, have been designed to give learner feedback and to track individual differences. With adaptive learning, resources and activities are tailored to the needs of individual students, providing an efficient, personalised learning experience for each. Additionally, personalised instruction, based on a real-time assessment of performance is made possible. Adaptive learning is also beneficial to institutions, as it can help school administrators increase pass rates and improve overall student proficiency. To empower teachers, there are three layers of adaptivity: adaptive feedback on students' present levels of knowledge, adaptive channels that specify how information is delivered, and adaptive capacity of teachers to modify their instruction on the basis of data analysis (Muñoz et al., 2022).

One of the key elements of adaptive systems in e-learning is the concept of the learning style. This refers to the unique ways in which students perceive and process information, and often determines how learning materials are presented. An e-learning approach that illustrates the use of the learning style is the Felder Silverman Learning Styles Model (FSLSM), a frequently used model in which learning styles are treated as a balance between pairs of extremes such as: Active/Reflective, Sensing/Intuitive, Verbal/Visual, and Sequential/Global. A study by Carver et al., (1999) suggested that FSLSM could be the most effective approach to the development of hypermedia course materials, while Yang et al., (2013) adopted FSLSM as one of the factors for developing an adaptive learning system.

Two of the most important concepts in student modelling for adaptive systems are those of the domain model and the overlay model. A domain model is a system of abstractions that describes particular aspects of a subject (domain). The model can then be used to solve problems related to that domain. An overlay model represents the student's knowledge as a subset of the domain model (Kahraman et al., 2010). When implemented in an educational context, the system is updated according to the user (student) progress status – i.e. it re-adapts to her or his new level of knowledge after the primary course objectives are achieved (Brusilovsky, 2001). The metrics used to define the overlay model as a subset of the domain model can be quantitative or qualitative, depending on the type and level of the user's knowledge of the subject (Brusilovsky and Millán, 2007).

In simple terms, the overlay model is designed to keep the learner in a ‘loop of learning and retesting’ until the learner has mastered the part of the domain in question. An example of the general form of overlay model can be found in Chapter 5 of this report, in the Functionality experiment. Learners who made a specific mistake in solving the equation were directed to a lesson which showed them why this was an error, and how to correct it. The learner was then retested until he or she met the standard required. Following this, the overlay model updated, and the learner returned to the general learning arena of solving a linear equation.

It is worth noting that other influential learning models have emerged in recent years. The deep learner model, for example, takes account of not only the user’s behaviour, but also the user’s emotional reaction to the learning experience and their social interactions (Essa, 2016). The reasoning behind this approach is that learner performance does not only depend on the level of cognitive understanding – it also depends partly on psychological factors such as motivation and self-esteem.

Building an intelligent tutoring system requires thorough study with careful consideration and implementation. Although student models play a valuable role in helping to address issues such as problem-solving skills, assessing student performance and identifying remedial paths, it is still necessary to consider carefully which aspects of the student should be modelled in a particular intelligent tutoring system. The CIRCSIM-Tutor, an intelligent tutoring system for the domain of cardiovascular physiology (Evens et al., 1997), illustrates this point well. Introduced in the late 1990s, the system engages in a natural language ‘conversation’ with users, deploying a set of tutoring tactics that simulate two expert human tutors. The information gathered, together with further interaction with different modules, can help in making appropriate decisions in the development of a student model. Experiments have shown that resulting student models improve student learning (Kaouni et al., 2023). quantitative data from the experiment also showed that users can find such systems fun to use, when integrated into the learning process. This is an important point, as it has been demonstrated that students can find e-learning systems boring (Gustiani, 2020), and that low quality and dull content in online learning systems can cause students to resist, and even reject, their use (Dong et al., 2020). The current study, however, found that a good interface and a well-designed system can help to reduce such feelings of boredom – a finding that supports the hypothesis of Vlachopoulos and Hatzigianni (2017) that the architecture of online learning has a significant impact on how students perceive it. The results of this experiment also suggested that learners felt positive about the system, in terms of its ability to help them improve their knowledge and skills.

The current experiment also provided qualitative data, which showed that were some bugs in the system. While a full discussion of the cause of these bugs, and the method of their repair, is beyond the scope of this report, it is worth noting that this study's use of the prototyping approach played an important role in helping to identify and fix system flaws and inadequacies. The use of such an approach meant that the system was tested many times before deployment in the real world, and the implementation of an Intentional Errors test was especially useful, as the tested errors happen only rarely in a real-world situation.

In fact, a variety of methods have been employed to gauge the effectiveness of e-learning programs (Galin, 2004), and the overriding goal of these methods has been to ensure that the proposed application is error-free, functional, fully aligned with user needs, and, ultimately, produces optimum results (Mahmoud et al., 2016). However, while the assessment methods have varied, none have adopted the approach used in this research, which included (among other techniques) evaluating the system indirectly, by observing learners' attitudes toward it. The results of this experiment showed that most learners had positive feelings toward the system, and may offered suggestions for improvement. The experiment also confirmed that, while that such a novel system can be difficult for learners at first, the perceived difficulty rapidly reduces as the learner gains familiarity with it.

Another important finding of the experiment was the high accuracy of the system, which succeeded in analysing 90.4% of all steps and correctly determined 94.1% of levels. There was only one case where the system failed at both tasks. In a commercial environment, this accuracy could be improved still further, as the system would be designed, built and tested by qualified professional experts (as opposed to the author and volunteers). While a number of studies have proposed and deployed approaches to the measurement of learner level within specific domains (e.g., Pyper and Lilley, 2010; Hwang, 2003; McAleese, 1994), the focus of the current study extends beyond the determination of level to the identification of the reasons for the learner having this level. What, for example, is hindering learner progress, and what have they misunderstood? This makes the current experiment different from other research projects. See Chapter 4 for further detail.

6.3.4 Experiment 4.: Teacher Evaluation

Acceptance by teachers, as well as learners, is critical to the effective use of any system such as the one under discussion in this research. Teachers can also offer valuable insights into development and improvement pathways. This experiment, therefore, was designed to garner teachers' views and suggestions concerning the final prototype of the system. Twenty volunteer teachers participated in the experiment, which allowed them to test the system using different sequences, as defined in Section 5.1.2. A full description of the aims, methodology and results of the experiment is given in Section 5.5.

One of the main findings of the experiment was a high overall level of satisfaction with the system among teachers. Most felt that it successfully identified the exact error made by learners, and supported the finding of Experiment 3 (Functionality), that the system could be instrumental in improving learners' skills and knowledge. Overall, the participants felt that an e-diagnostic system such as this could play an important and integral part in the learning process, and many suggested applying the concept in all domains, as this would help teachers identify and correct learners' academic weaknesses on an individual basis. This is currently impossible, due to the high number of students in each class.

While there was a high level of overall positivity, however, some teachers had reservations over some aspects of the system and its implementation. There were mixed views, for example, over the time required to learn and use the system. Although some participants felt that the time required would show a net benefit, others had doubts about the time-effectiveness of the system. This was for a variety of reasons, which are explored more fully in Experiment 5, below. There was also some concern that the system may prove difficult for learners to use, especially at the beginning of the usage process, but most teachers accepted that learners would soon become familiar with the system.

Most participants also pointed out that the benefits of the system under discussion could extend beyond learners and teachers, to areas such as school management and the ministry of education. The system could, for example, help to evaluate teacher performance by evaluating their students' level. Further, by aggregating and analysing such student-level data, it would be possible to identify teaching problems in specific schools, cities or territories. Alternatively, if most or all students in the country have a problem with a certain part of the domain, this may give an indication about a problem in the curriculum. The possibility of using such a system to evaluate teachers and/or the curriculum will be addressed in more detail in the Future Works section.

6.3.5 Experiment 5: Time Requirement

As mentioned above (Experiment 4), there were mixed views among teachers over the time-effectiveness of the system. This experiment set out to examine this issue in more detail, specifically by comparing the times taken to complete two specific Sequences (Sequence 1 and Sequence 3), using the final prototype. A full description of the aims, methodology and results of the experiment is given in Section 5.6.

The purpose of comparing the completion times of S1 and S3 was to explore the trade-off between cost and benefit of the two approaches. Full definitions of S1 and S3 can be found in Chapters 5, but the principal difference between them is the depth of analysis carried out by the system in completing each sequence. While S1 uses less analysis, and was shown (Section 5.6.6) to be significantly faster than S3, it (S1) nonetheless proved sufficiently accurate for use in a real learning environment. However, it is also considerably more expensive to build.

This leads to a cost-benefit dilemma. The main challenge in developing an e-learning system is to gain the greatest benefits at the lowest costs (Koper, 2004). While, for example, ‘slow’ systems may be relatively easy and cost-effective to design and build, learners may feel bored or unengaged with such systems, so the benefits, in terms of educational outcomes and other factors (e.g., management and administrative), are also low. On the other hand, more time-efficient systems may produce pedagogical and administrative benefits, but may also prove prohibitively expensive. The challenge is to find an acceptable balance between these two extremes.

This was the driving purpose of the current experiment. Although basing a commercial system on S3 may save time, money and effort , such a system is unlikely to support teachers, or help students to engage with the learning process, or learn more quickly. A system based on S1, however, though considerably more expensive to build, was found to be accurate and fast, with a range of significant benefits. If, for example, the system succeeds in improving educational outcomes, then the burden on teachers will be reduced, thus freeing them up to teach more students. There are also a range of other benefits to educational management and decision makers, offering high potential for major gains at a national level. This point will be further addressed in the Future Works section.

6.4 Summary

The initial chapters of this paper reviewed the field of e-learning and the role of AI, and discussed the development of various adaptive learning systems and educational theories. This chapter has discussed the purpose of the current research, and how it contributes to the literature on e-learning. In particular, we have discussed how different models has been used to enhance the learning process, in the context of adaptive systems for student evaluation and knowledge enhancement. A key focus of the research is on the development of a prototype e-diagnostic system, aimed at simulating teacher performance by delivering personalised learning paths based on student responses.

Several experiments were conducted to assess the prototype's usability, accuracy, and functionality. These experiments included testing the system's ability to analyse errors in solving linear equations, evaluating teacher feedback, and comparing the efficiency of different system sequences. Results showed that the system improved user experience through a simple and effective interface, allowing students to focus on learning rather than navigation. The integration of multiple models enabled an open-response method that enhanced the system's ability to identify individual knowledge gaps.

Although many teachers expressed satisfaction with the system's ability to help learners improve, some raised concerns about the time required to adopt and use it effectively. The research concluded that, while more expensive to develop, time-efficient systems like the final prototype could significantly improve learning outcomes and reduce teacher workload, offering broader benefits to educational institutions and policy-making bodies.

This study illustrates the potential of e-diagnostic systems in enhancing personalised learning and suggests future improvements in e-learning technologies.

Chapter 7: Conclusions

7.1 Introduction

In this chapter, the results of the five experiments carried out in this research are reviewed, and we describe how they provide valuable contributions to answering the study's RQs. The chapter also discusses how an effective e-diagnostic system can contribute to the field of e-learning and the potential benefits of such a system for learners, teachers, and educational management. The conclusions of the study suggest that a system such as that proposed in this research can not only accurately assess learners' current knowledge, but also diagnose gaps in their understanding and suggests tailored remedial actions. Further, the chapter discusses how the results suggest that the proposed system could redefine e-learning by simulating teacher performance, thereby reducing human intervention and enhancing consistency in student evaluations. It also examines the broader impacts of implementing such systems on a large scale, including the potential to reduce teachers' workloads, provide more accurate feedback to learners, and help educational institutions identify systemic teaching or curriculum issues. Additionally, the chapter addresses the limitations faced during the research, particularly related to time constraints and technical challenges in different schools' computer labs. It concludes with suggestions for future research, including the expansion of the system across subjects and its potential use in an exam-free education model.

7.1.1 RQ1 What are the main factors in the learning process (of solving equations) that an E-Diagnostic system must identify?

In order to be effective, an e-diagnostic system must have the ability to identify errors in the learning process. These errors may be due to several factors. The results of the Usability and Functionality experiments in this study showed that, in most cases, learner mistakes were a result of missing knowledge. This missing knowledge can be factual in nature, but it can also be process-based – i.e., a lack of knowledge about the process required to arrive at a correct solution to a problem. As the experiments in this study showed, this was most often the case in the context of solving equations, which demands the correct application of specific knowledge and skills. However, as was described in section 1.6, it is not easy to define these skills, as different equations involve different levels of difficulty. Overcoming this issue presents a significant challenge.

The system must also be designed to avoid overloading the student with information, as found by several studies (Sweller, 1988; Van Gerven et al., 2002; Paas et al., 2003). This can be a particularly challenging issue when designing systems that aim to help students solve complex problems. On the other hand, a system which is overly simplistic may not provide sufficient learner input to enable accurate analysis of errors. The experiments in this study showed that an effective balance can be found. The experiments also highlighted the need to ensure that the system contains a 'bug library' – i.e., an error model or repository where identified errors are stored, and which helps the system identify the type of error that a student has made (see section 3.0 of this report).

However, some learners may make mistakes not only because they are missing knowledge, but as a result of psychological issues. These issues can take the form of factors such as a lack of confidence, speech anxiety or low self-esteem, and can occur with teachers as well as students (Arifin, 2017). Students who have low self-confidence, for example, are often unwilling to engage in the learning process, which means the system must be easy to use and 'user-friendly'. Having a complex, unintuitive UI, for example, may prevent learners from engaging fully with the system. This is an important point, as it means that the system's UI is an important consideration in the design of an e-diagnostic system. The role of an effective UI was clearly demonstrated by the differences between the initial and final system prototypes developed in this research.

7.1.2 RQ2 How can these factors (from RQ1) be identified by an E-Diagnostic system (in the context of solving equations)?

To answer this question, it is necessary to recall the contents of Chapter 4, which concern the design and implementation of the system. Here, it was noted that, at the core of the e-diagnostic system, is the ability to break down the domain to its smallest components, each of which comprises a specific area of knowledge about the domain in question (in this case, solving a linear equation). These components can be processes such as addition, subtraction, division etc. The goal is to test each specific area of knowledge in isolation, in order to identify where the learner’s problem(s) lies, and then provide a remedial path. However, the issue can be complicated by the presence of hidden steps, which consist of internal (learner) cognitive processes and, therefore, are not apparent during the input phase. To address this, the current study deployed a strategy of allowing learners to input free text, which limited (but did not eliminate) the problem of hidden steps. Then a set sequence of steps (although it still permits hidden steps to be analysed, albeit with some limitations), is certainly an improvement on this method.

One of the experiments used in this study (on the final prototype) was designed to analyse learners’ answers step by step, in order to find out in which part of the domain the learner makes a mistake. While the practical (time) constraints of testing in the real-world (in a school) meant that it was difficult to identify all possible learner errors, at least one mistake was successfully identified, showing that the design strategy of the final prototype was a significant improvement over the initial design model. This was the result of integrating multi models with a standard UI, thus simplifying user options and minimising learner confusion.

Using different models was also shown to have benefits in identifying learner errors. The data which resulted from the testing process showed that the system was successful in analysing learners’ answers and could also allow educators to apply the system to other domains. Some teachers felt that the system should be applied across the entire domain of maths teaching, as well as other domains. Using a mix of models shifted the burden of effort from the learners to the system itself, giving them (learners) the opportunity to focus on learning their subject, rather than on learning to use the system.

