HANDHELD TECHNOLOGY FOR FACILITATING NEONATAL RESUSCITATION PERFORMANCE IN IMMERSIVE LEARNING ENVIRONMENTS

KHALID AZIZ

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by

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ABSTRACT

This thesis describes the rationale and development of software for a handheld computer for assessing neonatal resuscitation training in accordance with international protocols.

Immersive learning environments (ILE) are educational experiences, simulated or real, during which knowledge, skills and behaviours are enhanced for both individuals and teams. ILEs, based on constructivist learning theory, facilitate learning through experience, interaction and dialogue. Simulated and real neonatal resuscitation training are specific ILEs. Would a handheld computer contribute to evaluation and reflective dialogue, thus enhance knowledge construction in ILEs?

Following a review of the literature on ILEs and handheld devices during neonatal resuscitation training, software with a graphical user interface and paper output was developed for a handheld computer to facilitate recording of key events for the purpose of facilitating debriefing. This thesis describes the theories underpinning such a tool, the development of a working prototype, and procedures that might be followed to effectively evaluate the resultant device.

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I would like to express my heartfelt thanks to all those who supported me through this project. They include my family for their patience support and endless cups of tea while I worked on this project; my supervisors, Drs Barter, Shulz, Molgaard and Sharpe, for their advice and patience in supporting me through this dissertation; Drs. Rick Cooper and Wayne Andrews, who gave me the time and space to complete the courses; the Janeway Foundation, who supported the software development financially; the NRP Instructors who provided feedback on the device; and Mark Brophy, engineering student, for working diligently on the software, and implementing my repeated requests for design alterations.

I would like to add a special thank you to Dr. Sharpe, for the time he spent carefully reading and commenting on repeated drafts. Much of his advice has, and will be translated into real-life learning experiences of numerous learners in the field of neonatal resuscitation.

I would like to dedicate this thesis to all the babies, practitioners and educators who made the process of coming into this world so much safer for all of us.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ILE	immersive learning environment
AAP	American Academy of Pediatrics
DBR	design-based research
GUI	graphical user interface
ILCOR	International Liaison Committee on Resuscitation
NETC	Northwest Educational Technology Consortium
NRP	Neonatal Resuscitation Program
OSCE	objective structured clinical examination
PDA	personal digital assistant
SDK	software development kit
UCD	user-centred design
USB	universal serial bus

CHAPTER ONE

INTRODUCTION

This thesis outlines the theory behind, and development of, a handheld device designed to aid instructors and learners record the sequence of events during the real or simulated resuscitation of a newly born baby. Development is based on a constructivist learning paradigm within an immersive learning environment. The focus is on the development of the educational software and a held device for resuscitation training. The thesis concludes with a discussion of proposed ways to evaluate the resultant device, and includes preliminary user observations of the prototype software and hardware.

Neonatal Resuscitation

Resuscitation is the medical process for bringing a patient whose breathing or circulation has failed, back to stable lung and heart function. In the newly born baby, the transition from intrauterine to extrauterine life is often complicated by failure or delay in establishing breathing and circulation: neonatal resuscitation facilitates this transition. Neonatal resuscitation focuses on the basic and immediate necessities of life, breathing and circulation, while maintaining other body systems, like temperature control.

The Neonatal Resuscitation Program (NRP) of the American Academy of Pediatrics and American Heart Association (AAP, 2006) is the educational tool of choice for Canadian health care professionals who are training to resuscitate newly born babies (Health Canada, 2000). The knowledge, skills and behaviours required for NRP are assessed using a written exam and a simulated neonatal resuscitation scenario, otherwise known as a "Megacode". During training, the Megacode is evaluated using a validated checklist, the Canadian NRP Megacode Assessment Form (Canadian Paediatric Society, 2006), adapted from its American equivalent (AAP, 2006). The checklist is a paper-based tool, used by instructors to verify their students' understanding of the neonatal resuscitation process.

Constructivism and Immersive Learning Environments

Immersive learning environments (ILEs) are a broad concept derived from constructivist learning theory, and embracing experiential learning and reflection. During an ILE, the learner receives real or virtual inputs that challenge their existing knowledge; the experience includes subsequent dialogue and reflection, such that new knowledge is constructed. The term, ILE, is most often utilized in the computer software development domain, largely related to computer-based and virtual simulation. ILEs have rarely been associated with the medical domain. For the purpose of this thesis they have been deliberately adapted to distinguish the *process* of learning by immersion from the *method* of learning (which, in this case, is simulation or real-life experience).

Facilitating and evaluating ILEs of increasing complexity can be a daunting task for educators. A number of tools may be used to support teaching and learning, including the paper-based checklists, video recording, verbal feedback, and handheld devices.

Handheld computers and smartphones

Handheld computers and smartphones are being used increasingly by health care professionals. In most cases, in addition to their use to communicate, they are used to access data and libraries. In the minority of cases they are used to log or evaluate learning experiences. This thesis describes a specific type of data logging that can occur in real-time using a handheld device as an instructional aid.

A software prototype was developed for this thesis that resides on a Pocket PC handheld computer. Programmed with internationally accepted neonatal resuscitation algorithms, the device allows an instructor to record events in real time. The time-stamped data can be uploaded to a desktop or laptop computer for display or printing. The output, a time series chart, reflects the course of the resuscitation, and can be used for both reflection and evaluation.

Handheld devices and neonatal training

The NRP Megacode is a simulated ILE, characterized by an initial brief, subsequent action, and eventual debriefing and feedback using a checklist. A premise of this thesis is that an electronic handheld device, with on-screen and paper feedback, will facilitate and enhance learning during neonatal resuscitation training. The software for the handheld device should measure and record the key steps required during a neonatal resuscitation simulation or Megacode, and present findings to the instructor and learner that will facilitate learning.

A sequence of software and hardware evaluations is proposed as part of this thesis that blends qualitative and quantitative enquiry, and uses focus groups, questionnaires, and a modified Delphi process to refine the program. Preliminary feedback from expert users will be presented.

Rationale and hypothesis

For the NRP instructor, evaluation of neonatal resuscitation performance is not without difficulty. As described in the NRP Instructor's Manual (AAP, 2006), the instructor must observe (and time) a multiplicity of tasks, ensure appropriate performance and sequence, and memorize or record every step to provide evaluation and feedback. A recording device may ease the stress: technological systems can automatically time (and, in simulations, "pause") events. They can receive inputs by telemetry, augmenting information that may not be available to the instructor, during and after the event has occurred. They can provide objective feedback, using a computer screen, video recording, or in the form of scores or charts. Hand-held technology may permit similar evaluations at short notice, without the need to prepare a room, staff and parents for audiovisual recording.

A software prototype will be described that allows an instructor to record events during a simulated neonatal resuscitation in real time. The time-stamped data can be uploaded to a desktop or laptop computer for display or printing. The output, a time series chart, reflects the course of the resuscitation, and can be used to facilitate the instructor-learner interaction.

The hypothesis is that a handheld device that specifically targets and measures relevant learner performance and feeds it back to the learner and facilitator, encouraging reflection, will support learning during simulated and, eventually, real-life neonatal resuscitation.

This thesis outlines the potential role of a handheld device in supporting facilitation of neonatal resuscitation training based on the constructivist paradigm and using immersive learning. It describes the development of educational software and proposes methods for evaluation.

Thesis Organization

Chapter Two of this thesis is a review of the medical and educational literature as it relates to constructivist learning environments and neonatal resuscitation. The primary sources were the University of Alberta and Memorial University medical and educational libraries and their electronic databases (ERIC, PubMed, and Sage), National Library of Medicine database and H.H. Wilson's Omnifile database. Secondary sources included web searches using both Google and Yahoo! search engines. A hierarchical abstraction model is proposed that links constructivism and neonatal resuscitation training through a concept of ILEs. A functional model is proposed of immersive learning environment domains in order to classify educational activities using methods such as simulation and virtual reality.

Chapter Three is an overview of neonatal resuscitation training and the activities that occur in the classroom, providing an understanding of the curriculum covered by an NRP instructor. Chapter Four describes prototype software for a handheld device designed by the writer to evaluate neonatal resuscitation within a framework of an immersive learning environment. Chapter

Five proposes how such a device might be evaluated, while Chapter Six provides a preliminary evaluation of the prototype by expert users (NRP instructors), with initial suggestions for improvement and testing. Finally Chapter Seven includes a summary of the thesis as well as conclusions reached based on the developmental process followed and the resultant device.

CHAPTER TWO

REVIEW OF THE LITERATURE

Before elaborating on neonatal resuscitation training formats, a discussion of the tenets of constructivism and the nature of ILEs may be helpful in setting the stage. This will be followed by reviews of simulation in resuscitation care, use of handheld devices in healthcare, and factors involved in evaluating resuscitation training.

Constructivism

Life is an immersive learning environment: in the broadest sense, this is true, particularly when one considers continuous learning experiences of healthcare professionals. The focus of this thesis and the concepts portrayed herein lie in the overlapping domains of teaching and learning. So, although the term "immersive learning environment" is used in practice, more accurately, one is referring to "immersive teaching and learning environments".