The experiments in this study also demonstrated that the e-diagnostic process proposed can be time-efficient, compared with conventional pedagogical approaches. While there is a significant cost attached to the design and programming of such a system, it can produce improved learning outcomes in a shorter time, and provides learners with a self-learning system which is accessible, friendly, and efficient. The study also showed that pre-testing of all learner knowledge may take longer than having a smart system which can analyse learners’ answers to identify missing knowledge.

Despite these advantages, however, there are several things that need to be further studied regarding the system concept introduced in this paper, and these will be discussed in the Future Work section at the end of this chapter.

7.1.3 RQ3 What type of models and UI would achieve the goals of an e-diagnostic system most effectively?

The transition from the first prototype used in this study to the second (final) prototype provided some clear insights to answering this question. The initial version of the system was based on fewer models, and featured a complex UI. This clearly presented difficulties to the learners. The final prototype, in contrast, was supported with many models (including the Student Model, the Overlay Model, and the Attempt Progress model, which was designed especially for this study, as described in Chapter 5), and a much more user-friendly UI, which encouraged user engagement, as was shown in the findings of the Functionality experiment. The simplicity of the (final) system's UI, which featured a clear input method to help users find the mathematical symbols they needed to solve equations, meant that there was no requirement to select options, in order to 'tell' the system how the learner was solving the equation. Instead, the system used an 'open' method (a blank text box) to allow the learner to write whatever they want, and the system did the rest by using the models to analyse the learners' answer and find the missing knowledge. This allows learners to focus on learning instead of spending time learning how to use the UI. The main idea behind using models is that they have been redesigned in a way that helps achieve the goal of the current study, as described in Chapter 4.

7.1.4 RQ4 How can a student model be designed and implemented in an adaptive system or an E-Diagnostic system?

The goal of this study was to build on the general concept of the overlay model, by including the student in the identification of learning activities that improve the learning process, and by providing a framework that will raise the student's level of engagement, as described by Qodad et al. (2020). The results of this study showed that this could be achieved by combining an overlay model and domain model, and specifying the missing knowledge which will help to define the list of learning objects. This specially designed model was given the name of an Attempt Progress model. The model was designed to be triggered by the failure (by the system) to determine a learner's mistake when solving a linear equation. In this case, the model was designed to find the correct steps to identify the mistake. Each step linked in the model with a certain part of the domain. This process is fully described in Chapter 5.

Overall, the study showed positive results in terms of the level of students' mathematical preparedness. This validates the effectiveness of the algorithm used by the system to diagnose learning issues. This algorithm takes the form of a sequence of operations and actions focused on achieving the learning outcomes, including diagnostics, and detailing of students' personal characteristics. The algorithm also enables the system to select the resources and teaching methods most appropriate to the student's needs and preferences, as well as provide an individual learning path, and an analysis of the student's performance (Toktarova, 2022).

7.1.5 RQ5 How can this application be tested in a real-world context?

Before the system described in this paper can be used in the 'real world', it is obviously important to test it under similar (real-world) conditions. This was one of the purposes of the Usability experiment, which was designed to provide critical feedback on aspects of system performance, such as programming errors, time efficiency, suitable levels for student interaction/input and the opinions of students and teachers. However, in order to ensure the validity of the Usability experiment, it was decided to also deploy an 'Intentional Error Experiment' – i.e., an assessment of whether the testing process was able to identify intentional errors. This would provide confirmation the any reports of unintentional errors were reliable and valid.

As was noted in Section 6.3.2, this Intentional Error Experiment (Experiment 3) showed that the system correctly identified almost 90% of deliberate errors, indicating a high level of accuracy in the system's ability to recognise learners' mistakes. In a further test (of intentionally introduced programming bugs), the system was not quite so effective, and some of these bugs were still active after testing. Overall, however, the testing process proved effective. While it is true that it was not 100% accurate in its processes, it was sufficiently accurate to reduce any impact on the Functionality experiment (which followed the usability experiment) to acceptable levels.

The testing process described above was clearly important. Allowing system bugs to ‘survive’ until real-world deployment could cause serious issues with learner participation and may even prevent students from engaging with the system. However, this experiment confirmed that this is not likely to be the case if the system is ‘bug-free’. This conclusion was supported by the results of the Experiment (Functionality), which examined user’s views and opinions in terms of the system’s features, functionality and purpose.

7.1.6 RQ6 What are the potential benefits of such a system?

The current study shows that the system proposed in this paper could deliver several major benefits, both to individual students and educational institutions. By enabling accurate e-diagnostics, it would help to generate student models, provide valuable learning feedback to students, help design effective remedial pathways, and provide information for teachers and educational management. Specific conclusions include:

- Diagnostics

  While most known online systems evaluate a learner’s level in a domain, they do not tell us why the learner is at this level, or what he or she is missing. However, the system proposed by the current study shows a high level of accuracy in determining the reason for learners’ mistakes. Such a system can be very useful for categorising learners based on their missing knowledge, which can help educators focus on key learning issues.

- Generating student models

  The proposed system can help to generate appropriate student models which will help the teacher identify the best remedial pathway for each student or group. The student models used can vary. Not only can the model account for missing knowledge, but it can also identify specific actions, or sequences of action, within a process. Thus, for example, if a learner makes a mistake in multiplication, the model can identify the precise calculation that was incorrectly carried out and suggest a remedial pathway that corrects the error. This concept can be used across a wide range of domain areas, to which the overlay model applies. After identifying the error, the overlay model will be updated, while the student model can be designed with many features that enable the system to store a high level of detail about learners' behaviours during the answer process. To maximise the efficiency of capturing these details, each domain should use a student model which is specifically designed to help meet the system goal of enhancing the learning process. Appendix (11) describes how student model integrated in the current e-diagnostic system.

- Feedback to students

The current study found that the system's ability to provide accurate and direct feedback was a significant benefit to learners, especially the system's ability to suggest the missing domain part that the learner should study to pass the test. However, the system can be designed to give many types of feedback based on the system goals. For example, if the goal is evaluation, the system can give feedback at the end of the test, or – if the goal is to improve the learning process – the feedback can be dynamic and in real-time.

- Remedial pathway

The system facilitates the design of a remedial pathway. This can be specific to each learner, based on their missing knowledge, or it can address learner issues concerning a particular action, or sequence of actions, such as an arithmetical operation (see above: Generating Student Models). Furthermore, remedial pathways can be repeated as much as is necessary for the student to master the missing skill/knowledge, and this can be extended to all other areas of domain knowledge. The Functionality experiment in this study showed that this approach is effective, and that students pass the test after their mistake has been identified and addressed through suggested remedial actions.

- Information for teachers

The study also found that the e-diagnostic system proposed in this study is beneficial for educators. It allows teachers to easily assess students and understand the nature of specific learning problems with students. It also helps teachers understand whether student problems are caused by their own teaching processes. If a problem lies with a specific learner, it is likely to be a result of the learner's lack of understanding/knowledge of the domain; however, if the problem is general to groups of students, this may indicate a problem in the teaching method. Teachers can also design the remedial pathway based on the system report about learners' level in each part of the domain. The study found that teachers were happy to use such a system as part of their teaching process, and they recommended the application of the concept to all possible domains.

- Providing data for educational management

The results of this study also suggest that using an e-diagnostic system, such as that proposed in this research, can provide benefits to educational management. The results of the Functionality Experiment showed that the system had high levels of accuracy in identifying learners' missing knowledge, resulting in a high level of learner satisfaction with the system. This suggests that there may be significant benefits for educational management including;

- Teacher assessment. If, for example, all students taught by the same teacher misunderstand subtraction, that may indicate a problem with the teacher.
- Evaluation of areas or cities. If, for example, most students from the same city misunderstand a particular aspect of a domain (e.g. multiplication), then the problem may lie with that area's educational policy/curriculum.
- Curriculum, domain, or textbook design. If most students across the country have problems dealing with (for example) fractions, that may indicate a problem in the curriculum or any part of it, such as standard textbooks.
- Equality of evaluation methods. Using such a system can help in ensuring that all students are measured against the same objective standard, minimising the effect of teacher subjectivity and potential marking bias.
- Equality of teaching method. The system proposed in the research, which provides learners with full remedial pathways, allows all students to be taught in the same way and at the same level, thus minimising the effect of variations in teacher ability.

Although the cost of implementing a system such as that discussed in this study could be high, it could also deliver significant benefits to the entire learning environment if it is implemented at scale. These benefits could easily justify the associated cost by, for example, reducing the time requirement from teachers. However, more research is required to estimate more accurately what these savings might be in quantitative terms (see Future Works). Another potential benefit is that teachers can divide students into small groups, and/or mix them based on their level of domain knowledge/understanding. This will improve the learning process by allowing students to learn from each other. Teachers can also send tasks suggested by the system to students or parents by, for example, smartphone, helping to reinforce the learning process by facilitation an ‘anywhere, anytime’ aspect to learning.

In short, the findings of the current study suggest many benefits, not all of which have been discussed here. The next section will discuss the possible contribution of the current study to the body of existing knowledge.

7.2 Limitations and challenges

This chapter discusses the results and findings of the experiments done by this study. Those experiments faced some challenges and limitations. In Chapter 1 Section 7, the general limitations of the current research have already been addressed. This section will discuss the limitations and challenges that were faced during the experiment's design and process. The fact that these experiments were done in different schools in Saudi Arabia and the researcher of this study is sponsored by the Saudi Arabian government is important here. These facts resulted in a lot of limitations on the time that was available to apply to the experiments. It is inherently time consuming to apply five different experiments, where each experiment needs time to be prepared and be administered by the teachers who will help and supervise the participating students during the experiment. Although these schools voluntarily agreed to give time to do the research and to give the researcher the use of their facilities and the help of their teachers and students, they were actually only able to give a limited time to the experiment, as they have their own priority to teach their students these subjects on time. All these facts limit the experiment's time and limit the ability to repeat an experiment if there is any missing data or any mistake in the prototype that has been used in the experiments. There is another factor that affected the process of the experiments as they were done in different schools and by using different schools’ labs. Those labs have different settings and different security requirements. Some of these labs had old versions of the browser and an old version of the operating system which caused some conflict during the process of the experiments. However, there was enough data collected from most of the experiments which helps to support the goals of this study.

7.3 Contribution to knowledge

7.3.1 Introduction

This study is about an original idea. The idea is based on a concept of breaking down the domain to small elements which can be evaluated in a simple task. This concept intends to help in creating an e-learning environment based on a deep analysis diagnostic system which can analyse learners' answers to find out which of these elements are missing in a learner's knowledge. It can be argued that this system has opened a door to a new age of e-learning. This new age will maximize the duty of the computer to be able to deal with each student based on the student level, not only in the domain but in the pre-required knowledge. So if the learner doesn't have the fundamental knowledge for the current domain, then the system will distinguish between the missing knowledge and identify if it is in the current domain or in the fundamental level. This ability of the new age shows the difference between the system that is used in the current study and what is available in the market now. Most systems used in e-learning environments nowadays give the learner their level in the domain but do not tell them why they are at this level or what they are missing. The current study's system is able to tell the learners what their mistakes are and what knowledge they need to focus on and learn to be able to pass the test. Not only that, but the system succeeds in teaching some students the knowledge that they were missing, which then allows them to pass the test.

This study intends to present a new age of e-learning where the system reduces human intervention in learners' evaluation. This intends to increase the consistency and the accuracy of the evaluation in all the schools. If some teachers don't care about teaching their students in the right way, they will not be able to give them high scores to cover the fact that they are bad teachers. With this system students will be evaluated every day and their levels in all the knowledge areas will be recorded. This may lead to an exam-free education system. The learners will be evaluated every day in the entire domain. Their missing knowledge will be recorded, then the system will follow them until they reach the acceptable level in the missing knowledge. All this will be done individually, in a time frame that is suitable for the learner, with full flexibility. In a commercial system some other options can be added to allow the system to keep in touch with the learners all the time to remind them about the missing knowledge. This could even be during the vacation time. This could be as a continuing learning process where there is no final exam, but the system will be with the learner until they pass all the domain's knowledge. This will help to get students to a similar level all across the country, despite there being some differences in the students' ability.

This study can be the first brick where the definition of e-learning is changed. The only system which can be called an e-learning system is when the system can do the same as the teachers' tasks by sending the learning message, then receiving learners' understanding, then evaluating it, and giving feedback to the learners, then teaching them the missing knowledge, taking into account individual differences. This will require the renaming of the other, older type of system, which only presents the knowledge or just tests the level of the learners without going deep into the reason for the learner being at this level, as Educational Technology. This proposed change in the definition of what an 'e-learning system' is perhaps seems to be coming too early, but the current study intends to trigger the start of thinking about this necessary change.

There are nine principal ways in which the study contributes to current knowledge. These are:

1. **Provided an in-depth analysis of the prerequisite skills and knowledge essential for students to effectively solve equations.**

   A key contribution of the study was the in-depth analysis of the specific skills and knowledge required for students to solve mathematical equations. The research identified the prerequisite knowledge needed for students to break down complex learning objectives into manageable components. This granular approach is essential for designing effective e-diagnostic tools, which can gaps in a student's foundational knowledge and enable a more targeted teaching method. This focus on integrating pre-requisite knowledge with computational methods allows for the development of tests that are more aligned with learners' individual needs, ultimately making the diagnostic process more effective. This concept is crucial for adaptive learning, where the system responds dynamically to each student's performance level.

2. **Developed a robust e-diagnostic application capable of assessing student skill levels in solving equations and offering personalised remedial paths to enhance learning outcomes.**

   The study took the idea from conception through multiple development phases, creating a working e-diagnostic prototype. Each version of the prototype improved as a result of both technical and user feedback. The system was designed not only to assess where a student struggles but also to recommend tailored remedial actions. This is important because many current e-learning systems stop at identifying mistakes without offering personalised feedback. The ability to both diagnose errors and provide a clear path to higher skill levels is a significant step forward in e-learning technology. This contributes to the field by providing a case study in the iterative development of adaptive learning technologies

3. **Incorporated expert evaluations early in the prototype's development to ensure the system's usability and effectiveness, contributing to the refinement of adaptive learning technologies.**

   Incorporating expert feedback early in the development process helped refine the system before large-scale testing. Experts provided insights into both technical aspects and pedagogical approaches, ensuring that the system met educational standards and was user-friendly for both students and teachers. This early validation helped avoid potential design flaws and ensured the system was grounded in practical, real-world applications. Expert evaluations are vital in bridging the gap between theory and practice in e-learning system development.

4. **Conducted comprehensive empirical studies, both qualitative and quantitative, demonstrating the real-world application and effectiveness of the e-diagnostic system in educational settings.**

   The study didn't stop at theoretical exploration but took the system into real classrooms, where it was tested by both students and teachers. This empirical validation is a key contribution, providing insights into how the system performs in a real educational setting. Both quantitative data (such as accuracy in diagnosing errors) and qualitative feedback (such as user satisfaction) were gathered to ensure a comprehensive evaluation. The challenges faced, such as technical constraints and classroom dynamics, reflect the complexities of implementing e-learning technologies in diverse educational environments.

5. **Engaged tutors in qualitative research to gather valuable insights on the system's potential for broader application across various subjects, extending beyond mathematics.**

   By involving tutors in the evaluation process, the study highlighted how the system could benefit not just students, but also educators. Tutors were able to see how the e-diagnostic system could fit into their teaching practices, offering valuable insights into its potential across different domains. While the system was tested in mathematics, tutors pointed out that its application could extend to other areas, indicating its versatility. Gathering tutor feedback is critical because it ensures the system is not just technically sound but pedagogically useful.

6. **Designed and implemented an advanced student model that adapts to individual learning needs, providing a more personalised and effective learning experience in solving equations.**

   The research developed a student model that adapted to individual performance, mapping out a personalised learning journey for each user. This model was able to assess not only the students' current level of understanding but also pinpoint specific areas where they needed improvement. By integrating various models into the system, it was able to go beyond surface-level diagnostics, making it possible to individualise the learning experience based on a deep analysis of the students' cognitive processes. This model serves as an important step toward more sophisticated adaptive learning systems.

7. **Investigated the real-world benefits of the e-diagnostic system, demonstrating its capacity to identify learning gaps and provide efficient, targeted remediation for students.**

   The system was implemented in real-world classrooms, where its benefits were carefully observed. The ability to quickly and accurately diagnose learner weaknesses and provide immediate feedback is one of the key advantages of the system. In practice, the system reduced the time it took for teachers to assess student progress and allowed them to focus on guiding students through targeted learning paths. This real-world application demonstrated the system's potential for improving learning outcomes and increasing efficiency in educational environments.

8. **Developed an efficient method to reduce teachers' workloads by automating the diagnostic process, allowing more time for personalised instruction and classroom management.**

   One of the most significant contributions of the study is that it has shown how an e-diagnostic system can help alleviate the workload of teachers. With growing class sizes and the increasing complexity of educational demands, teachers are often overwhelmed with assessing individual student needs. This system automates much of that process, allowing teachers to focus more on instruction rather than diagnosis. The time saved can be redirected toward other educational tasks, making the system a valuable tool for managing large classrooms and ensuring each student receives attention tailored to their needs.

9. **Enabled the provision of timely and detailed feedback to students, offering granular insights into their learning gaps and improving their ability to focus on specific areas for improvement.**

   The proposed system's ability to offer granular feedback is one of its strongest features. Rather than simply telling a student that an answer was incorrect, the system breaks down the specific elements of the problem they need to review. This level of detailed feedback is essential for students to understand not just what they did wrong, but why, and how to correct it (a remedial pathway). This immediate and specific feedback loop helps learners focus their study efforts more efficiently, leading to better learning outcomes and a deeper understanding of the domain concerned.

7.4 Future Research

The pursuit of knowledge is an ongoing endeavour, with each study paving the way for further exploration. This research has opened up avenues for future investigations, both by extending its findings to other areas and by exploring new, related topics. Several educators have suggested applying the concepts of this study to other subjects, revealing a gap in current knowledge. This gap warrants further research to determine whether these concepts are universally applicable. If they are, what factors influence their implementation across different subjects? If not, what adaptations are necessary to make them compatible with each subject?

One potential area for expansion is within mathematics. The current study could be extended into a comprehensive, commercially viable system that includes remedial pathways and various types of lessons. By incorporating educational games, such a system could enhance student engagement, making learning more enjoyable. Additionally, a built-in communication platform could help students stay connected with the subject, aiding retention with less effort. All these ideas should be explored and tested through dedicated research projects.

There is also significant value in developing this system on a larger scale, covering multiple subjects with a wide variety of lessons. This approach could be combined with the use of a closed intranet system, which could provide students with a distraction-free environment, safeguarding them from the risks of using the open internet. Many parents hesitate to allow their children unrestricted access to the internet, despite its necessity for e-learning. By creating a self-contained system that teaches, evaluates, and offers personalised remediation, students could benefit from a more secure and focused learning environment. This concept, too, merits further investigation.

If implemented on a national scale, such a system would generate massive amounts of data. Analyzing this data could help identify patterns in students' learning preferences, which would benefit from advanced technologies such as Mega-modules. First introduced by Bézivin et al. (2004), a Mega-module is a software program designed to analyze "huge data" and perform complex calculationsn (Atzeni et al., 2012). In a large-scale educational system, where thousands of students are learning simultaneously, a high-tech solution capable of managing this workload will be necessary.

Artificial Neural Networks (ANN) offer another promising avenue (Kumar & Thakur, 2012). As part of the broader field of Artificial Intelligence, ANNs excel at pattern recognition and learning (Zurada, 1992), much like the human brain. By employing ANNs in conjunction with Mega-modules, researchers could develop a system capable of handling the complexities of a large student population, ensuring a tailored learning experience for each individual.

The idea of an exam-free education system is another area which is ripe for exploration. Studies could be conducted to measure student progress in such a system, comparing the outcomes with those of traditional exam-based systems. This approach seeks to reduce the stress typically associated with exams, categorising students by their abilities and learning preferences. Such a system would open the door to further psychological research, particularly on the impact of individualised learning.

During this study, some learners exhibited a lack of enthusiasm for completing their tests. Whether this is a genuine phenomenon or an anomaly, due to the voluntary nature of the study, is worth investigating. Future studies could explore students' emotional responses when participating in e-learning environments as part of their formal education, rather than on a voluntary basis.

7.5 Summary

This chapter has reviewed the results of the study, and discussed how they demonstrate the potential contribution of an e-diagnostic system in e-learning, by transforming the conventional approach to student assessment, learning processes and teacher support. The results have shown that the system, which is designed to analyse student mistakes and offer personalised remedial actions, breaks down educational domains into small, manageable units, thereby allowing for more detailed evaluation of student knowledge, and offering a flexible pathway to learning by identifying not just current gaps in understanding but also missing foundational knowledge.

For teachers, the study has shown that the proposed system provides valuable insights into student performance, enabling them (teachers) to adjust their methods or identify broader issues in their instructional processes. The system also highlights potential educational management benefits, such as assessing curriculum effectiveness and identifying common learning gaps across regions or schools. These insights can help inform policy decisions, such as modifying curricula or teaching strategies.

Overall, while the proposed e-diagnostic system was shown to offer many advantages, the research faced challenges, particularly with time constraints and varying technical conditions in the schools involved in the experiments. Despite these limitations, the study suggests that the system holds significant promise for improving learning outcomes and reducing teacher workloads. The chapter concludes by recommending future research to explore the system's application in other subjects and its potential role in establishing an exam-free education model, based on continuous assessment and feedback.

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Appendices

Appendix (1): The difficulty levels for the categories of equations.

Level	Description
1	All numbers are integers. Numbers in (* & /) will be between 1-5 Numbers in (+ &-) will be between 1-9
2	All numbers are integers. Numbers in (* & /) will be between 6-9 Numbers in (+ &-) will be between 10-99
3	Numbers are mixed integers and fractions. Numbers in (* & /) will be between 1-5 Numbers in (+ &-) will be between 1-9
4	Numbers are mixed integers and fractions. Numbers in (* & /) will be between 6-9 Numbers in (+ &-) will be between 10-99

Appendix (2): The main learning objectives required for a student to answer equation of Cat 3: n (ax +b) = m (cx + d)

Student No.	**Learning objectives**	**Statuses**	
1	Student should be able to follow the sequence of solving linear equation Cat 3	Current	
2	Student should be able to move a variable or constant from one side to other of equation with the right sign.	Current	
3	Student should know that addition or subtraction cannot be applied between a variable and a constant.	Prerequisite	
4	Student should be able to open brackets.	Prerequisite	
5	Student should apply the operations in the right order	Prerequisite	
6	Student should be able to apply addition on variables.	Prerequisite	
7	Student should be able to apply subtraction on variables.	Prerequisite	
8	Student should be able to apply division of variables by a constant	Current	
9	Student should be able to apply multiplication on variables and constant	Prerequisite	
10	Student should be able to apply addition on two constants.	Prerequisite	
11	Student should be able to apply multiplication on two constants.	Prerequisite	
12	Student should be able to apply division on two constants	Prerequisite	
13	Student should be able to apply subtraction on two constants.	Prerequisite	
14	Student should be able to apply division on a constant multiplied by bracket.	Prerequisite	

Appendix (3): Copy of the questionnaire

Introduction

Thank you for agreeing to take part in this pilot study. The application is intended to diagnose the mistakes students make when trying to solve simple equations. The prototype you will be using relates to solving basic level linear equations. It attempts to classify students' mistakes into those related to basic skills and those related to lack of knowledge in order that remedial paths can be established. I am attempting to find out if the application is usable and works correctly in order that I can apply the ideas to more complex equations and undertake a larger scale study in the future.

Instructions

Please open the application:

url: <PROVIDE URL HERE>
ID: <PROVIDE ID HERE>
Password: <PROVIDE PASSWORD HERE>

You will be presented with an equation to solve in steps. Please fill in the steps one by one. We would like you to attempt to solve the first equation ***correctly.***

After solving the first equation please make any comments you feel appropriate in the expandable box below

Comments:

You will be presented with 7 further equations. We would like you to make 5 simple errors when answering these and follow the on-screen instructions.

Error 1. Change side but forget to change sign. For example, 6x+3 = 5 becomes 6x = 3+5

Comments:

Error 2. Change side but multiply instead of divide. For example, 6x = 15 becomes x = 6 X 15

Comments:

Error 3. Calculate an addition incorrectly. For example, $6x = 3 + 5$ becomes $6x = 11$

Comments:

Error 4. Calculate a subtraction incorrectly. For example, $6x = 5 - 3$ becomes $6x = 3$

Comments:

Error 5. Calculate a division incorrectly. For example, $6x = 6/2$ becomes $6x = 2$

Comments:

Please complete a further TWO equations without any errors and make any comments you feel appropriate.

Comments:

Once you have followed the on-screen instructions and completed the eight equations, please rate the statements below using the scale provided.

Statement	Fully Agree 1	Agree Somewhat 2	Neither agree, nor disagree 3	Disagree Somewhat 4	Fully Disagree 5
The font size was suitable for this application					
Font colour was suitable					
The font type was suitable					
Text was easy to read					
I found the application easy to use					
Information on the screen was clear and well explained					
The language used was suitable for students between the ages of 13 and 17 years					
I rarely made errors related to using or interacting with the system					
The solutions provided by the system were accurate and error free					
I always knew what to do next					
When I made mistakes in the calculations, the procedure was easy to follow					
When I made mistakes in the calculations, the instructions were clear					

Please make any comment you feel appropriate in the expandable space below.

Comments:

Thank you for taking part.

Please return the completed questionnaire to A.Ahmed Almohammadi (mscuk2012@gmail.com)

Appendix (4): Copy of the ethical approval

University of Hertfordshire UH

UNIVERSITY OF HERTFORDSHIRE
SCIENCE & TECHNOLOGY

ETHICS APPROVAL NOTIFICATION

TO	Abdullatif Alohammadi
CC	Dr Trevor Barker
FROM	Dr Simon Trainis, Science and Technology ECDA Chairman
DATE	27/01/15

Protocol number: COM/PG/UH/00083

Title of study: Evaluation of two prototypes of a diagnostics test

Your application for ethical approval has been accepted and approved by the ECDA for your school.

This approval is valid:

From: 27/01/15

To: 30/04/15

Please note:

Approval applies specifically to the research study/methodology and timings as detailed in your Form EC1. Should you amend any aspect of your research, or wish to apply for an extension to your study, you will need your supervisor's approval and must complete and submit form EC2. In cases where the amendments to the original study are deemed to be substantial, a new Form EC1 may need to be completed prior to the study being undertaken.

Should adverse circumstances arise during this study such as physical reaction/harm, mental/emotional harm, intrusion of privacy or breach of confidentiality this must be reported to the approving Committee immediately. Failure to report adverse circumstance/s would be considered misconduct.

Ensure you quote the UH protocol number and the name of the approving Committee on all paperwork, including recruitment advertisements/online requests, for this study.

Students must include this Approval Notification with their submission.

Appendix (5): A copy of the approval letter to conduct the experiment in Saudi Arabia by the Ministry of Education (Arabic and English versions)

المملكة العربية السعودية
وزارة التعليم
(٢٨٠)
الإدارة العامة للتعليم بالمنطقة الشرقية
إدارة التخطيط والتطوير

بسم الله الرحمن الرحيم

وزارة التعليم
Ministry of Education

الرقم : ٣٧٩٣٣٨٠٠
التاريخ : ١٤٣٧/٥/٢١هـ
المرفقات : –

الرؤية: الريادة لبناء جيل مبدع	الرسالة: تقديم خدمات تربوية وتعليمية ذات جودة عالية وفق معايير عالمية بمشاركة مجتمعية	القيم: المواطنة- الإتقان- العدل- العمل بروح الفريق- التنمية الذاتية- المسؤولية الإجتماعية

المكرمين / مديري مكاتب التعليم (غرب الدمام – الظهران) حفظهم الله

من : مديرة إدارة التخطيط والتطوير

بشأن: تسهيل مهمة الباحث / عبد اللطيف المحمدي

السلام عليكم ورحمة الله وبركاته ، ، ،

بناءً على موافقتنا بشأن تسهيل مهمة الباحث عبد اللطيف أحمد المحمدي، طالب الدراسات العليا لمرحلة الدكتوراه من جامعة هيرتفورد شير ، والذي يجري بحثاً بعنوان (التقويم الالكتروني لمشكلات الطلاب لحل معادلات الدرجة الأولى)، حيث يتطلب البحث تطبيق برنامج حاسوبي على عينة من طلاب المرحلة المتوسطة .

عليه فلا مانع من تسهيل مهمته، علما أن التطبيق سيكون من قبل الباحث وفق اللوائح و الأنظمة خلال سنة من تاريخه .

يسعدني شكركم على عنايتكم وتجاوبكم مع ظروف الباحث

والسلام عليكم ورحمة الله وبركاته ، ، ،

نوال بنت عبد الرحمن التيسان

للطلب
٥/٢١

م/الجبر
٢١/٥/١٤٣٧هـ

وزارة التعليم
(٢٨٠)
الإدارة العامة للتعليم بالمنطقة الشرقية
إدارة التخطيط والتطوير

وزارة التعليم
Ministry of Education

الرقم :
التاريخ :
المرفقات :

الرؤية: الريادة لبناء جيل مبدع	الرسالة: تقديم خدمات تربوية وتعليمية ذات جودة عالية وفق معايير عالمية بمشاركة مجتمعية	القيم: المواطنة- الإتقان- العدل- العمل بروح الفريق- التنمية الذاتية- المسؤولية الإجتماعية

<u>English version</u>

Date: 01/03/2016

To: Directors of education offices (East Dammam- Dahran)

From: Director of Planning and Development Department

Subject: Facilitate the task of the researcher: Abdullatif Almohammadi

Upon our approval on facilitating the task of the researcher: Abdullatif Almohammadi, a doctoral student at University of Hertfordshire, whom conducting a research about E-assessment. This research requested to apply a computer based system on students at our elementary schools. We hereby that we agreed to facilitate his mission based on our rules and system for one year from the date of this letter.

It is my pleasure to thank you for your cooperation with the researcher.

Manager

Nawal Altaisan

Appendix (6): A sample of a survey of functionality experiment

System functionality **User ID:** Student 217 7765 **Test ID:** 2035

Please select number 5 for fully agree and number 1 for fully disagree.