A search of the phrase "immersive learning environment" reveals no hits in *PubMed*, the US National Library of Medicine web-based database (US National Library of Medicine, 2010). There were a handful of hits related to "immersive learning" or "immersive environments" that refer to virtual reality, for example Vincent, Sherstyuk, Burgess and Connolly (2008), who trained medical students in mass casualty triage using head-mounted displays and computer simulations. A similar search of Wilson's Omnifile (H.W. Wilson, 2010), a database of publications in the fields of education, business, social sciences and the humanities, revealed 2 hits, none of which addressed the concept of an ILE, but related to, firstly, school-age classrooms and, secondly, learning through virtual social networking (Burgess & Caverly, 2009; Huff & Saxberg, 2009). A web search of Google (Google, 2010) and Yahoo! (Yahoo!, 2010) revealed multiple hits, mostly related to computer games and virtual reality, but some related to school-age and university classrooms. It is clear from these searches that the use of the term, ILE, is new to the medical domain: it may, however, serve important theoretical and practical purposes, supporting prevailing learning theories as applied to the training of health care providers.

During the early 20th Century there was a paradigm shift in learning theory from a behavioural instructivist approach (Watson, 1913), centred on the teacher as the source of knowledge, to a cognitive approach, focusing on the learner as the processor of knowledge (Elias & Merriam, 1980). Behaviourists like Watson denied the need to consider introspection or consciousness in human adaptation. With respect to the science of psychology: "Introspection forms no essential part of its methods, nor is the scientific value of its data dependent upon the readiness with which they lend themselves to interpretation in terms of consciousness" (Watson, 1913, p158). He "would take as a starting point, first, the observable fact that organisms, man and animal alike, do adjust themselves to their environment by means of hereditary and habit equipments" (Watson, 1913, p167). Cognitivism, however, recognized the importance of the mind and memory in human behaviour and learning, contesting the premise that humans learned solely through conditioning. Molenda (2008, p14) says of cognitivism that "learners use their memory and thought processes to generate strategies as well as store and manipulate mental representations and ideas", thus concepts such as critical thinking and metacognition are derived from cognitivist learning theory. In the second half of the 20th Century, the cognitive approach evolved into the philosophical concept that knowledge is "constructed" in the mind of the learner irrespective of the existence of an external reality (Kanuka & Anderson, 1999). Known as the "constructivist theory of learning", this approach encourages the presumption that all observations are subjective, there being is no objective "truth". This may, at first, give the perception of anarchy, but, in reality, it reinforces the need for interaction and dialogue for learning to occur, and knowledge to be constructed.

"L'Office québécois de la langue française", in its "grande dictionnaire" (dictionary of the French language) defines constructivism by quoting « la connaissance n'est ni une copie de l'objet ni une prise de conscience de formes a priori qui soient prédéterminées dans le sujet, c'est une construction perpétuelle par échanges entre l'organisme et le milieu au point de vue biologique, et entre la pensée et l'objet au point de vue cognitif » (L'Office québécois de la langue française, 2011). This quote, attributed to Jean Piaget, explains that knowledge neither originates from consciousness, nor is it copied from an external source; it is, however, continually constructed by exchanges between the individual and the environment.

Constructivism is based on two philosophical tenets. The first lies in the premise that there is no need for an absolute (or external) reality or truth: the important reality is internal, perceived in the human mind. The second, most relevant to learning, is that the mind interprets reality as a series of paradigms that, it believes, mirror external reality, and "constructs" knowledge by testing those paradigms during interactions with the external world (in other words, through experiences, dialogues, or reflection). The tested paradigms are reinforced if supported by the test, or modified based on the outcome of the interaction. In this way, knowledge and meaning are not transferred to the learner as bits of data; knowledge is "constructed" through interaction and dialogue.

Constructivism is now a dominant theory of learning. The theory was reinforced by the work of Jean Piaget (Harlow, Cummings, & Aberasturi, 2006), who theorised that children learn by constructing models of the external world from experiences that either reinforce or modify their internal models ("assimilating" or "accommodating" the experience).

One of the prerequisites of constructivism is the interaction (or dialogue). The nature of this dialogue has divided theorists. So-called "radical" constructivists focus on reflection, or internal dialogue, as the primary mechanism: an extreme view of this position would lead one to question the existence or nature of the real world. A more pragmatic view of this interaction was proposed by Vygotsky (Liu & Matthews, 2005), who promoted the importance of interpersonal dialogue, or "social" constructivism in learning: we learn by sharing experiences. This view may be vitally important when healthcare teams work and learn together.

Constructivist and Immersive Learning Environments

ILEs are the real-world correlate of the constructivist theory of learning. In these environments, learners test their existing knowledge by interacting with people or objects, and construct new knowledge by reflecting on the experience.

For the purposes of this thesis, I would like to propose a model for ILEs that outlines four different types of "classroom", based on whether the learning experience is in the physical world (external), or in the mind alone (internal), and the degree to which realism is presented to the learner (fidelity). This model may be of value to instructors who need to think about which ILE they will use, and how to improve its effect on learning.

Duffy and Jonassen (1992) described "constructivist learning environments". They proposed eight conditions that should prevail to enable learning through social constructivism. They were summarised and paraphrased in a web-based review by Chen (2000), who stated that:

> Constructivist learning environments: provide multiple representations of reality; use multiple representations to avoid oversimplification and represent the complexity of he real world; emphasize knowledge construction instead of knowledge reproduction; emphasize authentic tasks in a meaningful context rather than abstract instruction out of context;

provide learning environments such as real-world settings or case-based learning instead of predetermined sequences of instruction; encourage thoughtful reflection on experience; 'enable context- and content-dependent knowledge construction'; and support 'collaborative construction of knowledge through social negotiation, not competition among learners for recognition'.

Although originally intended for the school classroom, these conditions are equally relevant to all ILEs. In these settings, educators become facilitators, presenting learners with opportunities to test paradigms and share reflections. ILEs for teaching health care providers knowledge, skills and behaviours are exactly these opportunities; the neonatal resuscitation instructor becomes a facilitator in this situation, with the handheld device a tool to assist facilitation.

There is, however, another important dimension for ILEs: the balance between internal and external reality. This balance is particularly evident when the ILE is a simulation. As in a Shakespearian play, the participant must "suspend disbelief" to enable internal dialogue (Shakespeare, c1599). One might argue that it is this suspension of disbelief that is the key to effective reflection, rather than how true-to-life the simulation is.

Modern simulators are expensive, using high technical fidelity to portray real-life scenarios. "Fidelity", being an engineering term, reflects the realistic nature of the simulator output. Engineers view fidelity as a descriptor of the machine, whether physical, operational, functional, or motivational (Sasse &

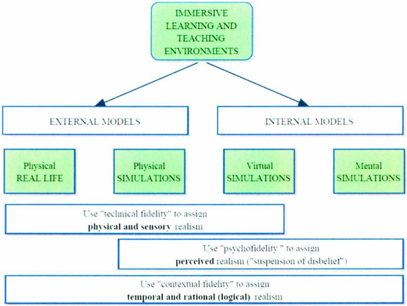
Johnson, 1999, p362). When viewed from the point of view of a neonatal resuscitation simulator, this fidelity refers to physical cues, such as visual, tactile, or auditory (Halamek, 2008). The constructivist might argue that engineering "fidelity" is not necessarily relevant to learning, as it is the internal dialogue, or perception of realism that is important. It may be preferable to use a concept that describes "perceived" fidelity or "realism" to measure how the mind interprets the realism of the ILE: to provide this mental correlate to technical fidelity, the phrase "psychological fidelity" (Halamek, 2008) or term "psychofidelity" (invented for this thesis) may be preferable. I would therefore surmise that ILEs with low technical fidelity might be constructed to have very high psychofidelity if learners are adequately briefed, and the experiences were relevant to their needs.

A third type of "fidelity" is proposed to complete the model. ILEs should make sense: actions should result in logical and temporally appropriate reactions. In the case of neonatal resuscitation, effective interventions should normally result in improvement in the simulated patient's condition within an expected timeframe. A proposed name for this type of fidelity is "contextual fidelity" – alternatives or subgroups to this concept might be "rational", "logical", "temporal", or "sequential" fidelity, all of which reflect the concept that context is key to the learner suspending disbelief. This logical sequence of events may be described using care maps or algorithms, and be captured and recorded using a time-stamped method, such as a checklist – or with a device programmed with resuscitation algorithms, like a handheld computer.

Thus ILEs could potentially be manipulated by facilitators, who can either adjust the "gain" on the technical fidelity (using high or low technology simulators), or turn up the "gain" on the contextual fidelity by presenting real-life and relevant scenarios irrespective of the technology. The consequence should be increased psychofidelity, suspension of disbelief, and perceived realism by the learner, who is then truly "immersed". The NRP Instructor must learn to manipulate the "gain" of a scenario to achieve learning objectives, particularly if high technology simulations are not available. Suggested tools include an effective brief, materials that mimic blood and secretions, realistic scenarios, etc. (AAP, 2011). A handheld device, as with video recording, would represent minimal interference in the immersive learning experience, functioning in ILEs with low or high technical fidelity or contextual fidelity, or, indeed the highest fidelity of all, real life!

Given the presumed importance of enhancing psychofidelity in ILEs, a theoretical model is proposed by the writer to encompass four overlapping types of ILE: (a) physical real-life, (b) physical (external) simulation, (c) virtual external (virtual simulation), and (d) virtual internal (mental simulation). These are represented in Figure 1. This model completes the definition of ILEs, recognizing that immersive learning occurs as much in the physical world as in the mind of the learner. It should be appreciated that these domains are not mutually exclusive, but a means of describing a variety of ILEs without referring to the relative contributions of psychological, contextual and technical fidelity.

Figure 1. Diagrammatic explanation of four types of immersive learning environment and their relationships to internal and external modelling as well as to technical fidelity versus psychofidelity versus contextual fidelity.