1- The system found my exact error every time

1( ) 2 ( ) 3 ( ) 4 ( ) 5 ( )

2- The system gave me the right suggestion about my missing skills

1( ) 2 ( ) 3 ( ) 4 (✓) 5 ( )

3- The system improved my missing skills

1( ) 2 (✓) 3 ( ) 4 ( ) 5 ( )

4- It is not boring to use such a system

1( ) 2 ( ) 3 ( ) 4 ( ) 5 (✓)

5- When the system couldn't find my error it tests the skills that caused the error fast without testing many skills

1( ) 2 ( ) 3 ( ) 4 ( ) 5 (✓)

6- After using the system I become good in solving equation

1( ) 2 ( ) 3 ( ) 4 (✓) 5 ( )

7- Please write any suggestion that you have to improve the system

Appendix (7): Forms to fill the time consumed by students in Sequences 3 and 1 (Edited)

26 : user IDرقم المستخدم　　　　: exam numberرقم الاختبار

ملحوظات	الزمن	المهمة
	1 : 1	Evaluating/study 1st skill دراسة/فحص المهارة الاولى
	1 : 2	Evaluating/study 2nd skill دراسة/ فحص المهارة الثانية
	4 : 48	Evaluating/study 3rd skill دراسة /المهارة الثالثة
	4 : 36	Evaluating/study 4th skill دراسة/ المهارة الرابعة
	0 : 55	Evaluating/study 5th skill دراسة/ المهارة الخامسة
	1 : 45	Evaluating/study 6th skill دراسة/ المهارة السادسة
	2 : 56	Answering first equation حل المعادلة الاولى
	2 : 55	Answering second equation حل المعادلة الثانية
	2 : 35	Answering third equation حل المعادلة الثالثة
	1 : 12	Reading report قراءة التقرير
	0 : 55	Missing skills الدخول على المهارات المفقودة
	2 : 33	Second stage الدخول على المرحلة

27.13

Sequence 3

user 26　　: user IDرقم المستخدم　　　　: exam numberرقم الاختبار

ملحوظات	الزمن	المهمة
	2 : 47	Answering first equation حل المعادلة الاولى
	3 : 12	Answering second equation حل المعادلة الثانية
	2 : 23	Answering third equation حل المعادلة الثالثة
	1 : 45	Reading report قراءة التقرير
	1 : 2	Missing skills الدخول على المهارات المفقودة
	4 : 13	Evaluating/study 1st skill دراسة/فحص المهارة الاولى
	:	Evaluating/study 2nd skill دراسة/ فحص المهارة الثانية
	:	Evaluating/study 3rd skill دراسة /المهارة الثالثة
	:	Evaluating/study 4th skill دراسة/ المهارة الرابعة
	:	Evaluating/study 5th skill دراسة/ المهارة الخامسة
	:	Evaluating/study 6th skill دراسة/ المهارة السادسة
	2 : 14	Second stage الدخول على المرحلة

17.36

Sequence 1

Appendix (8): Details of time consumed in Sequence 1

Student number	Task	Time consumed M:S
1	Answering first equation	2:47
	Answering second equation	3:12
	Answering third equation	2:23
	Reading report	1:45
	Missing piece of knowledge	1:02
	Evaluating/studying first skill	4:13
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	2:14
	Total time consumed	17:06
2	Answering first equation	2:35
	Answering second equation	2:40
	Answering third equation	2:25
	Reading report	1:25
	Missing piece of knowledge	4:20
	Evaluating/studying first skill	3:30
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	

	Answering second stage	1:40
	Total time consumed	18:05
3	Answering first equation	2:44
	Answering second equation	2:45
	Answering third equation	3:01
	Reading report	2:2
	Missing piece of knowledge	0:55
	Evaluating/studying first skill	3:35
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	1:33
	Total time consumed	16:05
4	Answering first equation	2:32
	Answering second equation	2:39
	Answering third equation	3:02
	Reading report	1:01
	Missing piece of knowledge	0:38
	Evaluating/studying first skill	3:58
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	2:35

	Total time consumed	16:04
5	Answering first equation	2:11
	Answering second equation	2:34
	Answering third equation	2:34
	Reading report	0:57
	Missing piece of knowledge	1:02
	Evaluating/studying first skill	3:55
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	1:55
	Total time consumed	15:01
6	Answering first equation	2:35
	Answering second equation	2:44
	Answering third equation	4:01
	Reading report	2:01
	Missing piece of knowledge	1:13
	Evaluating/studying first skill	5:03
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	2:04
	Total time consumed	19:06

7	Answering first equation	4:01
	Answering second equation	3:14
	Answering third equation	2:58
	Reading report	2:16
	Missing piece of knowledge	0:44
	Evaluating/studying first skill	3:02
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	1:35
	Total time consumed	17:08
8	Answering first equation	3:02
	Answering second equation	2:55
	Answering third equation	3:13
	Reading report	1:57
	Missing piece of knowledge	1:25
	Evaluating/studying first skill	3:13
	Evaluating/studying second skill	1:40
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	1:46
	Total time consumed	19:01
9	Answering first equation	3:34

	Answering second equation	2:45
	Answering third equation	3:45
	Reading report	1:35
	Missing piece of knowledge	1:04
	Evaluating/studying first skill	4:01
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	1:23
	Total time consumed	18:01
10	Answering first equation	3:01
	Answering second equation	2:44
	Answering third equation	2:35
	Reading report	1:18
	Missing piece of knowledge	0:56
	Evaluating/studying first skill	3:16
	Evaluating/studying second skill	
	Evaluating/studying third skill	
	Evaluating/studying fourth skill	
	Evaluating/studying fifth skill	
	Evaluating/studying sixth skill	
	Answering second stage	1:49
	Total time consumed	15:06

Appendix (9): Details of time consumed in Sequence 3

Student number	Task	Time consumed M:S
1	Evaluating/studying first skill	1:01
	Evaluating/studying second skill	1:02
	Evaluating/studying third skill	4:48
	Evaluating/studying fourth skill	4:36
	Evaluating/studying fifth skill	0:55
	Evaluating/studying sixth skill	1:45
	Answering first equation	2:56
	Answering second equation	2:55
	Answering third equation	2:35
	Reading report	1:12
	Missing piece of knowledge	0:55
	Answering second stage	2:33
	Total time consumed	27:02
2	Evaluating/studying first skill	1:02
	Evaluating/studying second skill	1:14
	Evaluating/studying third skill	4:13
	Evaluating/studying fourth skill	3:56
	Evaluating/studying fifth skill	1:01
	Evaluating/studying sixth skill	1:56
	Answering first equation	3:16
	Answering second equation	3:18
	Answering third equation	2:59
	Reading report	0:47
	Missing piece of knowledge	1:15

	Answering second stage	2:34
	Total time consumed	27:05
3	Evaluating/studying first skill	0:46
	Evaluating/studying second skill	0:38
	Evaluating/studying third skill	4:44
	Evaluating/studying fourth skill	4:29
	Evaluating/studying fifth skill	0:40
	Evaluating/studying sixth skill	1:11
	Answering first equation	2:02
	Answering second equation	2:11
	Answering third equation	2:01
	Reading report	1:05
	Missing piece of knowledge	1:00
	Answering second stage	3:07
	Total time consumed	23:09
4	Evaluating/studying first skill	0:51
	Evaluating/studying second skill	0:49
	Evaluating/studying third skill	4:12
	Evaluating/studying fourth skill	3:46
	Evaluating/studying fifth skill	2:05
	Evaluating/studying sixth skill	1:56
	Answering first equation	2:19
	Answering second equation	3:49
	Answering third equation	3:12
	Reading report	1:12
	Missing piece of knowledge	1:23
	Answering second stage	2:58

	Total time consumed	28:05
5	Evaluating/studying first skill	1:11
	Evaluating/studying second skill	1:12
	Evaluating/studying third skill	3:45
	Evaluating/studying fourth skill	4:12
	Evaluating/studying fifth skill	0:53
	Evaluating/studying sixth skill	1:33
	Answering first equation	4:13
	Answering second equation	4:1
	Answering third equation	5:33
	Reading report	1:52
	Missing piece of knowledge	1:14
	Answering second stage	3:45
	Total time consumed	33:04
6	Evaluating/studying first skill	0:58
	Evaluating/studying second skill	1:13
	Evaluating/studying third skill	4:12
	Evaluating/studying fourth skill	4:25
	Evaluating/studying fifth skill	1:36
	Evaluating/studying sixth skill	1:55
	Answering first equation	3:36
	Answering second equation	2:59
	Answering third equation	2:46
	Reading report	1:00
	Missing piece of knowledge	0:44
	Answering second stage	2:49
	Total time consumed	28:02

7	Evaluating/studying first skill	1:13
	Evaluating/studying second skill	1:16
	Evaluating/studying third skill	3:49
	Evaluating/studying fourth skill	4:12
	Evaluating/studying fifth skill	1:15
	Evaluating/studying sixth skill	1:35
	Answering first equation	2:55
	Answering second equation	3:33
	Answering third equation	3:43
	Reading report	0:47
	Missing piece of knowledge	1:33
	Answering second stage	3:12
	Total time consumed	29:00
8	Evaluating/studying first skill	1:18
	Evaluating/studying second skill	1:34
	Evaluating/studying third skill	4:52
	Evaluating/studying fourth skill	4:55
	Evaluating/studying fifth skill	2:03
	Evaluating/studying sixth skill	2:02
	Answering first equation	3:04
	Answering second equation	3:26
	Answering third equation	3:34
	Reading report	1:02
	Missing piece of knowledge	1:13
	Answering second stage	3:12
	Total time consumed	32:02
9	Evaluating/studying first skill	1:23

	Evaluating/studying second skill	1:43
	Evaluating/studying third skill	4:33
	Evaluating/studying fourth skill	4:14
	Evaluating/studying fifth skill	0:34
	Evaluating/studying sixth skill	1:34
	Answering first equation	3:12
	Answering second equation	3:18
	Answering third equation	3:26
	Reading report	0:58
	Missing piece of knowledge	1:01
	Answering second stage	3:01
	Total time consumed	27:49
10	Evaluating/studying first skill	0:57
	Evaluating/studying second skill	0:58
	Evaluating/studying third skill	4:02
	Evaluating/studying fourth skill	3:01
	Evaluating/studying fifth skill	1:05
	Evaluating/studying sixth skill	2:56
	Answering first equation	3:16
	Answering second equation	2:49
	Answering third equation	3:12
	Reading report	1:12
	Missing piece of knowledge	1:23
	Answering second stage	2:58
	Total time consumed	29:17

Appendix (10): System Analysis on steps of solving equations

TOSJ: Teacher’s opinion about system analysis

TOL: Teacher’s opinion about level analysis

Steps	Pre solve	Post solve	Analysis	Level	TOSJ	TOL
1	8x-5=6x+1	8x-6x=5+1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	8x-6x=5+1	2x=6	Correct - Add all x's terms & add all constant terms	B	T	T
3	2x=6	x=6/2	Correct - Isolate x	C	T	T
4	x=6/2	x=5	Error in division	C	T	T
1	4x-1=5x+8	4x-5x=1+8	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	4x-5x=1+8	-x=8	Error in addition (+1, +8)	B	T	T
3	-x=8	x=-8	Correct - Isolate x & simplify value of x	D	T	T
1	3x-6=x+6	3x-x=6+6	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	3x-x=6+6	2x=12	Correct - Add all x's terms & add all constant terms	B	T	T
3	2x=12	x=24	Multiply by factor of x instead of dividing	C	T	T
1	7x+2=4x+1	7x-4x=+2+1	Move a number from one side to another with the same sign	A	T	T
2	7x-4x=+2+1	3x=3	Correct - Add all x's terms & add all constant terms	B	T	T
3	3x=3	x=1	Correct - Isolate x & simplify value of x	D	T	T
1	5x-1=x+5	5x-x=1+5	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5x-x=1+5	5x-x=8	Error in addition (+1, +5)	B.2	T	T
3	5x-x=8	4x=8	Correct - Add all x's terms	B	T	T
4	4x=8	x=8/4	Correct - Isolate x	C	T	T
5	x=8/4	x=2	Correct	C	T	T
1	8x+1=5x-6	8x-5x=1-6	Move a number from one side to another with the same sign	A	T	T
2	8x-5x=1-6	3x=-5	Correct - Add all x's terms & add all constant terms	B	T	T
3	3x=-5	x=-5/3	Correct - Isolate x & simplify value of x	D	T	T
1	6x-7=7x-6	6x-7x=7-6	Correct - Move all x's to one	A	T	T

			side & move all constants to one side			
2	6x-7x=7-6	-x=1	Correct - Add all x's terms & add all constant terms	B	T	T
3	-x=1	x=-1	Correct - Isolate x & simplify value of x	D	T	T
1	8x-6=5x-3	8x-5x=6-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	8x-5x=6-3	3x=6	Error in subtraction (+6 , -3)	B	T	T
3	3x=6	x=6/3	Correct - Isolate x	C	T	T
1	2x-6=3x+1	2x-3x=6+1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	2x-3x=6+1	-x=5	Error in Stages 1 & 2 after hints provided	B	T	T
3	-x=5	x=-5	Correct - Isolate x & simplify value of x	D	T	T
1	2x+4=3x+4	2x-3x=4+4	Move a number from one side to another with the same sign	A	T	T
2	2x-3x=4+4	-x=8	Correct - Add all x's terms & add all constant terms	B	T	T
3	-x=8	x=-8	Correct - Isolate x & simplify value of x	D	T	T
1	2x-4=4x-3	2x-4x=4-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	2x-4x=4-3	-2x=1	Correct - Add all x's terms & add all constant terms	B	T	T
3	-2x=1	x=1/-2	Correct - Isolate x & simplify value of x	D	T	T
1	8x+2=3x-3	8x-3x=-1	Move a number from one side to another with the same sign	B.2	T	T
2	8x-3x=-1	4x=-1	Error in subtraction (8x, -3x)	B	T	T
3	4x=-1	x=-4	Multiply by factor of x instead of dividing	D	T	T
1	8x+2=3x-3	8x-3x=-1	Move a number from one side to another with the same sign	B.2	T	T
2	8x-3x=-1	4x=-1	Error in subtraction (8x, -3x)	B	T	T
3	4x=-1	x=-4	Multiply by factor of x instead of dividing	D	T	T
1	97/14x-69/94 =28x-31	-13865x= -19915	Correct - Move all x's to one side & move all constants to one side. Add all x's terms & add all constant terms	B	T	T
2	-13865x= -19915	x=19915/ 13865	Correct - Isolate x	C	T	T
3	x=19915/	x=3983/2773	Correct	C	T	T

	13865					
1	38x-82=34 /29x+88/83	38x-34/29x= 82+88/83	unnecessary step	A	T	T
2	38x-34/29x =82+88/83	1068/29x= 4/29	Error in addition (+82, +88/83)	B	T	T
3	1068/29x= 4/29	x=1/267	Correct - Isolate x	C	T	T
1	97/14x-69/94 =28x-31	97/14x-28x =69/94-31	unnecessary step	A	T	T
2	97/14x-28x =69/94-31	-295/14x =55/2	Error in subtraction (+69/94, -31)	B	T	T
3	-295/14x =55/2	x=-77/59	Correct - Isolate x & simplify value of x	D	T	T
1	38x-82=34/ 29x+88/83	38x-34/29x =82+88/83	unnecessary step	A	T	T
2	38x-34/29x =82+88/83	1068/29x= 2/29	Error in addition (+82, +88/83)	B	T	T
3	1068/29x= 2/29	x=1/534	Correct - Isolate x	C	T	T
4	x=1/534	x=1/549	Error; Simplify value of x	C	T	T
1	8/4x-3=7x+1	8/7x+7x=3+1	Error in subtraction (8/4x,-7x)	A	0	T
2	8/7x+7x=3+1	57/7x=4	Correct - Add all x's terms & add all constant terms	B	T	T
3	57/7x=4	x=28/57	Correct - Isolate x	C	T	T
4	x=28/57	x=28/47	Error; x value in its simplest form in the step above	C	T	T
1	4/2x-2/5= 3x+1	4/2x-3x= -2/5+1	Move a number from one side to another with the same sign	A	T	T
2	4/2x-3x= -2/5+1	-1x=3/5	Correct - Add all x's terms & add all constant terms	B	T	T
3	-1x=3/5	x=-3/5	Correct - Isolate x & simplify value of x	D	T	T
1	2x-5=1/5x+6	2x-1/5x= -5+6	Move a number from one side to another with the same sign	A	T	T
2	2x-1/5x= -5+6	9/5x=1	Correct - Add all x's terms & add all constant terms	B	T	T
3	9/5x=1	x=5/9	Correct- Isolate x	C	T	T
1	3/7x+8=4x-7	3/7x-4x=-8-7	unnecessary step	A	T	T
2	3/7x-4x=-8-7	-25/7x=-15	Correct - Add all x's terms & add all constant terms	B	T	T
3	-25/7x=-15	x=21/5	Correct - Isolate x	C	T	T
1	x+4=3x-1	x-3x=-1+4	Move a number from one side to another with the same sign	A	T	T
2	x-3x=-1+4	-2x=3	Correct - Add all x's terms & add all constant terms	B	T	T
3	-2x=3	x=-3/2	Correct - Isolate x & simplify value of x	D	T	T
1	4x+1/2=5/3x	4x-5/3x=2	Move a number from one side	A	T	T

	+2	+1/2	to another with the same sign			
2	4x-5/3x=2 +1/2	7/3x=5/4	Error in addition (+2, +1/2)	B	T	T
3	7/3x=5/4	x=15/28	Correct - Isolate x	C	T	T
4	x=15/28	x=3/7	Error: x value in its simplest form in the step above	C	T	T
1	5/8x+3=x-8/2	5/8x-x=-8/2 +3	Move a number from one side to another with the same sign	A	T	T
2	5/8x-x=-8/2 +3	-3/8x=-1	Correct - Add all x's terms & add all constant terms	B	T	T
3	-3/8x=-1	x=8/3	Correct - Isolate x	C	T	T
1	x+4=3x-1	4=3x-1-x	Correct - Move all x's to one side	A.1	T	T
2	4=3x-1-x	4+1=3x-x	Correct - Move all constants to one side	A	T	T
3	4+1=3x-x	5=2x	Correct - Add all x's terms & add all constant terms	B	T	T
1	x+4=3x-1	4=3x-1-x	Correct - Move all x’s to one side	A.1	T	T
2	4=3x-1-x	4-1=3x-x	Move a number from one side to another with the same sign	A	T	T
3	4-1=3x-x	3=2x	Correct - Add all x's terms & add all constant terms	B	T	T
1	x+4=3x-1	x=4+3x-1	Move a number from one side to another with the same sign	A.2	T	T
2	x=4+3x-1	x+3x=4-1	Move a number from one side to another with the same sign	A	T	T
3	x+3x=4-1	x+3x=3	Correct - Add all constant terms	B.2	T	T
1	2x-4=8x+8	-4-8=8x-2x	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	-4-8=8x-2x	-12=6x	Correct - Add all x's terms & add all constant terms	B	T	T
3	-12=6x	-2=x	Correct	B	T	T
1	2x-4=8x+8	-4=8x+8-2x	Correct - Move all x's to one side	A.1	T	T
2	-4=8x+8-2x	-4-8=8x-2x	Correct - Move all constants to one side	A	T	T
3	-4-8=8x-2x	-12=6x	Correct - Add all x's terms & add all constant terms	B	T	T
1	2x-4=8x+8	-4-8=8x-2x	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	-4-8=8x-2x	-12=6x	Correct - Add all x's terms & add all constant terms	B	T	T
3	-12=6x	-2=x	Correct	B	T	T
1	2x-4=8x+8	2x=8x+8+4	Correct - Move all constants	A.2	T	T

			to one side			
2	2x=8x+8+4	2x-8x=8+4	Correct - Move all x's to one side	A	T	T
3	2x-8x=8+4	-6x=12	Correct - Add all x's terms & add all constant terms	B	T	T
4	-6x=12	x=-2	Correct - Isolate x & Simplify its value	D	T	T
1	2x-4=8x+8	2x-4-8x=+8	Correct - Move all x's to one side	A.1	T	T
2	2x-4-8x=+8	2x-8x=8+4	Correct - Move all constants to one side	A	T	T
3	2x-8x=8+4	-6x=12	Correct - Add all x's terms & add all constant terms	B	T	T
1	x+4=3x-1	3x+x=4-1	Move a number from one side to another with the same sign	A	T	T
2	3x+x=4-1	4x=3	Correct - Add all x's terms & add all constant terms	B	T	T
1	x+4=3x-1	x=3x-1-4	Correct - Move all constants to one side	A.2	T	T
2	x=3x-1-4	x=3x-2	Error in subtraction (-1, -4)	A.2	T	T
3	x=3x-2	x=1x	Correct	A.2	T	T
1	x+4=3x-1	x+4-3x=-1	Correct - Move all x's to one side	A.1	T	T
2	x+4-3x=-1	x-3x=-1-4	Correct - Move all constants to one side	A	T	T
3	x-3x=-1-4	-4x=-5	Error in subtraction (x, -3x)	B	T	T
4	-4x=-5	x=5/4	Correct - Isolate x	C	T	T
1	x+4=3x-1	x+4=3x-1	Extra step. Repeat the original equation	0	T	T
2	x+4=3x-1	x=3x-1+4	Move a number from one side to another with the same sign	A.2	T	T
3	x=3x-1+4	x=3x+3	Correct	A.2	T	T
4	x=3x+3	x+3x=3	Move a number from one side to another with the same sign	B.2	T	T
5	x+3x=3	4x=3	Correct - Add all x’s terms	B	T	T
1	2x-4=8x+8	2x=8x+4	Move a number from one side to another with the same sign	A.2	T	T
2	2x=8x+4	2x-8x=4	Correct - Move all x's to one side & add all x’s terms	B.2	T	T
3	2x-8x=4	-6x=4	Correct - Add all x’s terms	B	T	T
1	x+4=3x-1	x-3x=-1-4	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	x-3x=-1-4	-2x=-5	Correct - Add all x's terms & add all constant terms	B	T	T
3	-2x=-5	x=-5/-2	Correct - Isolate x	C	T	T
4	x=-5/-2	x=5/2	Correct	C	T	T

1	4x+1/2=5/3x +2	4x=1/2+5/3x +2	Move a number from one side to another with the same sign	A.2	T	T
2	4x=1/2+5/3x +2	4x+5/3x=1/2 +2	Move a number from one side to another with the same sign	A	T	T
1	x+4=3x-1	x-3x=-5	Correct - Move all x's to one side & move all constants to one side. Add all constant terms	B.2	T	T
2	x-3x=-5	-2x=-5	Correct - Add all x’s terms	B	T	T
3	-2x=-5	x=5/2	Correct - Isolate x	C	T	T
1	x+4=3x-1	x=3x-1-4	Correct - Move all constants to one side	A.2	T	T
2	x=3x-1-4	x-3x=-1-4	Correct - Move all x's to one side	A	T	T
3	x-3x=-1-4	-2x=-5	Correct - Add all x's terms & add all constant terms	B	T	T
4	-2x=-5	x=-5/2	Error in division	D	F	T
1	x+4=3x-1	x=3x-1-4	Correct - Move all constants to one side	A.2	T	T
2	x=3x-1-4	x-3x=-1-4	Correct - Move all x's to one side	A	T	T
3	x-3x=-1-4	-2x=-5	Correct - Add all x's terms & add all constant terms	B	T	T
4	-2x=-5	x=-5/2	Error in division	D	F	F
1	x+4=3x-1	x+3x=4-1	Move a number from one side to another with the same sign	A	T	T
2	x+3x=4-1	4x=3	Correct - Add all x's terms & add all constant terms	B	T	T
1	2x-4=8x+8	2x-4-8x=8	Correct - Move all x’s to one side	A.1	T	T
2	2x-4-8x=8	2x-8x=8+4	Correct - Move all constants to one side	A	T	T
3	2x-8x=8+4	-6x=12	Correct - Add all x's terms & add all constant terms	B	T	T
4	-6x=12	x=12/6	Error in division	C	F	T
5	x=12/6	x=2	Correct	C	T	F
1	x+4=3x-1	x+4=4x	Error; Move all constants to one side	A.2	T	T
2	x+4=4x	x+3=3x	Error	A.2	F	T
3	x+3=3x	3x-1=2x	Error	A.2	F	T
4	3x-1=2x	4x=2x	factor of x in calculation without the x	A.2	T	T
1	2x-8=6/4x-3	2x-6/4x=8-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	2x-6/4x=8-3	1/2x=5	Correct - Add all x's terms & add all constant terms	B	T	T

3	1/2x=5	x=10	Correct - Isolate x	C	T	F
1	5/8x+3= x-8/2	5/8x= x-8/2+3	Move a number from one side to another with the same sign	A.2	T	T
2	5/8x=x-8/2 +3	5/8x+x=-8/2 +3	Move a number from one side to another with the same sign	A	T	T
1	2x-4=8x+8	2x+8x=8-4	Move a number from one side to another with the same sign	A	T	T
2	2x+8x=8-4	10x=8-4	Correct - Add all x's terms	B.1	T	T
3	10x=8-4	10x=4	Correct - Add all constant terms	B	T	T
4	10x=4	x=5/4	Error in division	C	T	T
1	4x+1/2=5/3x +2	4x-5/3x= 2-1/2	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	4x-5/3x= 2-1/2	10/3x=3/2	Error in subtraction (4x,-5/3x)	B	T	T
3	10/3 x=3/2	x=9/20	Correct - Isolate x	C	T	T
1	2x-8=6/4x-3	2x=6/4x-3+8	Correct - Move all constants to one side	A.2	T	T
2	2x=6/4x-3+8	2x-6/4x= -3+8	Correct - Move all x's to one side	A	T	T
3	2x-6/4x= -3+8	2x-6/4 x=5	Correct - Add all constant terms	B.2	T	T
1	x+4=3x-1	x-3x=-4-1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	x-3x=-4-1	2x=5	Correct - Add all x's terms & add all constant terms	B	T	T
3	2x=5	x=3/10	Error in division	C	T	T
1	x+4=3x-1	x+4=3x-1	Extra step. Repeat the original equation	0	T	T
2	x+4=3x-1	x+3x=4-1	Move a number from one side to another with the same sign	A	T	T
3	x+3x=4-1	-2x=3	Error in addition (x, +3x)	B	T	T
1	x+4=3x-1	x-3x=-4-1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	x-3x=-4-1	-2x=-5	Correct - Add all x's terms & add all constant terms	B	T	T
3	-2x=-5	x=-5/-2	Correct - Isolate x	C	T	T
1	2x-8=6/4x-3	2x-6/4x=8-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	2x-6/4x=8-3	1/2 x=5	Correct - Add all x's terms & add all constant terms	B	T	T
3	1/2 x=5	x=10	Correct - Isolate x	C	T	F
1	x+4=3x-1	x=3x-1-4	Correct - Move all constants to one side	A.2	T	T

2	x=3x-1-4	x-3x=5	Error in subtraction (-1, -4)	B.2	T	T
3	x-3x=5	-2x=5	Correct - Add all x's terms	B	T	T
4	-2x=5	x=3/10	Error in division	C	T	T
1	x+4=3x-1	3x-x=-4-1	Error in subtraction (x, -3x)	A	T	T
2	3x-x=-4-1	2x=5	Error in subtraction (-4, -1)	B	T	T
3	2x=5	x=5/2	Correct - Isolate x	C	T	T
1	2x-4=8x+8	-4=8x+8-2x	Correct - Move all x's to one side	A.1	T	T
2	-4=8x+8-2x	-4-8=8x-2x	Correct - Move all constants to one side	A	T	T
3	-4-8=8x-2x	-12= 6x	Correct - Add all x's terms & add all constant terms	B	T	T
1	2x-4=8x+8	2x-8x=-4+8	Move a number from one side to another with the same sign	A	T	T
2	2x-8x=-4+8	-6x= 4	Correct - Add all x's terms & add all constant terms	B	T	T
1	x+4= 3x-1	x+4-3x= -1	Correct - Move all x's to one side	A.1	T	T
2	x+4-3x= -1	x-3x= -1-4	Correct - Move all constants to one side	A	T	T
3	x-3x= -1-4	-2x= -5	Correct - Add all x's terms & add all constant terms	B	T	T
4	-2x= -5	x= 5/2	Correct - Isolate x	C	T	T
1	x+4=3x-1	x-3x=-1-4	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	x-3x=-1-4	-2x= -5	Correct - Add all x's terms & add all constant terms	B	T	T
3	-2x= -5	x= 5/2	Correct - Isolate x	C	T	T
1	2x-4=8x+8	2x=8x+4	Move a number from one side to another with the same sign	A.2	T	T
2	2x=8x+4	-6x= 4	Correct - Move all x's to one side. Add all x's terms & add all constant terms.	B	T	T
3	-6x= 4	x= 4/-6	Correct - Isolate x	C	T	T
1	2x-4=8x+8	2x/4 =8x/8	Error; Move all constants to one side	A.2	T	T
2	2x/4 =8x/8	x=8=x=62	Error; Move all x's to one side & add all x's terms & add all constant terms. Isolate x	C	F	0
3	x=8=x=62	8/62 =x=8	Error	B	F	0
1	x+4=3x-1	x-3x=-4-1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	x-3x=-4-1	-2x=-5	Correct - Add all x's terms & add all constant terms	B	T	T
3	-2x= -5	x= 5/2	Correct - Isolate x	C	T	T

1	x+4= 3x-1	3x+x+4= -1	Move a number from one side to another with the same sign	A.1	T	T
2	3x+x+4= -1	4x+4= -1	Correct	A.1	T	T
3	4x+4= -1	x= -4	Error; Move all constants to one side. Add all x's terms & add all constant terms. Isolate x & simplify its value	D	T	T
1	7/4x+1=2/8x +4	7/4 x=2/8x +4-1	Correct - Move all constants to one side	A.2	T	T
2	7/4x=2/8x +4-1	7/4x-2/8x= 4-1	Correct - Move all x's to one side	A	T	T
3	7/4x-2/8x= 4-1	6/4x=3	Correct - Add all x's terms & add all constant terms	B	T	T
1	4x+½=5/3x+ 2	4x+½=5/3x+ 2	Correct	0	F	T
2	4x+½=5/3x+ 2	4x-5/3x= ½ +2	Move a number from one side to another with the same sign	A	T	T
3	4x- 5/3x=½ +2	-7/3x=½ +2	Error in subtraction (4x,-5/3x)	B.1	T	T
4	-7/3x=½ +2	-7/3x=1	Error in addition (+1/2, +2)	B	T	T
1	7/4x+1=2/8x +4	7/4x-2/8x= 4-1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	7/4x-2/8x= 4-1	12/8x=3	Correct - Add all x's terms & add all constant terms	B	T	T
3	12/8x=3	3/2x=3	Correct	B	T	T
4	3/2x=3	x=2	Correct - Isolate x	C	T	F
1	2x-4=8x+8	2x=8x+8+4	Correct - Move all constants to one side	A.2	T	T
2	2x=8x+8+4	2x-8x=8+4	Correct - Move all x's to one side	A	T	T
3	2x-8x=8+4	-6x=12	Correct - Add all x's terms & add all constant terms	B	T	T
4	-6x=12	x=-2	Correct - Isolate x & simplify its value	D	T	T
1	2x-4=8x+8	2x=8x+8+4	Correct - Move all constants to one side	A.2	T	T
2	2x=8x+8+4	2x-8x=8+4	Correct - Move all x's to one side	A	T	T
3	2x-8x=8+4	-6x=12	Correct - Add all x's terms & add all constant terms	B	T	T
4	-6x=12	x=-2	Correct - Isolate x & simplify its value	D	T	T
1	2x-4=8x+8	8x=2x-4-8	Correct - Move all constants to one side	A.2	T	T
2	8x=2x-4-8	8x-2x=-4-8	Correct - Move all x's to one side	A	T	T