Physical real-life events

Real-life events may be viewed and utilized as ILEs. Technical and contextual fidelity is maximized, and no suspension of disbelief is required. However, knowledge construction can still be facilitated and enhanced as if one were in a simulation. Research shows that debriefing after real resuscitations has positive outcomes for participants (Dine, Gersh, Leary, Riegel, Bellini & Abella, 2008; Edelson, Litzinger, Arora, Walsh, Kim, Lauderdale, Vanden Hoek, Becker & Abella, 2008). Their results reaffirm that real-life is a very effective learning experience, with high technical, contextual, and psychological fidelity. The tools used to reinforce learning in simulations, like debriefing checklists and video recording, may be easily transposed into real-life learning, and would be expected to enhance that learning.

Physical simulations

These ILEs are central to neonatal resuscitation training and come with varying technical fidelity. NRP Megacodes are standardized simulated resuscitations during which the learner is evaluated using a validated checklist tool. Megacodes, for most learners and instructors, tend to be low technical fidelity and vary in psychofidelity – most classrooms and institutions do not presently have access to the high technical fidelity manikins designed for use in health training simulations. For example, Alberta, Canada, with NRP instructors in approximately 50 perinatal centres, has no centre routinely using high fidelity simulation for NRP training (personal communication, Dr. Khalid Aziz, Chair, Neonatal Coordinating Committee, Alberta).

During physical simulations, contextual fidelity is usually provided by the instructor guiding the student(s) through the scenario with verbal prompts in low technology environments, or with computer-controlled actuators in high technology environments. The superiority of a human providing cues and context during simulated neonatal resuscitation over a high fidelity machine (or vice versa) has not been adequately studied (Aziz, 2010). There is some suggestion that high fidelity simulations may be preferred by learners but the quality of studies does not allow for firm conclusions.

Virtual simulations

These virtual ILEs are exemplified by computer-based learning systems, of varying technical fidelity, ranging from text-based problem solving to anatomically correct three-dimensional surgical virtual reality simulations with haptic sensors that allow operators to "feel" tissue.

Interactive video-assisted or web-based learning might be included in this category. These simulations are mentally generated by interaction with a computer or virtual sensory system. With suspension of disbelief, the psychofidelity can be high. In addition, virtual reality can present the learner with very high levels of technical and contextual fidelity.

Mental simulations

This ILE overlaps with all three previously mentioned types, depending on the degree of suspension of disbelief, or psychofidelity. Protagonists of Piaget would argue that this is, in fact, the only model that we experience, as our minds cannot have perfect replications of the external world. Instead we have a conceptual model constructed from our experiences and pre-existing paradigms. Von Glasersfeld described this as "radical constructivism", such that "knowledge can be built up by individual knowers within the sensory and conceptual domain of individual experience and without reference to ontology" (Steffe & Thompson, 2000, p4). In this framework there is no absolute truth, and paradigms are always open to question by new experiences.

Virtual internal ILEs include thought experiments, and learners placing themselves in imaginary scenarios, using internal reflection and external dialogue to test courses of action. Such experiences may be triggered by any form of case-based learning where the learner immerses themselves in the moment.

Three phases of constructivist learning

A further refinement in the definition of ILEs is the premise that, ideally, all constructivist learning experiences contain the steps of preparation (before instruction), action (during instruction), and reflection (after instruction). This series of events is essential to the constructivist process. Learners need to start with a basic set of knowledge, skills and behaviours that are either individual or team-related, which may be reinforced by a 'brief" (or may simply reflect their existing naïve, knowledge or experience). The subsequent "action" (simulation or real-life) allows them to experience and test knowledge, skills and behaviours to varying degrees. In the final phase, reflection may be internally mediated, or it may be facilitated by formal debriefing (Dreifuerst, 2009). Given the above, and in the educational sense, I would define an immersive learning environment (ILE) as:

> "an event experienced by an individual or team with the primary and/or secondary purposes of improving knowledge, skills, or behaviours, and of preparation for similar future tasks. ILEs may be planned, spontaneous, or

serendipitous, but do, however, always involve a preparation, action, and reflection. Simulated ILEs may be physical, virtual, or imaginary (mental), and of varying technical and contextual fidelity. Increased perception of realism (psychofidelity) during simulation requires suspension of disbelief, and is facilitated by realistic and timely consequences of actions."

Using abstraction hierarchy (Lind, 1999), parallels may be drawn between constructivist learning theory, ILEs, and the NRP simulation, all of which contain the same three phases of learning. Table 1 shows the three hierarchies of the learning model being studied in this paper, with the phases of learning running from left to right. The highest abstraction is constructivist learning theory, where a paradigm exists, is tested, and either assimilated or remodelled. The middle level is the ILE, a type of constructivist learning environment where there is preparation, (inter)action, and reflection. The lowest level is the neonatal resuscitation training experience, where there is prior knowledge and experience, a Megacode experience, and a debrief (or feedback). The model has remarkable symmetry: other hierarchies may be added to complete the model, such as the evaluation and assessment tools for each phase, or characteristics of the participant or facilitator.

How does this all relate to reality? For the NRP instructor, evaluation of neonatal resuscitation performance is fraught with difficulty. As described in the NRP Instructor's Manual (AAP, 2006), the instructor must observe (and time) a multiplicity of tasks, ensure appropriate performance and sequence, and memorize

Table 1. Drawing parallels between constructivist learning theory, immersive learning environments, and neonatal resuscitation training.

	BEFORE	DURING	AFTER
Constructivist learning theory	Existing internal paradigm	Paradigm is tested through interaction with external world	Paradigm is strengthened or modified based on outcome
Immersive learning environments	Existing individual or team knowledge, skills or behaviours	Real or virtual interaction with a planned, spontaneous, or serendipitous experience	Reflection and dialogue is facilitated to reinforce learning and action in future experiences
Neonatal resuscitation training	Prior learning (knowledge and experience) in neonatal resuscitation	Performance of a Megacode	Review, feedback, and debriefing

every step to provide evaluation and feedback. A written checklist assists in this evaluation but is limited to the nature of the scenario, and inadequately accommodates time measurement. Scenarios may vary widely and not fit a particular paper checklist. On the other hand, technological recording systems can automatically time (and, in simulations, "pause") events. They can receive inputs by telemetry, augmenting information that may not be available to the instructor. They can provide objective feedback, in the form of scores or charts. Video recording has shown that, in real-life, neonatal resuscitation does not always follow the algorithms recommended in NRP (Carbine, Finer, Knodel & Rich, 2000): hand-held technology may permit similar evaluations without the need to prepare a room and staff (and parents, in real life) for audiovisual recording.

Computers and immersive learning environments

Computer assisted learning has been touted as an ideal format for constructivist learning which, by its nature should be both facilitated and self-directed (Herrington & Standen, 2000; Tam, 2000). A number of instructional principles that operate during computer assisted learning derive from constructivism. Murphy (2003) summarized these on a website from an original text by Jonassen (1991):

Learning should be relevant;

Instructional goals should be consistent with the learner's goals;

Cognitive demands and tasks in the learning environment should be consistent with cognitive demands and tasks for the environment for which the learner is being prepared.

Teachers' role is to challenge the students' thinking;

Students' ideas should be tested against alternate views through social negotiation and collaborative learning groups; and

Educators should encourage reflection on the learning process.

The implication for this thesis is that a handheld device that specifically targets and measures relevant learner performance and feeds it back to the learner and facilitator, encouraging reflection, should be strongly support learning in the constructivist paradigm.

Simulation and neonatal resuscitation

Physical simulations are a type of ILEs (see within Figure 1), characterised by artificially created scenarios designed to suspend disbelief and allow participants to act out events at varying levels of technical, psychological and contextual fidelity. Neonatal resuscitation training in North America has embraced simulation as a means to teaching and evaluating learners (NRP Update, 2009).

Evaluating simulation

Simulation in the health care industry has become "sexy", with a massive expansion in availability of high technical fidelity tools (Campbell, Barozzino, Farrugia & Sgro, 2009) (and limited utilization because of both capital cost and the cost of human resources). A number of computer controlled manikins are available on the market that simulate the signs of a patient requiring resuscitation and that allow learners to test their knowledge, skills or behaviours. Examples in Canada include SimNewB©, manufactured by Laerdal, Norway, and S3010 Newborn HAL® Mobile Team Trainer (Gaumard, USA). An important question for educators and the health care industry is whether simulation-based training makes any difference to learner, patient, or system outcomes – more study is needed to clarify this question. Three systematic reviews of this very question were performed by the International Liaison Committee on Resuscitation (ILCOR, 2010) that concluded some benefit from simulation in the classroom, but insufficient evidence that clinical outcomes were changed.

Kirkpatrick (1994) elegantly outlined a systematic process for evaluating educational programs by defining four distinct outcomes: (a) reaction, (b) learning, (c) transfer, and (d) results. These evaluations should not be confined to quantitative studies, as qualitative evaluation is very relevant to the processes of learning and teaching.

NRP could be evaluated using Kirkpatrick's process. "Reaction" represents the perception of the educational program by participants. Learners may be queried on subjective perceptions such as value, confidence, and effectiveness. NRP course evaluations fall in this domain, as well as learners' perceptions of their knowledge, skills and confidence after training. Reaction is vital to an effective educational experience, as adult learners are encouraged or discouraged by how important and relevant they feel a course is to their own goals and objectives.

"Learning" in Kirkpatrick's model represents the subjective or objective measures of whether learning happened, best represented by the pretest-posttest assessments. This is a common method to evaluate course outcomes, being easy to administer, validate, and reproduce. In NRP we have a written exam and the Megacode.

"Transfer" relates to measured changes in practice as a consequence of an educational program, and to outcomes that are distant to a training event. It is important to know whether what is learned in a course translates into practice. It may be, however, quite difficult to measure and often requires longitudinal study and future observations. Difficulty measuring distant outcomes may be compounded by the infrequent and unpredictable need for neonatal resuscitation.