1	x+4=3x-1	x=-1-4	Error; Move all x's to one side & move all constants to one side & add all x's terms	B.1	T	T
2	x=-1-4	x=-5	Correct - Add all constant terms. Isolate x & simplify its value	D	T	T
3	x=-5	3x=-5	Error	B	F	T
1	2x-8=6/4x-3	-8=6/4x-3-2x	Correct - Move all x's to one side	A.1	T	T
2	-8=6/4x-3-2x	-8+3=6/4x-2x	Correct - Move all constants to one side	A	T	T
3	-8+3=6/4x-2x	-5=3x	Error in subtraction (+6/4x, -2x)	B	T	T
1	5/8x+3= x-8/2	5/8x-x=-8/2-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5/8 x-x=-8/2-3	3/8x=7	Correct - Add all x's terms & add all constant terms	B	T	T
3	3/8x=7	x=56/3	Correct - Isolate x	C	T	T
1	5/8x+3=x-8/2	5/8x+3=x-8/2	Correct	0	F	T
2	5/8x+3=x-8/2	5/8x-x=3-8/2	Move a number from one side to another with the same sign	A	T	T
3	5/8x-x=3-8/2	4/8x=3-8/2	Error in subtraction (5/8x, -x)	B.1	T	T
4	4/8x=3-8/2	4/8x=-8	Error in subtraction (+3, -8/2)	B	T	T
1	x+4=3x-1	x=3-1-4	Error; Move all x's to one side & move all constants to one side. Add all x's terms	B.1	T	T
2	x=3-1-4	x=3-2	Error	B.1	F	T
3	x= 3-2	x= 1	Correct - Add all constant terms. Isolate x & simplify its value	D	T	T
1	4x+1/2=5/3x+2	4x=5/3x+2-0	Error; Move all constants to one side	A.2	T	T
2	4x=5/3x+2-0	4x=5/3x+1	Error	A.2	F	T
3	4x=5/3x+1	4x=1	Error; Move all x's to one side. Add all x’s terms & add all constant terms	B	T	T
4	4x=1	x=1/4	Correct - Isolate x	C	T	F
1	4x+1/2=5/3x+2	-5/3x-4x=2-1/2	Move a number from one side to another with the same sign	A	T	T
2	-5/3x-4x=2-1/2	-17/3x=3/2	Correct - Add all x's terms & add all constant terms	B	T	T
3	-17/3x=3/2	x=-34/9	Error in division	D	T	T
1	4x+1/2=5/3x+2	4x-5/3x=2-1/2	Correct - Move all x's to one side & move all constants to one side	A	T	T

2	4x-5/3x=2-1/2	7/3x=3/2	Correct - Add all x's terms & add all constant terms	B	T	T
1	4x+1/2=5/3x +2	5/3x+4x+1/2 =2	Move a number from one side to another with the same sign	A.1	T	T
2	5/3x+4x+1/2 =2	17/3x=1/2 +2	Move a number from one side to another with the same sign	B.1	T	T
1	2x-4=8x+8	2x=8x+4	Move a number from one side to another with the same sign	A.2	T	T
2	2x=8x+4	-6x=-4	Move a number from one side to another with the same sign	B	T	T
3	-6x=-4	x=-4/-6	Correct - Isolate x	C	T	T
1	2x-8=6/4x-3	2x-8=6	Error; Move all x's to one side	A.1	T	T
2	2x-8=6	6/4x-3=18-12	Error	A.1	F	T
3	6/4x-3=18-12	18-12=6	Error	A.1	F	T
1	4x+1/2=5/3x +2	4x+1/2=5/3x +2	Correct	0	F	T
2	4x+1/2=5/3x +2	4x-5/3x= 1/2+2	Move a number from one side to another with the same sign	A	T	T
3	4x-5/3x= 1/2+2	4x-5=1+2	Error	A.1	F	T
4	4x-5=1+2	1/3x=2/2	Error; Move all constants to one side. Add all x's terms & add all constant terms	B	T	T
1	x+4=3x-1	x+4-3x=-1	Correct - Move all x's to one side	A.1	T	T
2	x+4-3x=-1	x-3x=-1-4	Correct - Move all constants to one side	A	T	T
3	x-3x=-1-4	-2x=-5	Correct - Add all x's terms & add all constant terms	B	T	T
4	-2x=-5	x=9/4	Error in division	C	T	T
1	2x-8=6/4x-3	2x-6/4x=8-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	2x-6/4x=8-3	1/2x=5	Correct - Add all x's terms & add all constant terms	B	T	T
3	1/2x=5	x=10	Correct - Isolate x	C	T	F
1	4x+1/2=5/3x +2	8x+2-15x=6	Error; Move all x's to one side	A.1	T	T
2	8x+2-15x=6	8x-15x=6-2	Correct - Move all constants to one side	A	T	T
3	8x-15x=6-2	-7/-7x=4/-7	Correct - Add all x's terms & add all constant terms	B	T	T
4	-7/-7x=4/-7	x=15/2	Error in division	C	T	T
1	4x+1/2=5/3x +2	4x-5/3x= 2-1/2	Correct - Move all x's to one side & move all constants to	A	T	T

			one side			
2	4x-5/3x= 2-1/2	7/3x=3/2	Correct - Add all x's terms & add all constant terms	B	T	T
1	5/8x+3=x-8/2	x+5/8x+3=-8/2	Move a number from one side to another with the same sign	A.1	T	T
2	x+5/8x+3=-8/2	x+5/8x=3-8/2	Move a number from one side to another with the same sign	A	T	T
3	x+5/8x=3-8/2	x+5/8x=1	Error in subtraction (+3, -8/2)	B.2	T	F
1	2x-4=8x+8	2x=8x+8+4	Correct - Move all constants to one side	A.2	T	T
2	2x=8x+8+4	2x-8x=8+4	Correct - Move all x's to one side	A	T	T
3	2x-8x=8+4	-6x=12	Correct - Add all x's terms & add all constant terms	B	T	T
4	-6x=12	x=-2	Correct - Isolate x & simplify its value	D	T	T
1	5/8x+3=x-8/2	5/8x-x=-8/2-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5/8x-x=-8/2 - 3	-3/8x=-1	Error in subtraction (-8/2, -3)	B	T	T
1	2x-4=8x+8	8x+2x=8-4	Move a number from one side to another with the same sign	A	T	T
2	8x+2x=8-4	10x=4	Correct - Add all x's terms & add all constant terms	B	T	T
3	10x=4	x=5/4	Error in division	C	T	T
1	7/4x+1=2/8x +4	7/4x-2/8x= 4-1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	7/4x-2/8x= 4-1	12/8x=3	Correct - Add all x's terms & add all constant terms	B	T	T
3	12/8x=3	3/2x=3	Correct	B	T	T
4	3/2x=3	x=2	Correct - Isolate x	C	T	T
1	5/8x+3= x-8/2	5/8x-1x= -8/2-3	unnecessary step	A	T	T
2	5/8x-1x= -8/2-3	-3/8x=-14/2	Correct - Add all x's terms & add all constant terms	B	T	T
3	-3/8x=-14/2	x=21/8	Error in division	C	T	T
1	5/8x+3= x-8/2	5/8x-x= -8/2-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5/8x-x= -8/2 -3	-3/8x=1	Error in subtraction (-8/2, -3)	B	T	T
1	2x-4=8x+8	2x+8x=8-4	Move a number from one side to another with the same sign	A	T	T
2	2x+8x=8-4	10x=4	Correct - Add all x's terms & add all constant terms	B	T	T

3	10x=4	x=5/4	Error in division	C	T	T
1	7/4x+1=2/8x +4	7/4x+1=7+4	Error; Move all x's to one side	A.1	T	T
2	7/4x+1=7+4	2/8x+4=8+32	Error	A.1	F	T
3	2/8x+4=8+32	11/40=11/20	Error	A.1	F	0
1	4x+1/2=5/3x +2	4x=5/3 +1	Error; Move all x's to one side & move all constants to one side & add all x's terms	B.1	T	T
2	4x=5/3 +1	4x=7/2	Error; Add all constant terms	B	T	T
3	4x=7/2	x=1+5	Error	B.1	F	T
4	x=1+5	x=5	Error in addition (+1, +5)	C	T	T
1	x+4=3x-1	x-3x=-5	Correct - Move all x's to one side & move all constants to one side & add all constant terms	B.2	T	T
2	x-3x=-5	-2x=-5	Correct - Add all x's terms	B	T	T
3	-2x=-5	x=5/2	Correct - Isolate x	C	T	T
1	2x-8=6/4x-3	2x-8-6/4x=-3	Correct - Move all x's to one side	A.1	T	T
2	2x-8-6/4x=-3	2x-6/4x= -3+8	Correct- Move all constants to one side	A	T	T
3	2x-6/4x= -3+8	3/2x=5	Error in subtraction (2x,-6/4x)	B	T	T
1	5/8x+3=x- 8/2	40x+3-x=-16	Error; Move all x's to one side	A.1	F	T
2	40x+3-x=-16	40x-x=-16-3	Correct - Move all constants to one side	A	T	T
3	40x-x=-16-3	39/39x= -19/39	Increased the equation values by using unnecessary multiplying steps	B	T	T
4	39/39x= -19/39	x=-19/39	Correct - Isolate x & simplify its value	D	T	T
1	x+4=3x-1	-3x=x+4-1	Error; Move all constants to one side	A.2	T	T
2	-3x=x+4-1	-3x=x+3	Correct	A.2	T	T
3	-3x=x+3	x=x-3	Error	A.2	F	T
1	2x-8=6/4x-3	2x=6/4x-3+8	Correct - Move all constants to one side	A.2	T	T
2	2x=6/4x-3+8	2x-6/4x= -3+8	Correct- Move all x's to one side	A	T	T
3	2x-6/4x= -3+8	2/4x=5	Correct - Add all x's terms & add all constant terms	B	T	T
4	2/4x=5	x=10	Correct - Isolate x	C	T	T
1	2x-8=6/4x-3	2x=6/4x-3+8	Correct - Move all constants to one side	A.2	T	T
2	2x=6/4x-3+8	2x-6/4x= -3+8	Correct - Move all x's to one side	A	T	T

3	2x-6/4x= -3+8	2/4x=5	Correct - Add all x's terms & add all constant terms	B	T	T
4	2/4x=5	x=10	Correct - Isolate x	C	T	T
1	2x-8=6/4x-3	2x+6/4x=-8-3	Move a number from one side to another with the same sign	A	T	T
2	2x+6/4x=-8-3	2x+3/2x=-11	Correct - Add all constant terms	B.2	T	T
1	2x-8=6/4x-3	2x+6/4x=-8-3	Move a number from one side to another with the same sign	A	T	T
2	2x+6/4x=-8-3	2x+3/2x=-11	Correct - Add all constant terms	B.2	T	T
1	2x-8=6/4x-3	2x+6/4x=-8-3	Move a number from one side to another with the same sign	A	T	T
2	2x+6/4x=-8-3	2x+3/2x=-11	Correct - Add all constant terms	B.2	T	T
1	x+4=3x-1	x=3x-1+4	Move a number from one side to another with the same sign	A.2	T	T
2	x=3x-1+4	x=3x+3	Correct	A.2	T	T
3	x=3x+3	x=6	Add constant with variable	C	T	T
1	2x-4=8x+8	2x-8x=4+8	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	2x-8x=4+8	-6x=12	Correct - Add all x's terms & add all constant terms	B	T	T
3	-6x=12	x=-2	Correct - Isolate x & simplify its value	D	T	T
1	7/4x+1=2/8x +4	7/4x+1-2/8x =4	Correct - Move all x's to one side	A.1	T	T
2	7/4x+1-2/8x =4	7/4x-2/8x= 4-1	Correct - Move all constants to one side	A	T	T
3	7/4x-2/8x= 4-1	5/-4x=3	Error in subtraction (7/4x, -2/8x)	B	T	T
1	7/4x+1=2/8x +4	7/4x+2/8x=1 +4	Move a number from one side to another with the same sign	A	T	T
2	7/4x+2/8x=1 +4	7/4x+2/8x=5	Correct - Add all constant terms	B.2	T	T
1	7/4x+1=2/8x +4	7/4x=2/8x+4 -1	Correct - Move all constants to one side	A.2	T	T
2	7/4x=2/8x+4 -1	7/4x-2/8x= 4-1	Correct - Move all x's to one side	A	T	T
3	7/4x-2/8x= 4-1	12/8x=3	Correct - Add all x's terms & add all constant terms	B	T	T
4	12/8x=3	x=1	Error in division	D	T	T
1	5/8x+3=x-8/2	5/8x-x=3-8/2	Error; Move all x's to one side & move all constants to one side	A	T	T
2	5/8x-x=3-8/2	4/8x=3+3/5	Error; Add all x's terms	B.1	T	T
3	4/8x=3+3/5	x=3/4	Error; Add all constant terms	C	T	T

			& isolate x			
1	4x+1/2=5/3x +2	4x+5/3x=1/2 +2	Move a number from one side to another with the same sign	A	T	T
2	4x+5/3x=1/2 +2	4/3x+5/3x= 1/2 +2/2	Error	A	F	T
3	4/3x+5/3x= 1/2+2/2	9/3x=3/2	Correct - Add all x's terms & add all constant terms	B	T	T
1	7/4x+1=2/8x +4	7/4x+2/8x=4 +1	Move a number from one side to another with the same sign	A	T	T
2	7/4x+2/8x=4 +1	7/4x+1/4x=5	Correct - Add all constant terms	B.2	T	T
1	7/4x+1=2/8x +4	7/4x+2/8x=1 +4	Move a number from one side to another with the same sign	A	T	T
2	7/4 x+2/8x=1 +4	7/4x+2/8x=5	Correct - Add all constant terms	B.2	T	T
1	7/4x+1=2/8x +4	7/4x=2/8x+4 -1	Correct - Move all constants to one side	A.2	T	T
2	7/4x=2/8x+4 -1	7/4x-2/8x=4-1	Correct - Move all x's to one side	A	T	T
3	7/4x-2/8x=4-1	12/8x=3	Correct - Add all x's terms & add all constant terms	B	T	T
4	12/8x=3	x=2	Correct - Isolate x	C	T	T
1	4x+1/2=5/3x +2	4x-5/3x=2-1/2	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	4x-5/3x=2-1/2	7/3 =3/2	Add constant with a variable	A.1	F	T
1	5x-7=6x+3/8	5x=7+6x+3/8	Correct - Move all constants to one side	A.2	T	T
2	5x=7+6x+3/8	5x-6x=7+3/8	Correct - Move all x's to one side	A	T	T
3	5x-6x=7+3/8	x=-59/8	Correct - Add all x-terms & add all constant terms. Isolate x & simplify its value	D	T	T
1	2x-8=6/4x-3	-8=6/4x-3-2x	Correct - Move all x's to one side	A.1	T	T
2	-8=6/4x-3-2x	-8+3=6/4x-2x	Correct - Move all constants to one side	A	T	T
3	-8+3=6/4x-2x	-5=3x	Error in subtraction (+6/4x, -2x)	B	T	T
1	2x-8=6/4x-3	-8=6/4x-3-2x	Correct - Move all x's to one side	A.1	T	T
2	-8=6/4x-3-2x	-8+3=6/4x-2x	Correct - Move all constants to one side	A	T	T
3	-8+3=6/4x-2x	-5=3x	Error in subtraction (+6/4 x, -2x)	B	T	T
1	4x+1/2=5/3x +2	4x-5/3x=2-1/2	Correct - Move all x's to one side & move all constants to one side	A	T	T

2	4x-5/3x=2-1/2	7/3x=3/2	Correct - Add all x's terms & add all constant terms	B	T	T
3	7/3x=3/2	x=9/14	Correct - Isolate x	C	T	T
1	4x+1/2=5/3x +2	4x+1/2=5/3x +2	Correct	0	F	T
2	4x+1/2=5/3x +2	4x+1/2=5/3 +2	Error; Move all x's to one side	A.1	T	T
3	4x+1/2=5/3 +2	4x-5/3x=2-1/2	Error; Move all constants to one side	A	F	T
4	4x-5/3x=2-1/2	3/2x=3/2	Error - Add all x's terms & add all constant terms	B	F	T
5	3/2x=3/2	x=6/6	Correct- Isolate x	C	T	T
6	x=6/6	x=1	Correct - Simplify value of x	D	T	T
1	4x+1/2=5/3x +2	5/3x+4x=1/2 +2	Move a number from one side to another with the same sign	A	T	T
2	5/3x+4x=1/2 +2	7/3x=3/2	Move a number from one side to another with the same sign	B	F	T
1	2x-8=6/4x-3	2x+6/4=-8-3	Error; Move all x's to one side	A.1	F	T
2	2x+6/4 =-8-3	2x+3/2=-11	Correct	A.1	T	T
1	7/4x+1=2/8x +4	7/4x+1-2/8x =4	Correct - Move all x's to one side	A.1	T	T
2	7/4x+1-2/8x =4	7/4x-2/8x= 4-1	Correct - Move all constants to one side	A	T	T
3	7/4x-2/8x= 4-1	1/4x=3	Error in subtraction (7/4x, -2/8x)	B	T	T
1	5/8x+3=x-8/2	x+5/8x=3-8/2	Move a number from one side to another with the same sign	A	T	T
2	x+5/8x=3-8/2	1/8x+5/8x= 3/2-8/2	Error	A	F	T
3	1/8 x+5/8x= 3/2-8/2	6/8x=5/2	Error - Add all x's terms & add all constant terms	B	F	T
1	7/4x+1=2/8x +4	7/4x+2/8 x=1 +4	Move a number from one side to another with the same sign	A	T	T
2	7/4x+2/8 x=1 +4	7/4x+1/4 x=5	Correct - Add all constant terms	B.2	T	T
1	5/8x+3=x-8/2	5/8x-x=-8/2-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5/8 x-x= -8/2 -3	-3/8x=-7/1	Correct - Add all x's terms & add all constant terms	B	T	T
3	-3/8 x=-7/1	x=56/3	Correct - Isolate x	C	T	T
1	5/8x+3=x-8/2	5/8x-x=-8/2 -3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5/8x-x=-8/2-3	-3/8x=-7/1	Correct - Add all x's terms & add all constant terms	B	T	T
3	-3/8x=-7/1	x=56/3	Correct - Isolate x	C	T	T

1	4x+1/2=5/3x +2	4x+1/2-5/3x =2	Correct - Move all x's to one side	A.1	T	T
2	4x+1/2-5/3x =2	4x-5/3x =2-1/2	Correct - Move all constants to one side	A	T	T
3	4x-5/3x=2-1/2	10/3x=3/2	Error in subtraction (4x,-5/3x)	B	T	T
4	10/3x=3/2	x=1/2	Error in division	C	T	T
1	5/8x+3=x-8/2	5/8x+x=-8/2-3	Move a number from one side to another with the same sign	A	T	T
2	5/8x+x=-8/2-3	13x=-14/2	Error in addition (5/8 x, +x)	B	T	T
1	2x-8=6/4x-3	8/4x-6/4 x= -3+8	unnecessary step	A	F	T
2	8/4x-6/4x= -3+8	2/4x=5	Correct - Add all x's terms & add all constant terms	B	T	T
3	2/4x=5	1/2x=5	Correct	B	T	T
1	7/4x+1=2/8x +4	14/8x-2/8x =4-1	Increased the equation values by using unnecessary multiplying steps	A	F	T
2	14/8x-2/8x =4-1	12/8x=3	Correct - Add all x's terms & add all constant terms	B	T	T
3	12/8x=3	3/2x=3	Correct	B	T	T
1	5x-7=6x+3/8	5x-6x=7+3/8	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5x-6x=7+3/8	x=7/8+3/8	unknown step	B.1	F	T
3	x=7/8+3/8	x=10/8	Correct - Add all constant terms and isolate x	C	T	T
1	5/8x+3=x-8/2	5/8x-x=-8/2-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	5/8x-x=-8/2-3	5/8x=-8/2 -3	Error; Add all x's terms	B.1	T	T
3	5/8x=-8/2-3	x=7/10	Error; Add all constant terms. Isolate x	C	T	T
1	7/4x+1=2/8x +4	7/4x=2/8 x+3	Correct - Move all constants to one side	A.2	T	T
2	7/4x=2/8x+3	7/4x-2/8x=3	Correct - Move all x’s terms & add all x’s terms.	B.2	T	T
3	7/4x-2/8 x=3	x=5	Error in subtraction	C	F	T
1	4x+1/2=5/3x +2	4x+1/2-5/3x =2	Correct - Move all x's to one side	A.1	T	T
2	4x+1/2-5/3x =2	4x-5/3x=2-1/2+9	Correct - Move all constants to one side	A	T	T
3	4x-5/3x=2-1/2@@	7/3x=3/2	Correct - Add all x's terms & add all constant terms	B	T	T
1	4x+1/2=5/3x +2	4x+5/3x=1/2 +2	Move a number from one side to another with the same sign	A	T	T

2	4x+5/3x=1/2 +2	4x+5/3x=5/2	Correct - Add all constant terms	B.2	T	T
1	7/4x+1=2/8x +4	7/4x=2/8x+3	Correct - Move all constants to one side	A.2	T	T
2	7/4x=2/8x+3	7/4x-2/8x=3	Correct - Move all x's to one side & add all x's terms	B.2	T	T
3	7/4x-2/8x=3	12/8x=3	Correct - Add all x’s terms	B	T	T
4	12/8 x=3	6/4 x=3	Correct	B	T	T
1	2x-8=6/4x-3	2x-6/4x=8-3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	2x-6/4 x=8-3	-4/-2x=5	Error in subtraction (2x,-6/4x)	B	T	T
3	-4/-2 x=5	x=2/3	Error in division	C	T	T
1	5/8x+3= x-8/2	5/8x+3-x= -8/2	Correct - Move all x's to one side	A.1	T	T
2	5/8x+3-x= -8/2	5/8x-x=-8/2-3	Correct - Move all constants to one side	A	T	T
3	5/8x-x=-8/2-3	-13/8x=-8/2-3	Error in subtraction (5/8x, -x)	B.1	T	T
4	-13/8x=-8/2-3	-13/8x=-7	Correct - Add all constant terms	B	T	T
1	5/8x+3= x-8/2	5/8x-x= -8/2 +3	Move a number from one side to another with the same sign	A	T	T
2	5/8x-x= -8/2 +3	5/8x-x= -4/1 +3	unnecessary step	A	T	T
1	5x-7=6x+3/8	5x-6x=7/1 +3/8	Error in Stages 1 & 2 after hints provided	A	F	T
2	5x-6x=7/1 +3/8	-1x=59/8	Correct - Add all x's terms & add all constant terms	B	T	T
3	-1x=59/8	1x=52/8	unknown step	B	T	T
1	2x-8=6/4x-3	x=3	Error; Move all x's to one side & move all constants to one side. Add all x-terms & add all constant terms. Isolate x	C	T	T
2	x=3	x=6	Error	C	F	T
1	7/4x+1=2/8x +4	7/4x=-1+4	Error in subtraction (7/4x, -2/8x)	B.1	T	T
2	7/4x=-1+4	7/4x=3	Correct - Add all constant terms	B	T	T
3	7/4 x=3	x=3	Error in division	C	T	F
1	3x-8=4/5x+7	3x-4/5x=7-8	Move a number from one side to another with the same sign	A	T	T
2	3x-4/5x=7-8	x=11	Error; Add all x-terms & add all constant terms. Isolate x	C	T	T
3	x=11	x=13	Error	C	F	T
4	x=13	x=12	Error	C	F	T

1	8x+7/3=3x+4	5x=5/3	Correct - Move all x's to one side & move all constants to one side. Add all x's terms & add all constant terms	B	T	T
2	5x=5/3	x=1/3	Correct - Isolate x	C	T	F
1	8x+7/3=3x+4	5x=19/3	Move a number from one side to another with the same sign	B	T	T
2	5x=19/3	x=6	Error in division	C	T	F
1	8x+7/3=3x+4	8x-3x=5x	Error; Move all constants to one side	A.2	F	T
2	8x-3x=5x	7/3 -4=-1	Error	A.1	F	T
3	7/3 -4=-1	5x=-1	Error; Move all constants to one side. Add all x's terms & add all constant terms	B	T	F
4	5x=-1	x=-2/10	Increased the equation values by using unnecessary multiplying steps	C	T	T
1	3x+3=1/4x-8	11=-11/4 x	Correct - Move all x's to one side & move all constants to one side. Add all x's terms & add all constant terms	B	T	T
2	11=-11/4 x	-4=x	Correct	B	T	F
1	8x+7/3=3x+4	5x+7/3 =4	Correct - Move all x’s to one side	A.1	T	T
2	5x+7/3 =4	5x=5/3	Correct - Move all constants to one side. Add all x's terms & add all constant terms	B	T	T
3	5x=5/3	x=1/3	Correct - Isolate x	C	T	F
1	8x+7/3=3x+4	8x=3x+5/3	Correct - Move all constants to one side	A.2	T	T
2	8x=3x+5/3	5x=5/3	Correct - Move all x’s to one side. Add all x's terms & add all constant terms	B	T	T
3	5x=5/3	x=1/3	Correct - Isolate x	C	T	F
1	8x+7/3=3x+4	8x=82	Error; Move all x's to one side & move all constants to one side. Add all x's terms & add all constant terms	B	F	T
2	8x=82	6x=12	Error	B	F	T
3	6x=12	x=32	Error; Isolate x	C	T	T
1	8x+7/3=3x+4 @@	5x+73=4@@ -7	Error in subtraction factor	A.1	0	T
2	5x+73=4@@ -7	5x=53	Error in subtraction factor	B	0	T
3	5x=53	x=13	Error in division	C	T	F
1	8x+7/3=3x+4	8x=3x+5/3	Correct - Move all constants to one side	A.2	T	T

2	8x=3x+5/3	5x=5/3	Correct - Move all x’s to one side. Add all x's terms & add all constant terms	B	T	T
3	5x=5/3	x=1/3	Correct - Isolate x	C	T	F
1	8x+7/3=3x+4 @@-	5x+7/3=4- 7/3	Correct - Move all x’s to one side	A.1	T	T
2	5x+7/3=4@ @-7	5x=5/3/5	Correct - Move all constants to one side. Add all x's terms & add all constant terms	B	T	T
3	5x=5/3@@	x=1/3	Correct - Isolate x	C	T	F
1	3x+3=1/4x-8	12x+3=-8-3	Error in subtraction (3x,-1/4x)	A.1	T	T
2	12x+3= -8@@	12x=-11	Correct - Move all constants to one side. Add all x's terms & add all constant terms	B	T	T
3	12x=-11	x=-11/12	Correct - Isolate x & simplify its value	D	T	T
1	3x+3=1/4x-8	3x=1/4 x-11	Correct - Move all constants to one side	A.2	T	T
2	3x=1/4 x-11	11/4 x=-11	Correct - Move all x’s to one side. Add all x's terms & add all constant terms	B	T	T
3	11/4 x=-11	x=-4	Correct - Isolate x & simplify its value	D	T	T
1	3x+3=1/4x- 8@@-1	3x+3=-8-3	Error in subtraction factor	A.1	T	T
2	3x+3=-8@@	3x=5/3	Error in subtraction factor	B	0	T
3	3x=5@@	x=5/3	Correct - Isolate x	C	T	T
1	3x+3=1/4x-8	3x=1/4 x-11	Correct - Move all constants to one side	A.2	T	T
2	3x=1/4 x-11	11/3 x=-11	Error in subtraction (3x,-1/4x)	B	T	T
3	11/3 x=-11	x=-4	Error in division	D	T	T
1	8x+7/3=3x+4	24x+7=9x+ 12	unnecessary step	0	F	T
2	24x+7=9x+ 12	15x+7=12	Correct - Move all x's to one side	A.1	T	T
3	15x+7=12	15x=5	Correct - Move all constants to one side. Add all x's terms & add all constant terms	B	T	T
4	15x=5	x=1/3	Correct - Isolate x	C	T	F
1	3x+3=1/4x-8	3x-1/4 x=-8- 3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	3x-1/4 x=-8- 3	11/4 x=-11	Correct - Add all x's terms & add all constant terms	B	T	T
3	11/4 x=-11	x=-44/11	Correct - Isolate x	C	T	T
4	x=-44/11	x=-4	Correct - Simplify value of x	D	T	T
1	3x+3=1/4x-8	12x=2	Error; Move all x's to one	B	F	T

			side & move all constants to one side. Add all x's terms & add all constant terms			
2	12x=2	3x=-11	Error	B	F	T
3	3x=-11	15/4 x=-11	Error	B	F	T
4	15/4x=-11	x=12	Error in division	C	T	F
1	8x+7/3=3x+4	24x+7=9x+ 12	unnecessary step	0	F	T
2	24x+7=9x+ 12	15x+7=12	Correct - Move all x's to one side	A.1	T	T
3	15x+7=12	15x=5	Correct - Move all constants to one side & add all x's terms & add all constant terms	B	T	T
4	15x=5	x=1/3	Correct - Isolate x	C	T	F
1	8x+7/3=3x+4 @@-	5x+7/3 =4- 7/3	Correct - Move all x's to one side	A.1	T	T
2	5x+7/3 =4@ @-7	5x=5/3/5	Correct - Move all constants to one side & add all x's terms & add all constant terms	B	T	T
3	5x=5/3@@	x=1/3	Correct - Isolate x	C	T	F
1	8x+7/3=3x+4 @@-	5x+7/3 =4- 7/3	Correct - Move all x's to one side	A.1	T	T
2	5x+7/3 =4@ @-7	5x=5/3/5	Correct - Move all constants to one side & add all x's terms & add all constant terms	B	T	T
3	5x=5/3@@	x=1/3	Correct - Isolate x	C	T	F
1	3x+3=1/4x- 8@@	3x+13=14x- 3x	Error in subtraction factor	A.2	0	T
2	3x+13=14x @@-	13=234x	Error in subtraction factor	B	0	T
3	13=234x	234x=13	Correct	B	F	T
4	234x=13	x=6	Error in division	C	T	F
1	8x+7/3=3x+4	8x-3x=4-7/3	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	8x-3x=4-7/3	5x=5/3	Correct - Add all x's terms & add all constant terms	B	T	T
3	5x=5/3	x=5/15	Correct - Isolate x	C	T	T
4	x=5/15	x=1/3	Correct	C	T	F
1	3x+3=1/4x-8	3x-1/4x=-8-3	Correct- Move all x's to one side & move all constants to one side	A	T	T
2	3x-1/4x=-8-3	11/4x=-11	Correct - Add all x’s terms & add all constant terms	B	T	T
3	11/4x=-11	x=-44/11	Correct - Isolate x	C	T	T
4	x=-44/11	x=-4	Correct - Simplify value of x	D	T	T
1	3x+3=1/4x-	3=-11/4x-8	Correct - Move all x's to one	A.1	T	T