Lastly, the most challenging aspect of Kirkpatrick's model is the "results" phase. Although patient outcomes are the most important outcome of healthcare education, they are infrequently studied and measured, particularly with newer educational technologies (Curran & Fleet, 2005). Patient outcomes are the "Holy Grail" of educational research, and should be considered whenever a new, resource intensive, learning intervention, such as NRP or simulation, is widely proposed. Unfortunately, to date, literature searches revealed that no good prospective studies have been done investigating the clinical benefit of NRP training on the clinical outcomes of babies (ILCOR, 2010).

In an evidence review of the medical literature by the International Liaison Committee on Resuscitation (2010), all controlled studies involving teaching resuscitation to health care providers using simulation were reviewed by three separate authors (Khalid Aziz, Lou Halamek, and Jane McGowan, all members of the AAP Neonatal Resuscitation Program Steering Committee). Databases scanned included PubMed, EMBASE, Cochrane, Scopus and Omnifile. Studies were included if they related to resuscitation and compared simulation-based and non-simulation-based training, regardless of level of technical fidelity. The reviews included adult, pediatric and neonatal resuscitations. One reviewer (Aziz, 2010) categorized studies by Kirkpatrick level, virtual versus real, and adult resuscitation versus neonatal resuscitation. There were 37 relevant articles published up to February 2010. All studies were limited in quality: particularly noteworthy was the absence of primary outcome measures and/or power analyses for those primary outcomes. Studies focussed on either physical or computer-based simulations. The outcomes of these studies fell into two categories. The first category encompassed educational outcomes (Kirkpatrick's "reaction" and "learning"), and represented the majority of studies. These studies essentially asked whether simulation training improved learning, as tested by learner or course outcomes. The second category, only three out of 37 studies, measured clinical outcomes ("transfer" or "results") by looking at changes in practice or patient outcomes – none of these included neonatal resuscitation, so no conclusion could be drawn as to whether simulation training improved the outcome of babies.

Five of the 37 studies reviewed looked at the educational outcomes of neonatal resuscitation training (as opposed to older patients). Three of them showed no improvement in learner outcomes when simulation was compared with controls (Cavaleiro, Guimaraes & Calheiros, 2009; Curran, Aziz, O'Young & Bessell, 2004; Kaczorowski, Levitt, Hammond, Outerbridge, Grad, Rothman & Graves, 1998). This neutral outcome was not surprising, considering that these studies were underpowered. Two studies appeared to be supportive (Campbell, Barozzino, Farrugia & Sgro, 2009; Thomas, Taggart, Crandell, Lasky, Williams, Love, Sexton, Tyson & Helmreich, 2007), suggesting that simulation training might improve learning during neonatal resuscitation courses. The conclusion drawn from this literature review was that simulated ILEs when used to teach resuscitation may have improved learner outcomes, but have not been shown to improve clinical outcomes.

Recognizing that ILEs include a post-event debrief, there is a subset of literature on debriefing that supports this activity in both real and simulated situations. Debriefing after both resuscitation and resuscitation training were also reviewed by the International Liaison Committee on Resuscitation in 2010. In this case two reviewing authors were in disagreement regarding the strength of evidence in support of debriefing as a learning tool. There was general agreement, however, that learners valued debriefing as a learning strategy. Again, few studies look at Kirkpatrick's higher levels, and the impact on patient outcomes, thus affirming an important knowledge gap.

Given the potential benefits of simulation and debriefing on learner outcomes, a tool such as a handheld device that facilitates observation and feedback may be beneficial in facilitating a simulated or real resuscitation. Further study would be required to validate and test such a tool. The next section reviews the evidence for the use of handheld devices in a variety of ILEs.

Handheld computers in healthcare

The hypothesis that handheld (computing) devices, also known as personal digital assistants (PDA) and smartphones, can be used effectively to observe and record events during neonatal resuscitation is based on two factors: firstly, the use of handheld devices in medical practice, and, secondly, the use of evaluation tools to assess resuscitation performance.

Koope and Mosges (2002) reviewed the use of handheld devices studied in clinical trials, elaborating on the advantages and disadvantages of the technology, and concluding that handheld devices are useful in most circumstances, provide attention has been paid to software design and validation. However, reviews of the use of handheld devices in health sciences indicate opportunities for more diverse applications (Fischer, Stewart, Mehta, Wax & Lapinsky, 2003; Torre & Wright, 2002). Fischer, Stewart, Mehta, Wax and Lapinsky (2003) performed a systematic review of articles describing a variety of uses that included basic functions, access to medical literature, pharmacopoeias, patient tracking applications, medical education, research; business management, prescribing, and specialty specific applications (including family practice, pediatric, pain management, critical care, and cardiology).

Garrity and El Emam (2006), in a systematic review of PDA usage surveys identified 23 surveys of health care professionals. Overall adoption rates ranged from 45% to 85%, with higher rates among young physicians, residents, and those working in large, hospital-based practices. This, incidentally, is where most neonatal resuscitation and neonatal resuscitation training occurs. The authors also concluded that technology is no longer the barrier to the use of handheld devices.

More recently, Lindquist, Johansson, Petersson, Saveman and Nilsson (2008) performed an extensive review of the use of PDAs by health care personnel. They concluded that PDAs were viewed positively, and their use was considered both feasible and convenient. The heterogeneous studies pointed to usefulness, efficiency, satisfaction, and reduction of errors. They also noted that, of 48 reviewed articles, only six were randomized controlled trials, indicating that the evidence of benefit was weak. They concluded that further study was needed to evaluate when and how to best use the devices.

Searching randomized controlled trials related to PDAs in PubMed revealed investigation of a variety of uses. Leung, Johnston, Tin, Wong, Ho, Lam and Lam (2003) found PDAs superior to pocket cards as decision support tools for medical students engaged in patient care. The same group of investigators, however, discovered hurdles in the use of PDAs related to user preferences and lack of familiarity with the technology (Johnston, Leung, Tin, Ho, Lam & Fielding, 2004). However, one might question whether that would be a problem with today's technology-savvy students. One of the most interesting studies provided lay providers with a mobile device that provided decision support for resuscitation, the control being no training at all. In this study, Ertl and Christ (2008) showed that untrained providers performed better in the simulation with prompting from the handheld device. None of these randomized controlled studies specifically utilized the handheld device to observe, evaluate and provide feedback; they do, however, demonstrate that these electronic tools can impact learning and care in acute care situations.

Other studies that could be categorized as observational and subjective revealed that handheld devices are being used increasingly by healthcare providers. A survey by the library services at the University of Illinois at Chicago in 2004 showed that 61% of respondents used handheld devices (De Groote, 2004). The same year, a survey of pediatricians across the USA by Carroll and Christakis (2004) showed that 35% of pediatricians used a handheld device at work. Both these studies recognized that the majority of use was for the purposes of organization (largely scheduling), calculation, and storage of information (often proprietary reference material). More recently, the Internet connectivity of handheld devices and smartphones has expanded their capability and use, but also making access to information and communication, rather than self assessment and evaluation the primary role (Garrity & El Emam, 2006).

Aside from randomized controlled trials, several authors have observed the clinical use of handheld devices in both acute and ambulatory settings. Lapinsky, Weshler, Mehta, Varkul, Hallett and Stewart (2001) used focus groups to study the impact of the introduction of handheld patient management software to intensive care staff: Physicians and paramedical staff found them "convenient and functional" but suggested that more training was required in their use. The electronic format compared well with paper, but was felt to improve communication between caregivers. VanDenKerkhof, Goldstein, Lane, Rimmer and Van Dijk (2003) used handheld devices to record clinical data on pain management: using a "time and motion" design, they found that handheld devices were as efficient and "content-rich" as paper, with the added benefit of digitized data for audit and research. Use of handheld devices for clinical management in a burn unit showed that data entry was 23% faster than using a desktop computer, and that operators made 58% fewer errors (Lal, Smith, Davis, Castro, Smith, Chinkes & Barrow, 2000).

The educational use of handheld devices has largely been confined to evaluation, essentially the recording or logging of performance. A number of studies show that residents can effectively record patient interactions, procedures, and critical incidents, thereby providing opportunities to evaluate training and improve curricula. Bird, Zarum and Renzi (2001) found that handheld devices resulted in more efficient logging of emergency resident patient care; whereas Fischer, Lapinsky, Weshler, Howard, Rotstein, Cohen and Stewart (2002) found that staff required more training to log reliably, even if the information could be used more readily. Three studies showed that gaps in training and in residency curricula could be exposed using data collected by handheld devices (Bent, Bolsin, Creati, Patrick & Colson, 2002; Engum, 2003; MacNeily, Nguan, Haden & Goldenberg, 2003). Of relevance to evaluating simulations and real-life events found in neonatal resuscitation, Schmidts described the effective use of a handheld device to evaluate an objective structured clinical examination (OSCE) (Schmidts, 2000): although the observations were subjective, feedback was positive on ease of use, rapidity of feedback to students, and time-saving. A similar study by Treadwell (2006) found PDAs to be as effective, and more efficient in time for evaluating OSCEs – preceptors perceived them to be superior to paper. Fox, Day, Griffin and Huckstadt (2007) described the development and testing of a PDA for health care provider training: they showed the PDA to be superior to paper and web-based logs for completion of data collection. In a literature review, a different group (Fox, Felkey, Berger, Krueger & Rainer, 2007) found improved data collection by pharmacists in 12 comparable studies.

Torre, Simpson, Elnicki, Sebastian and Holmboe (2007) showed that mini-clinical evaluations could be performed on medical students using PDAs – the tool was highly rated by both preceptors and students. Penciner, Siddiqui and Lee (2007) showed that medical students could log their own emergency department encounters on PDAs: unfortunately half the students never reviewed their evaluations when they were made available on-line, and only one out of six found the process beneficial. The inference was that, as adult learners, this evaluation tool was not useful. One would expect that the more immediate feedback that might be available on a handheld device following a simulated resuscitation would appear more valuable to the educator and learner: this hypothesis would require testing.

In conclusion, evidence from the literature points to the increasing use and acceptability of handheld devices by health care professionals. Much of this use relates to access to medical information and logging of workload. There is limited information on the use of handheld devices for evaluation, particularly during acute care interactions such as resuscitation, but available information is positive and supportive.

Design-Based Research

The development and evaluation of a PDA to facilitate neonatal resuscitation training in ILEs may be considered "design-based research" (DBR). DBR is a means of matching theory to practice – through the process of development of methods or instruments, one is able to advance new theories and test them: "there are times when one has to create something to explore its properties" (Schoenfield, 2006, p193). An ILE is a concept that brings together theories of adult learning and constructivism, and the PDA is a tool that works within this framework. Developing and evaluating the PDA is indeed a process of matching theory and practice.

What are the practical implications of DBR? Sandoval and Bell (2004, p200) stated "Design-based research simultaneously pursues the goals of developing effective learning environments and using such environments as natural laboratories to study learning and teaching." This exciting concept turns our classrooms into test tubes where educational theories react with real-life experiences, where constructivism is tested against the care of a sick baby, facilitated by computer-based tools.

The Design Based Research Collective (2003, p8) identified four promising directions for DBR in education: "(a) exploring possibilities for creating novel learning and teaching environments, (b) developing theories of learning and instruction that are contextually based, (c) advancing and consolidating design knowledge, and (d) increasing our capacity for educational innovation." Neonatal resuscitation training in ILEs is very much a novel field for which the use of handheld devices to augment learning and teaching has not previously been described. The educational theories underpinning this activity are being applied for the first time. The PDA and its utilization require further investigation and may, in the long term, bring us closer to understanding how individuals and teams learn during critical healthcare events. This project may be viewed through the lens of "design-based research", a methodology that has potential to bring new understanding to neonatal resuscitation training.

Summary

In this literature review chapter the concepts of the NRP Megacode as an ILE, and ILEs as constructivist learning environments, have been introduced and clarified. The process of learning has been broken down into three phases: the brief, the action, and the debrief. The literature on neonatal resuscitation training using simulation was reviewed, demonstrating significant gaps in current knowledge, but supporting the inference that simulation and debriefing may improve learner outcomes. The literature on the use of handheld devices by healthcare personnel was also reviewed, demonstrating this to be an expanding field, with a wide variety of potential uses, including the evaluation of critical events.

CHAPTER THREE

NEONATAL RESUSCITATION TRAINING

The previous chapter outlined the educational theories underpinning immersive learning environments and how they might apply to neonatal resuscitation training. The published evidence describing and supporting the use of handheld devices in medical education was also examined. This chapter focuses more specifically on neonatal resuscitation and how this relates to a tool that could be developed to facilitate training for this.

To develop an educational tool it is necessary to map the educational processes involved. It is proposed that six domains contribute to evaluation of neonatal resuscitation performance, each affecting overall evaluation and its usefulness. These are the standard of practice, the individual being evaluated, the setting in which the resuscitation occurs, the medium by which the resuscitation is observed and recorded, the tool used to evaluate performance, and the observer.

The standard of practice

In North America, training of health care providers in neonatal resuscitation of newborn infants is largely based on the Neonatal Resuscitation Program (NRP) (American Academy of Pediatrics and American Heart Association, 2006), which is the neonatal education program recommended by Health Canada (2000). The NRP, in turn, is based on best available evidence and expert consensus, in particular that outlined by the International Liaison

Committee on Resuscitation (Kattwinkel, Niermeyer, Nadkarni, Tibballs, Phillips, Zideman, Van Reempts & Osmond, 1999). As a result one looks to these sources to establish a standard by which providers are assessed. The NRP manual clarifies the basic knowledge, skills and behaviours required of a neonatal resuscitation practitioner: knowledge is evaluated by multiple-choice questionnaire, whereas skills and affective learning are evaluated by observed simulations or "Megacode". During a Megacode, an instructor is physically present, recording the performance of a pair of learners by completing a formal or informal checklist. The instructor then provides feedback once the Megacode is complete.

The Megacode checklist started as a list of over 100 fields, developed as part of a simulation study at Memorial University (Curran, Aziz, O'Young & Bessell, 2004). The checklist was compressed in a second study (Lockyer, Singhal, Fidler, Weiner, Aziz & Curran, 2006), and further developed using a modified Delphi process. It was then validated using an internet survey of NRP Instructors and observations of video recordings of simulated resuscitations by a number of instructor observers.

The resultant validated Megacode Assessment Form (Canadian Paediatric Society, 2006) has been in educational use in Canada since 2006. For the purposes of this study, it was converted into a time-sensitive template (Appendix A) that was used to code the basic algorithms in the PDA software. During the Megacode, individual items during resuscitation can be scored as (a) not done, (b) done incorrectly or out of sequence, or (c) done correctly. Certain items can be scored as occurring more than once.

The individual being evaluated

The NRP Megacode is based on the principle of instructors evaluating providers (either for first time learners, or during provider updates which occur every two years); these are usually providers who have just completed a self-learning module (the NRP Manual), as well as a written (multiple choice) exam. It is clear, however, that providers come with all levels of experience and expertise.

Individuals vary in their ability to retain knowledge, skills, and behaviours. Curran, Aziz, O'Young and Bessell (2004) showed that these three characteristics of learning were often poorly related in medical students learning NRP, and that there is therefore a clear need to introduce both objectivity and on-going evaluation to ensure that providers perform in all these areas. In addition, studies of retention of NRP knowledge and skills in both medical students and residents show a degradation of ability over several weeks or months (Kaczorowski, Levitt, Hammond, Outerbridge, Grad, Rothman & Graves, 1998; Levitt, Kaczorowski, Outerbridge, Jimenez, Connolly & Slapcoff, 1996; Skidmore & Urquhart, 2001). A simple system for on-going evaluation and feedback, such as a handheld checklist would facilitate provider evaluation in the field, as well as keeping a standardized record of learner performance.

The evaluative scope of the handheld tool has been deliberately limited to evaluation of the skills required for neonatal resuscitation. The review of the simulation literature at the inception of this project did not find a validated checklist for NRP provider behaviours. More recently, Thomas, Taggart, Crandell, Lasky, Williams, Love, Sexton, Tyson and Helmreich (2007) developed such a tool. They suggested that three additional "teamwork" domains require evaluation during neonatal resuscitation: management, leadership, and communication. It is becoming clear that teamwork during resuscitation is an important factor that contributes to effective care, and has its own set of knowledge, skills and behaviours (in addition to knowledge, skills and behaviours attributed to learners. In their study, Thomas, Taggart, Crandell, Lasky, Williams, Love, Sexton, Tyson and Helmreich (2007) concluded that even brief training in teamwork competencies improved task performance in later simulations. More research is required to evaluate and develop the most effective means of training and evaluating teamwork competencies. Future iterations of the software of the handheld device being proposed by this research could introduce validated evaluation tools for both individuals and teams.

The setting in which the resuscitation occurs

The NRP course and Megacode are unique settings, and are quite different from real-life. The challenge for institutions and instructors is to develop a means of assessing on-going performance and adherence to standards.

A significant advantage of a handheld evaluation device may be its applicability to both low and high technical fidelity environments. The PDA is simple, portable, and requires minimal setup. Most resuscitation training occurs outside expensive, high technology laboratories. It is also true of real-life resuscitations that the instructor needs minimal distraction from the important task of mentoring the learner. The PDA is unobtrusive and easily put aside if supervisory intervention is required.

Studies by Carbine, Finer, Knodel and Rich (2000), and Finer and Rich (2004) used video recordings to show that performance of resuscitation by experienced providers in real-life differed substantially from that recommended in the NRP text. An alternative to real-life evaluation might be high technical fidelity simulation as described by Halamek, Kaegi, Gaba, Sowb, Smith, Smith and Howard (2000). However, both video recording and high technical fidelity simulations require considerable organization and resources. For now, it is likely that most NRP training will continue to occur in low technical fidelity, simulated ILEs.

The interesting question relating to settings is whether evaluation tools designed for simulated ILEs can be transferred in to real-life ILEs. It is important to keep this question in mind during the development of the handheld device and its software. If all learning occurs "internally" the tools that support that learning should not differ substantially between simulated and real ILEs, or indeed physical, mental and virtual ILEs.

The medium through which the resuscitation is observed and recorded

The existing NRP Megacode is designed for synchronous face-to-face evaluations by Instructors. The instructor is required to observe and interrogate both visually and verbally while providers perform the simulation.

In addition to video recording, distant technologies have been used to evaluate the performance of NRP with varying levels of success. Cronin, Cheang, Hlynka, Adair and Roberts (2001) suggested that teleconferencing using video was an effective means by which one might evaluate a simulated resuscitation. With more discrete item analysis, Curran, Aziz, O'Young, Bessell and Schulz (2005) found that evaluation of effective bag-mask ventilation on a video screen did not correlate with face-to-face evaluation. In this circumstance a direct feed of ventilating pressure might have enhanced instructor performance.