	8@@-	+8	side			
2	3=-11/4x-8@@	11=-11/4x	Correct - Move all constants to one side. Add all x's terms & add all constant terms	B	T	T
3	11=-11/4x	-4=x	Correct	B	T	F
1	4x+6/8=8x-3	4x-8x=-3+ 6/8	Move a number from one side to another with the same sign	A	T	T
2	4x-8x=-3+ 6/8	-4x=4	Error in addition (-3, +6/8)	B	T	T
3	-4x=4	x=-1	Correct - Isolate x & simplify its value	D	T	T
1	7x-1=8x-8/4	7x-8x=-8/4 +1	Correct - Move all x's to one side & move all constants to one side	A	T	T
2	7x-8x=-8/4 +1	-x=-12/4	Error in addition (-8/4, +1)	B	T	T
3	-x=-12/4	x=12/4	Correct - Isolate x	C	T	T
4	x=12/4	x=3	Correct	C	T	F
1	5x-7=6x+3/8	5x=7+6x+3/8	Correct - Move all constants to one side	A.2	T	T
2	5x=7+6x+3/8	5x-6x=7+3/8	Correct- Move all x's to one side	A	T	T
3	5x-6x=7+3/8	x=-59/8	Correct - Add all x’s terms & add all constant terms. Isolate x & simplify its value	D	T	T
1	5x-7=6x+3/8	5x=7+6x+3/8	Correct - Move all constants to one side	A.2	T	T
2	5x=7+6x+3/8	-x=7+3/8	Correct - Move all x's to one side	B.1	T	T
3	-x=7+3/8	x=-59/8	Correct - Add all x’s terms & add all constant terms. Isolate x & simplify its value	D	T	T
1	5x-7=6x+3/8	5x=7+6x+3/8	Correct - Move all constants to one side	A.2	T	T
2	5x=7+6x+3/8	5x-6x=59/8	Correct - Move all x's to one side	B.2	T	T
3	5x-6x=59/8	x=-59/8	Correct - Add all x’s terms & add all constant terms. Isolate x & simplify its value	D	T	T
1	5x-7=6x+3/8	5x=7+6x+3/8	Correct - Move all constants to one side	A.2	T	T
2	5x=7+6x+3/8	5x-6x=7+3/8	Correct - Move all x's to one side	A	T	T
3	5x-6x=7+3/8	x=-59/8	Correct - Add all x’s terms & add all constant terms. Isolate x & simplify its value	D	T	T
1	6x-3/4=2x-7/5	6x-3/4-2x= 7/5	Correct - Move all x's to one side	A.1	T	T

2	6x-3/4-2x= 7/5	6x-2x=7/5 +3/4	Correct - Move all constants to one side	A	T	T
3	6x-2x=7/5 +3/4	4x=43/20	Correct - Add all x’s terms & add all constant terms	B	T	T
4	4x=43/20	x=43/80	Correct	C	T	F
1	6x-3/4=2x- 7/5	6x-3/4-2x= 7/5	Correct - Move all x's to one side	A.1	T	T
2	6x-3/4-2x= 7/5	6x-2x=7/5 +3/4	Correct - Move all constants to one side	A	T	T
3	6x-2x=7/5 +3/4	4x=43/20	Correct - Add all x terms & add all constant terms	B	T	T
4	4x=43/20	x=43/80	Correct	C	T	F
1	6x-3/4=2x- 7/5	6x-2x=7/5 +3/4	Correct - Move all x's to one side	A	T	T
2	6x-2x=7/5+ 3/4	4x=43/20	Correct - Move all constants to one side	B	T	T
3	4x=43/20	x=43/80	Correct - Add all x terms & add all constant terms	C	T	F

Appendix (11): How student model integrated in the current E-Diagnostic System

In contemporary educational landscapes, e-diagnostic systems have the potential to play a key role in improving educational outcomes, and supporting educators, by identifying gaps in student knowledge and providing personalised remedial pathways. The student model proposed in this study implements a prototype system designed to diagnose process errors in the solution of linear equations and provide targeted remediation to improve skill levels.

System Overview

The (e-diagnostic) system is focused on assessing learners' ability to solve linear equations. Upon identifying errors, the system pinpoints specific missing skills or knowledge areas, and offers personalised pathways to address these gaps. After the learner has engaged with these pathways, the system then re-evaluates the their ability to solve linear equations.

Key Components of the Student Model

A fully commercialised version of the prototype system described in this research could be designed to include many aspects of the learning process which could improve outcomes, such as learner preferences in lesson type, historical mistakes and error patterns. However, the prototype system described in this study is designed to enable only the basic e-diagnostic process, which is sufficiently accurate to provide remedial suggestions. The key components include:

- Basic Learner Information: The use of minimal necessary details, such as learner ID, name and current grade/level or course.
- Diagnostic Assessment: Tests to evaluate the learner’s ability to solve linear equations. Errors and performance data are recorded.
- Error Analysis: An analysis of mistakes to identify specific gaps in skills or knowledge.
- Remedial Path Assignment: The creation of a customised learning path, based on the diagnostic results, including lessons, practice problems and interactive modules.
- Remediation Tracking: Recording progress through the remedial path, including completion of lessons and practice exercises.
- Ability Evaluation: conducting re-assessments to determine if the learner has reached the target skill level.
- Progression Management: depending on the Ability evaluation, the learner either progresses to more advanced topics or continues with additional remediation.

System Workflow

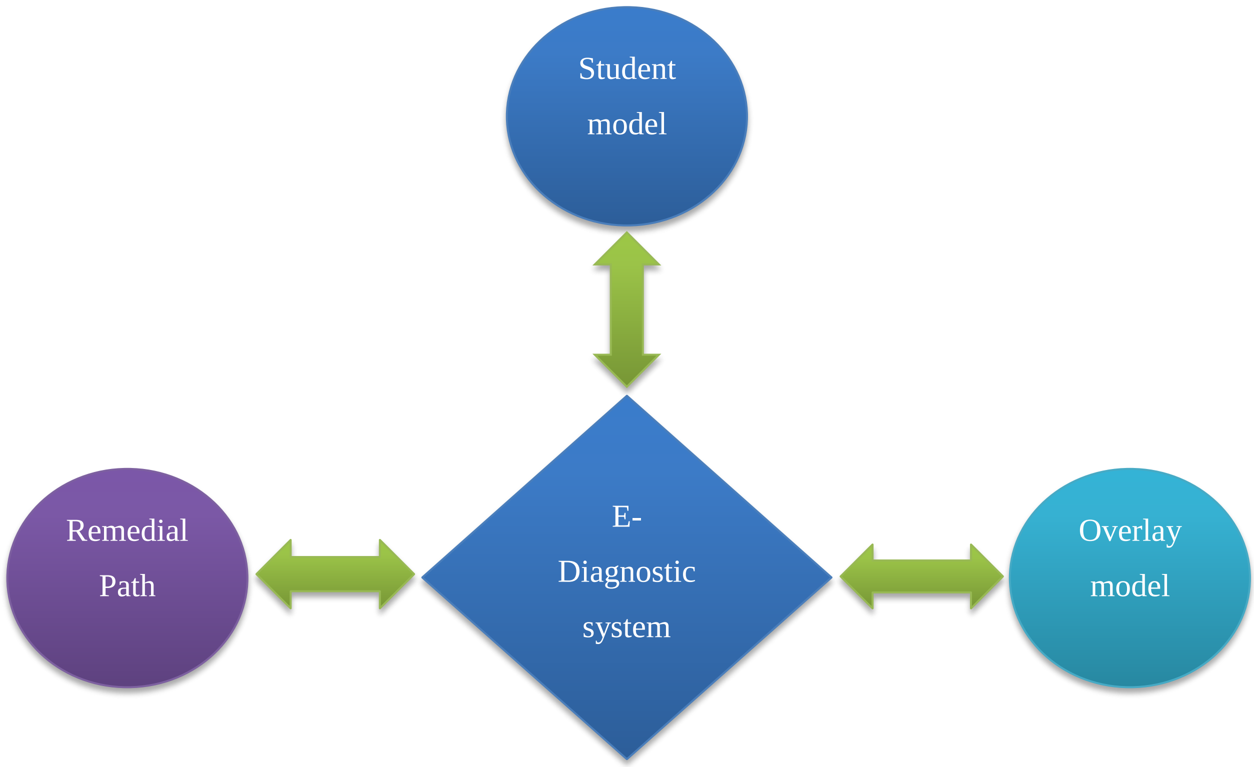
a) Initial Assessment: The learner takes a test designed to evaluate ability in solving linear equations.
b) Error Analysis: The system identifies specific knowledge gaps based on the errors made.
c) Remedial Path Assignment: A tailored learning path is assigned to address the identified gaps.
d) Remediation: The learner engages with the suggested remedial content.
e) Re-assessment: The learner is re-tested to assess improvement in ability.
f) Progression or Further Remediation: Based on the re-assessment, the learner either progresses to more advanced topics or continues with additional remediation.

Relationship with an Overlay Model

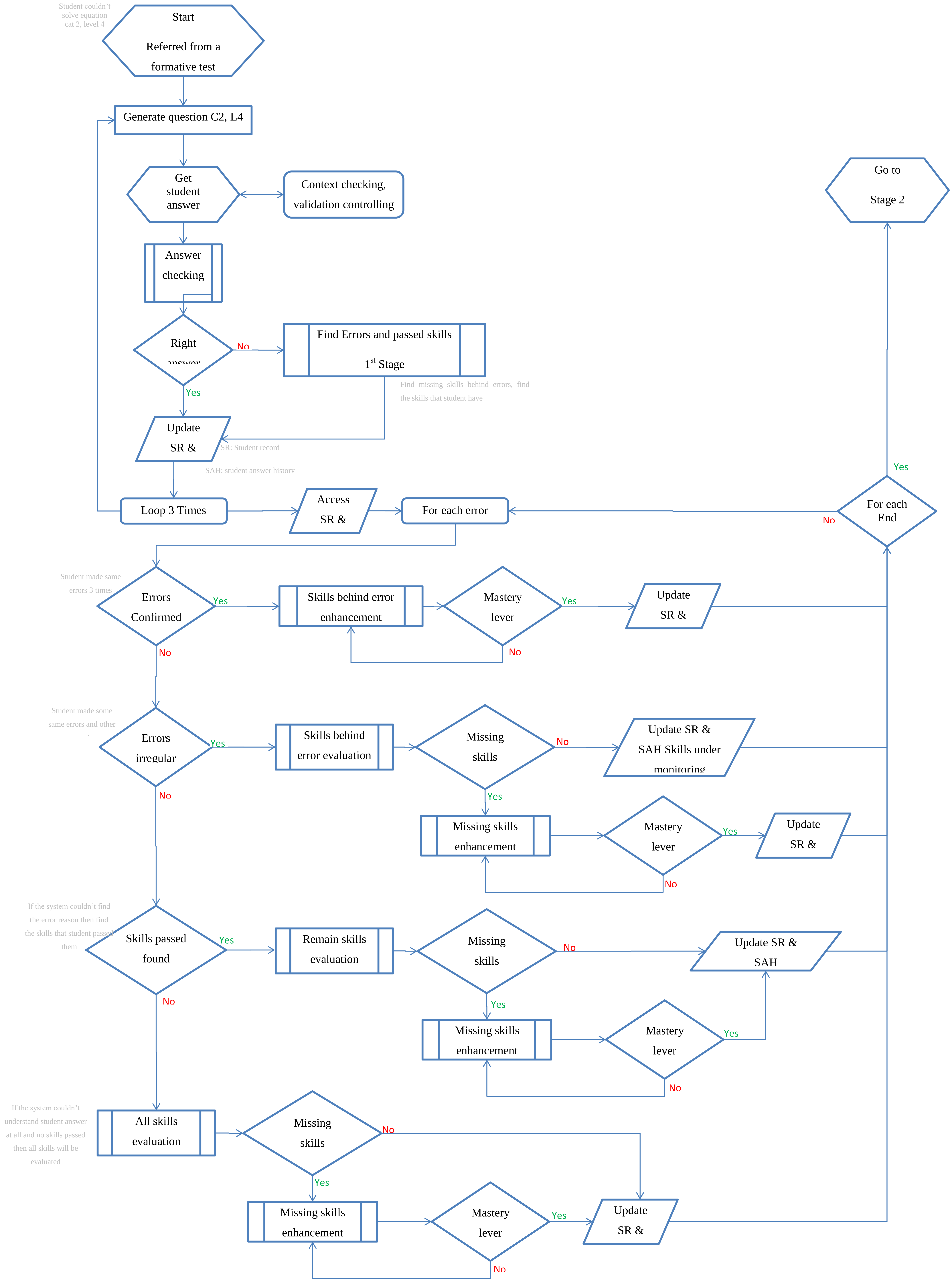
The overlay model in an e-diagnostic system works in conjunction with the student model to enhance the system's adaptive capabilities. The overlay model maintains a dynamic representation of the learner's knowledge state, which is continuously updated, based on the learner's interactions with the system. This model helps to:

1. Personalise the learning experience by dynamically adjusting the type and difficulty of content presented.
2. Provide real-time feedback and hints based on the learner's performance.
3. Adapt the remedial paths dynamically as the learner progresses.
4. Analyse errors - while the student model identifies gaps, the overlay model updates the learner's knowledge state.
5. Assign remedial pathways - the overlay model helps tailor the learning path by providing feedback based on the learner's preferences and past performance.
6. Evaluate the learner's progress and skill-level – the overlay model supports and affirms the student model in this process.

As a result of these processes, the overlay model also helps to establish whether the learner is ready to progress or requires further support. The following chart illustrates the relationship between the current E-diagnostic system components.


Student
model
Remedial
Path
E-
Diagnostic
system
Overlay
model

Appendix (12): Stage One algorithm



Appendix (13): Stage two algorithm