The handheld device and software are primarily designed for face-to-face, synchronous learner evaluation. However, it is likely that this tool would be amenable to conversion for distant and asynchronous evaluations. A validation process, such as that described by Curran, Aziz, O'Young, Bessell and Schulz (2005) would be required to confirm this inference: instructors could compare their use of the tool in face-to-face and video recorded simulations or real life to evaluate the utility of the handheld device. In effect, a PDA device may be used regardless of the distance between the learner and the instructor.

The tool used to evaluate performance

Critical thinking is required to both perform and evaluate the complex tasks found in neonatal resuscitation. As an abstract concept made up of multiple complex steps, critical thinking is more difficult to evaluate than factual knowledge or skills, particularly when it relates to interactive systems like the human body and a resuscitation team. As a result, simplified, algorithmic simulations (Megacodes) have been used to evaluate NRP performance. Clinical simulations make students "interpret data, make decisions, and develop systematic plans of action" (Weis & Guyton-Simmons, 1998, p33). There are high expectations of an evaluation tool if it is to assess these multiple actions with respect to knowledge, skills, and behaviours. Therefore any initial prototype PDA device would be appropriately limited to the evaluation of skills.

Evaluation can be item specific or global. Murray, Boulet, Ziv, Woodhouse, Kras and McAllister (2002) and Boulet, Murray, Kras, Woodhouse, McAllister and Ziv (2003) validated tools for evaluating clinical simulations in both ways, which they described as "analytic" or "holistic". Both methods correlated well with one another and final score. The Megacode is very much an analytic tool, focusing on specific steps and interventions. The proposed prototype in this research mirrors this model. In future, holistic evaluation tools may be added to augment functionality (and usefulness) of the handheld device, in particular in the domains of teamwork.

Another important evaluation outcome is how students perceive their ability to perform. According to Bandura (1977), self-efficacy is an important determinant of learning outcomes and future practice. Curran, Aziz, O'Young and Bessell (2004) used both checklists and focus groups to evaluate confidence (self-efficacy), surprisingly showing poor correlation with knowledge and performance. Adding this dimension to an evaluation may also augment software functionality.

There is also a need to develop a tool that will provide a structure and scale to evaluation, so instructors and learners can discriminate strengths and weaknesses, and provide/receive constructive feedback. To create and validate such tools one needs to establish so-called "norms" within which experienced practitioners perform. Lane, Finer and Rich (2004) demonstrated just this in determining that time taken to intubate during resuscitation can be safely extended to 30 seconds (from the NRP recommended 20 seconds). Thus, practitioner performance is a moving target: although the Megacode checklist has significant content and face validity, more needs to be done to confirm its validity in the real-world. Development of an electronic tool that will observe resuscitation will provide new opportunities to validate the Megacode checklist itself.

The observer

Evaluation of NRP using the Megacode is based on instructors' analyses of performance. As a consequence the existing Megacode checklist has limited validity for peer- or self-assessment of performance in real-life, video-recorded scenarios, or simulations.

A handheld device could be used by a learner or practitioner to evaluate other learners or practitioners in both real-life and in recordings. Whether in real-time or asynchronously, the device will permit review of the steps of resuscitation. Ultimately, as technology becomes available, handheld devices might simultaneously record video images over wireless connections, allowing video feedback for debriefing and quality improvement.

Whatever the technology or medium, an observer is presently required to enter learner performance and annotate the checklist. In future, sensors in a manikin or in resuscitation equipment will be able to directly enter data into the handheld device, augmenting evaluation. Curran, Aziz, O'Young, Bessell and Schulz (2005) used such sensors in evaluating instructor performance, demonstrating an inability of instructors to agree on adequate ventilation using visual cues, and poor correlation with electronically observed ventilation.

Summary

The handheld PDA device containing prototype software being developed as a key part of this research will focus on learner skills described in the internationally accepted and validated NRP Megacode checklist. It is recognized that future iterations may add options for holistic evaluation of individual and team behaviours, direct interaction with the ILE, and asynchronous or distance learning.

The six domains of learning that potentially contribute to neonatal resuscitation training were proposed and reviewed, emphasizing the complexity of training for critical events in healthcare.

A tool that facilitates reflective practice should work as an intermediary between the learner and the instructor/observer/facilitator. It should ideally work in a variety of settings, real-life or simulated, face-to-face or distant, synchronous or asynchronous. It should confirm the timing and sequence of neonatal resuscitation, benchmarked against NRP algorithms. It should facilitate reflective practice in keeping with the prerequisites of an ILE. Can a handheld computer meet these prerequisites? The next chapter will outline the potential role of a handheld device in facilitating teaching and learning in during neonatal resuscitation training.

CHAPTER FOUR

A PROTOTYPE HANDHELD DEVICE

By this point, I have discussed (a) the theoretical constructs underpinning the Megacode; (b) a framework for evaluating an educational program or tool (Kirkpatrick, 1994); (c) the evidence that simulation impacts learning; and (d) the evidence that handheld technology is being used increasingly by health care professionals. This chapter describes the proposed software and respective hardware that will be used to facilitate learning during a Megacode using a hand held device.

Requirements will be specified and promising software and hardware presented. The final steps of software evaluation, however, require input from the wider community of computer experts and end users. The later process will be discussed in future subsequent chapters of this thesis.

Technological requirements

At the time of inception of this project, smartphones were in their infancy, and the predominant handheld device was the personal digital assistant (PDA or pocket computer). Considerable thought was given to the existing choices of Pocket PC (Windows®) systems and Palm®. This decision was taken in consultation with the software designer. As the task of data entry was to take just a few minutes with several data entry points, the proposed software design would: track performance of the Megacode in real time; focus on usability; allow grading of learner performance; time-stamp events; and produce a user-friendly graphic report

Given the ease of interfacing between personal computers operating Windows® and the "Pocket PC" systems, the decision to use these operating systems was made. Software was designed for the Pocket PC platform using Microsoft's .NET Mobile SDK (Software Development Kit available from Microsoft®). The software included the Megacode checklist, as well as a fast method of grading each task. Because it was intended to run on a mobile device in rapid real time, text data entry was not an option - radio boxes (indicating varying degrees of success) were used instead, with arguments derived directly from the NRP algorithm and Megacode.

Software was designed to be loaded onto the personal computer and PDA using a Windows installation package available on a CD-ROM. The process is simple and intuitive. Software requirements included the Windows XP or 2000 operating systems loaded with ActiveSync and .NET Framework 1.1 or higher (downloaded freeware from Microsoft®).

Two graphic user interfaces were designed: the first would appear on the PDA (see Figure 2), permitting data entry in real-time, the second on the interfaced personal computer, showing a graphical representation of the Megacode (see Figure 3). Data would be saved in time-stamped files that would be retrievable for later analysis. Once installed, users would only need to know how to save and retrieve files.

Software installation

Software installation requires Windows XP or higher. The desktop should already have ActivSync and .NET Framework installed. The installation CD-ROM has two installation programs: "Neonatal PPC setup" installs on the handheld device using the ActiveSync interface; "Neonatal Desktop setup" installs to the Program File directory of the desktop by default. Installation is simple and takes a few seconds.

User-Centred Design and the Handheld Graphical User Interface

User-centred design. The principles described in the design philosophy known as "user-centred design" (UCD) were used to develop the PDA graphical user interface (GUI). UCD is a process that recognizes the characteristics, needs and wants of the end-user during the development and evaluation of a user interface. Kontogiannis and Embrey (1997) describe UCD as requiring an understanding of the user, engagement of the user, and feedback from that user during the development process. In keeping with constructivist learning theory, the team developing a human-computer (or -engineering) interface requires (a) "a cognitive engineering approach to user requirements", (b) "user participation and communication processes", (c) "iterative design and review of operational needs" (Kontogiannis & Embrey, 1997, pp110-111): in this way, knowledge about the device is "constructed" by the team. UCD recognized the importance of human factors in engineering design, and the complexity of systems that require the interface of humans and machines. According to Kontogiannis and Embrey

(1997, p111) complexity is seen in four domains: "Dynamism of the system", "Highly interacting parts", "Uncertainty", "Risk". A neonatal resuscitation, simulated or not, certainly exposes both humans and machines to all four of these domains. Only by recognizing the expertise of the resuscitator (learner or instructor) as a user, can one expect to design an efficient and effective evaluation tool. The final development of the PDA software in this study will, however, not be complete until input and feedback from users have been included in the process.

Sutcliffe, Thew, De Bruijn, Buchan, Jarvis, McNaught and Procter (2010) summarized their UCD approach to the development of health services software for a visualization tool to support epidemiological research. They used a process of scenario-based design (SBD) to map the steps taken (Appendix I). Their team consisted of health care users and domain experts (statistical and visualization advisers). Each group, while focusing on their areas of interest, provided support and feedback to the other. Developing the handheld device for evaluating neonatal resuscitation required a similar process, with the clinical domain providing algorithms and scenarios, while the technical domain provided inputs, processing, and outputs – both processes flowing in parallel.

Graphical user interfaces. It is the human-computer interface that the NRP interacts with, and, in the case of the handheld device, this is an interactive graphical user interface (GUI) operated by the instructor. The handheld device has a touch sensitive screen that operates subroutines within the device programming which are either part of the operating system or part of the superimposed evaluation software. The second GUI is the personal computer screen that displays the recorded output for both the learner and the instructor. This output is operated by a keyboard, and the main interactions required are those needed to install, view, save, and print.

A search of "Graphical User Interface" (or "User-Computer Interface") and "PDA" (or "Computer, Handheld") in PubMed and Omnifile revealed limited information with respect to medical learners or evaluation of acute care skills. In a systematic review of user interface issues related to PDA-based decision support systems in health care (Lee, Starren & Bakken, 2005), display was considered an important interface issue (other important issues included security, memory, web browser, and communication). Display issues included the font size, color depth, and data entry. Silvey, Lobach, Macri, Hunt, Kacmaz and Lee (2006) held focus groups to identify problems with PDA displays: problems included font sizes that could not be read at arm's length, checkbox sizes that were too small to tap with a stylus, and radio buttons that could not be unchecked or left unchecked. Need for scrolling was also viewed as a problem with a preference for tabbed browsing. Many of these factors have been considered in the development of this NRP Megacode handheld device software. Silvey, Lobach, Macri, Hunt, Kacmaz and Lee (2006, p1096) also concluded that "Creation of customizable user interface components is required to provide appropriate collection of clinical data at the point of care". Such functionality could be built into future handheld devices as technology advances and screens can be modified to be user-specific.

The PDA Graphical User Interface

The PDA GUI in this research was primarily based on the steps of the NRP Megacode. The GUI allows the recorder start with observations of the pre-resuscitation equipment check. The timer can be started when the baby is born, and the resuscitation can progress from initial steps, to assisted breathing, and circulatory support. Each of six steps of the Megacode is tabbed at the bottom of the screen for ease of navigation, particularly if steps are done out of sequence. The six steps include the Pre-Checklist, Rapid Assessment, Initial Steps, Ventilation, Intubation, and Compressions, each with a standard screen (see Appendices C to H).

Pre-Checklist. During this step, the instructor observes the learner checking essential equipment and confirming their knowledge of their tools. This step may be part of the "brief" of an ILE.

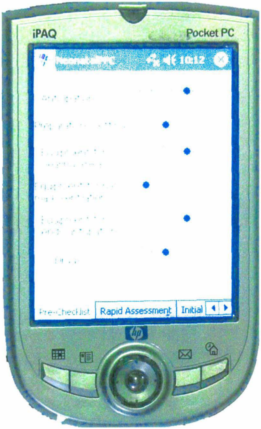


Figure 2. Image of pre-checklist screen on iPAQ® handheld device.

Rapid assessment. Once the Pre-Checklist is complete, the learner is ready to receive the newly born baby (or manikin). The instructor can activate the timer when the baby is born. At this point in time the learner must evaluate whether resuscitation is required. Most babies are well at birth and should not be resuscitated. Those who do require resuscitation should be identified so the learner can proceed to Initial Steps.

Initial Steps. The learner should normally spend up to 30 seconds drying the baby and making sure the airway is clear and open, while observing for normal or abnormal signs. This is a critical evaluation period in NRP. The instructor can score and time the learner through this time period. If the baby/manikin does not start breathing spontaneously, the learner should proceed to the Ventilation step.

Ventilation. If the scenario requires the learner to demonstrate assisted ventilation, this screen permits recording of critical, life-saving events. This section includes the essential steps required to ensure effective ventilation and correct for ineffective ventilation.

Intubation. This screen allows the instructor to record how well an endotracheal tube is placed, as well as assessing the roles of an assistant.

Compressions. This screen records the use of chest compressions and cardiac medications in babies who continue to require resuscitation despite adequate ventilation.

Each screen has 4 to 6 questions that are answered using check boxes on the touch screen. The instructor has 3 choices for each statement: (a) "Not done", (b) "Done incorrectly, incompletely, or out of sequence", and (c) "Done correctly and in correct sequence". A similar scale was used by Curran, Aziz, O'Young & Bessell (2004) in their evaluation tool and was subsequently introduced in the NRP Megacode checklist (Lockyer, Singhal, Fidler, Weiner, Aziz & Curran, 2006). When a radio button is activated (or deactivated) the electronic resuscitation record is time-stamped. If the instructor feels that redirection or instruction is needed during a scenario, there is an option to pause and restart the timer.

Once the exercise is completed, the time-stamped data are saved to a file on the PDA that downloads to the synchronized personal computer for the instructor and learner to view. Synchronization is automatic following connection using a universal serial bus (USB) port.

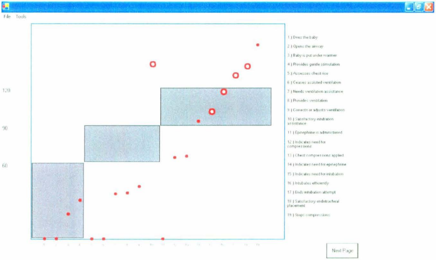
The Desktop Graphical User Interface

The desktop software saves the time-stamped data to a selected folder that is automatically opened by the program. Opening the data file with the desktop software shows the instructor and learner a graph of interventions (horizontal axis) against time (vertical axis), essentially plotting the course of the resuscitation (Figure 3).

Within a few seconds, the team are able to visually review the resuscitation against time, and see whether steps occurred correctly, incorrectly, out-of-sequence, or not at all. The instructor can debrief with a physical record of events, all viewed on one screen. The events are listed in chronological order, and 30 second epochs indicated on the chart as grey blocks.

The graphical representation of the resuscitation scenario has advantages over the traditional paper checklist. Firstly the whole resuscitation can be viewed on one screen. Secondly, the paper record is poor at recording events out of sequence, whereas the desktop GUI will immediately show this. Thirdly, timeframes are easily viewed on a chart, compared to a checklist (that may not be time-stamped). In addition graphical records can be visually compared, showing improvements in timing and sequence that are not easily visualised on a paper checklist. In this way, a second simulation of the same clinical scenario could be undertaken, and improvements in timing and sequence easily demonstrated.

Figure 3. Final report presented on the desktop user interface showing time on the vertical axis and flow of resuscitation on the horizontal axis.



Note: Rectangles indicate 30 second blocks. Red markings indicate events. Order of events is listed in the right margin.

Utility and PDA Feedback

During a simulated neonatal resuscitation scenario, the instructor will observe the team while operating the handheld device. After an initial briefing, and scoring the equipment checklist, the instructor will advise that the baby is born and will activate the timer. Using the tabs the instructor will follow the flow of the simulation, checking boxes as required, and indicating when the simulation has ended. At this point the file can be saved to the PDA.

Connecting the PDA to the desktop or laptop using a USB cable will automatically initiate ActiveSync and upload the time-stamped data to a file in the software directory. The desktop software, when opened, will offer to retrieve this file for display. The graphic interpretation of the simulation will be displayed on the desktop screen. Alternatively it can be printed as a paper record for review and debriefing.

This process matches the theoretical steps of a constructivist learning environment, which includes a brief or preparation, action, and debriefing and reflection. The PDA and desktop are designed to enhance that learning experience.

Summary

In this chapter the development of a handheld device with prototype software utilizing user-centred design has been described, the role of the device being to facilitate debriefing during simulated or real-life neonatal resuscitation.

The technology requirements have utilized readily available software products and employ simple and intuitive processes. Appropriate graphical user interfaces have been devised for the NRP Megacode along with a basic and easily used rating scale to be completed using a convenient touch screen. Such a device with this new software can potentially enhance feedback from the Megacode to the learner, and therefore enhance reflective practice. Such reflection is central to the concept of the Megacode as an ILE, and to the constructivist theory of learning.

CHAPTER FIVE

EVALUATING EDUCATIONAL SOFTWARE

The process of constructivism is implicit in each chapter of this thesis. We have seen how developing the human computer interface using team dialogue and shared iterations follows the principles of knowledge "construction" using dialogue and feedback. In this chapter we will see that evaluating educational software is akin to a constructivist learning process: One has a preconceived model of the software, tests it against some evaluation tool, and reflects on the result of the test, modifying the original model. As in user-centred design, a number of iterations may be required to improve on the model (Sutcliffe, Thew, De Bruijn, Buchan, Jarvis, McNaught & Procter, 2010). Piaget's described constructivism consisting of the « construction perpétuelle par échanges » (L'Office québécois de la langue française, 2011) which may be translated as "continual construction through interaction".

The Megacode is a complex series of interventions that requires a variety of knowledge, skills and behaviours to perform. It has been systematically evaluated and validated (Lockyer, Singhal, Fidler, Weiner, Aziz & Curran, 2006). The purpose of this chapter is to discuss an approach to evaluate the PDA software and GUI developed rather than the Megacode.

Software Evaluation

A search of the Education Resources Information Center (ERIC) database at the Institute of Education Sciences for the keywords, "Computer software evaluation" reveals an interesting pattern over the last two decades (ERIC, 2011). Searching all documents reveals a relatively constant output of articles relating to the topic (317, 305, 144, and 393 for each consecutive 5-year epoch from 1991). However, academic interest has grown exponentially, as indicated by limiting the search to peer-reviewed journal articles in English (revealing 0, 3, 72 and 337 articles respectively). This is clearly a rapidly expanding field of computer-assisted education, where the demand for valid and effective tools is growing.

The primary objective of this proposed software evaluation of the PDA device is to make a decision regarding the use of the developed software with a specific group of instructors and learners. An important goal would be successful implementation of the new software with associated achievement of curriculum outcomes.

In developing this paradigm a metacognitive approach to the software evaluation tool will permit analysis of the learning processes involved. In doing so, the software evaluation tool is viewed as the "technology". If this is the case, how does the technology perform? What learning processes do the evaluators utilize to reach their conclusions? Does the PDA software evaluation tool developed encourage higher order thinking and collaboration, or is it simply a mechanistic score sheet?

A web-based search for educational software evaluation tools revealed a number of sites expounding the virtues and values of a variety of evaluation methods. There are a number of differing approaches, often within the same tool.

A good starting point is the Northwest Educational Technology Consortium (NETC) (1995). The authors break the evaluative process down into the seven steps as shown in Table 2.

Table 2. Northwest Educational Technology Consortium seven steps to responsible software selection (NETC, 2005).

Step 1. Analyze Needs
Step 2. Specify Requirements
Step 3. Identify Promising Software
Step 4. Read Relevant Reviews
Step 5. Preview Software
Step 6. Make Recommendations
Step 7. Get Post-Use Feedback

This type of assessment is designed for use by a small team of users with some expertise in delivering the educational program and/or administrative responsibility for its use. NETC starts with a needs assessment (Step 1) followed by specifying requirements (Step 2). The needs assessment should include the needs of the learners, instructors, the course curriculum, and the learning environment. Once the requirements are set, a search should be made of available software (Step 3). Software documentation and (hopefully) independent reviews should be scrutinized (Steps 3 and 4). Software should then be installed and previewed (Step 5): note that software characteristics require review by learners, teachers, curriculum designers, information systems personnel, and administrators. Only after this comprehensive review can a recommendation be made (Step 6). Included in the recommendation should be the method of evaluation (Step 7), with feedback to the reviewers. It should be noted that some of these steps have been actually been taken and described through the initial stages of this PDA software development project.

Another software evaluation tool is that of Kerr (2004) from Brock University, who uses a content evaluation approach with Likert scales that could be used in parallel with NETC Steps 2 to 5. In Kerr's model (Table 3), the evaluator scores or remarks on a number of domains, with responses ranging from "excellent" to "poor" to questions regarding appropriateness, flexibility, and user response, etc. Care is required to be sure that the appropriate questions are being asked: one approach might be to ask experts to comment on the value of the individual questions themselves, rather than just answering them. This approach would result in improvement in the face and content validity of the tool with each iteration, improving the objectivity of the instrument. Subjectivity is compounded

Table 3. An alternative educational software evaluation tool (Kerr, 2004).

Educational Value and Pedagogy

1) Program is flexible for intended user(s)
2) Appropriate for classroom setting
3) Meets relevant educational needs
4) New terms are defined
5) Student has chance to correct errors
6) Help is available
7) Material is presented clearly and interestingly
8) Branches to new information, reviews old information and adjusts feedback
9) Follows progression of skills
10) Student response input is in a familiar manner
11) Student advances at appropriate speed
12) Criteria for advancing can be adjusted by teacher

Ease of Use

1) Clear, complete teacher documentation
2) Clear, complete student documentation
3) Instructions can be bypassed
4) Easy to exit from program
5) Easy to set up program

Effective Use of Computer

1) Computer presentation is more effective/efficient than other methods
2) Video display is pleasing and functional
3) Audio is effective
4) Other peripherals are employed when needed
5) Computer maintains useful information for records

as instructors evaluating the software may come from different backgrounds and professions, and may teach students with differing expertise and experience. It would be preferable to use a broad spectrum of instructors to complete this type of evaluation.

However, instructors and learners differ in cognitive styles (Riding & Douglas, 1993). An example would be the tendency of some instructors to be holistic, looking at the whole picture; while others might focus on analyzing minutiae – while each perspective is valuable, undue emphasis on one or the other might unbalance the evaluation process. An attempt was made in developing the NRP Megacode to merge both analytical and holistic evaluations of the student by giving the instructor freedom to evaluate not just whether an intervention occurred, but also its relative value (clinically and in time sequence) (Lockyer, Singhal, Fidler, Weiner, Aziz & Curran, 2006). A robust process needs to evaluate the flexibility of the PDA in the analytic and holistic dimensions, taking into account these differences in instructors who must look at both the individual steps of a process and the sum of its constituent steps, or the "big picture".

A technical approach to evaluation of the device would be to test reliability and validity by asking a number of users to submit evaluations of the same video-recorded Megacodes, as well as repeated evaluation of the same Megacodes (Gwet, 2010). This process was followed in the development of the Megacode itself, where a number of NRP instructors viewed and scored a library of simulated resuscitations (Lockyer, Singhal, Fidler, Weiner, Aziz & Curran, 2006).

One approach to evaluating that particularly brings balance to the evaluation process is the focused interview or facilitated focus group. The focussed interview evolved in the mid 1940's from a set of procedures developed at the Bureau of Applied Social Research, led by one of its faculty, Robert Merton (Merton, Lowenthal & Kendall, 1990). Merton, Lowenthal and Kendall (1990, p21) comment:

> The primary objective of the focused interview is to elicit as complete a report as possible of what was involved in the experience of a particular situation. Without detailed reports, the clinical data resulting from the interview will not encompass the qualities of range depth, specificity and personal context essential to an understanding of the nature and meaning of the responses.

Krueger and Casey (2000), in their guide to focus groups, outline the key components of this type of research. Focus groups provide qualitative data from people with characteristics relating to the subject being studied, obtained through directed and facilitated inquiry. They may be used primarily as a research tool, but also in the clinical, sociological and commercial domains for decision-making; for evaluation of tools, products or programs; for needs assessment, planning and goal-setting; for evaluation of quality, satisfaction, and employment practices; and for policy making and testing. Krueger and Casey (2000) recommend having a clear research design. Questions should be developed that are relevant to the audience and research question, using simple language and concepts. A predetermined categorization and sequence of questions may be used to maintain both focus and flow. The strategy for seeking participants should be transparent and relevant to the question. The investigators require two important skills, those of moderation, and those relating to analysis of the data (in this case, transcripts).

A common technique for analyzing information from transcripts, whether from interviews with individuals or groups, is "grounded theory". Glaser and Strauss (2009, p2) define grounded theory as "the discovery of theory from data systematically obtained from social research". As with the focused interview, grounded theory requires a systematic approach, starting with preparation. The investigator needs to minimize preconceptions so that artefacts, often but not always, text and be reviewed from a position of neutrality. Four stages follow: sorting into codes, grouping codes into concepts, categorizing concepts, and developing theories. Thus ideas arising from the transcript or artefact can be coded, with constant comparisons with new and old coded artefacts. Through and iterative process codes are sorted into concepts. Categories are based on theoretical or structural concepts that arise from the observations. It is from these categories that theories are proposed. Information from focussed interviews with end-users may be an invaluable tool in software development, and at very least could be used to improve evaluation tools.

Another method, particularly when dealing with expert instructors, might be to utilize the Delphi method or technique. According to Linstone and Turoff (2002, p3), "Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem." For structured communication to occur the group need to have a facilitated dialogue relating to that problem. The Delphi dialogue may occur around a paper tool, such as a questionnaire, that is circulated, improved upon, and recirculated until consensus is reached – a process known as a Delphi "exercise". It may also occur as a Delphi "conference" allowing real-time, almost synchronous dialogue verbally or using computer and social media.

Both the "exercise" and the "conference" require a monitor or facilitator. In the case of our PDA software, it would involve sharing the tool with a number of users (experts), modifying it using feedback, and sharing again until all are satisfied with the product. A questionnaire using a Delphi exercise may be preferable for busy clinicians and educators.

It is interesting that even the Delphi technique has parallels in constructivist design. Consensus is "constructed" through several iterations, facilitated by dialogue and reflection. The ability to apply constructivist theory to all learning systems strongly supports its validity.

Proposed Evaluation Template

The first sections of this chapter reviewed a variety of methodologies for evaluation that may be applicable to the handheld device: they range from evaluation of software, its development, utility and effectiveness using checklists, focus groups, and expert dialogue. It is proposed that several of these elements would provide a practical and informative approach to an evaluation of the PDA software and GUI, and the desktop GUI and outputs.

It is also evident from the examples of evaluating software discussed (and the most relevant processes within these) that some of the preliminary steps have already been completed for the work described in this thesis. The first steps in software development included the theoretical constructs and literature-based evidence discussed in initial chapters. Development of the actual prototype required interaction between two expert professionals, the software engineer and clinician instructor: as described by Sutcliffe, Thew, De Bruijn, Buchan, Jarvis, McNaught and Procter (2010) in their description of user-centred design (UCD), this process required mapping of the Megacode from both and engineering and clinical education perspective.

With the completion of the prototype, initial pilot testing would be completed by a group of expert users who, in addition to evaluating the software itself would provide feedback on the evaluation process. Ideally, this process would include a questionnaire, focus group, and Delphi conference, but in the very least through a questionnaire feedback process.

A demonstration to a group of instructors of the functionality of the prototype device would facilitate initial testing. A focus group of these instructors could be convened to identify the strengths and weaknesses of the system. This should lead to correction of any serious deficits. Themes from the focus group could be developed into a questionnaire, perhaps base on Kerr (2004), using a

Likert scale but adding the opportunity for expert commentary. This might include key questions, for example, on functionality and user interface (see Chapter 6).

Future evaluation might include prototype testing using multiple video recorded Megacodes, as done by Lockyer, Singhal, Fidler, Weiner, Aziz and Curran (2006) in their original Megacode evaluation study. This method also allows for validation of the device and testing of inter- and intra-rater reliability, as was done prior to development of the Megacode assessment checklist (Curran, Aziz, O'Young, Bessell & Schulz, 2005).

Also, as discussed in Chapter Two, the ultimate test of an educational program is its impact on output, or, in the case of healthcare, on outcome (Kirkpatrick, 1994). As Curran and Fleet (2005) pointed out, few electronic medical educational programs achieve this rigorous level of evaluation. Aziz (2010), in his systematic review of the literature on simulation education in neonatal resuscitation outlines the paucity of studies that measure patient outcomes. The ultimate test for the handheld device for assessing neonatal resuscitations would the one that evaluates the effect on neonatal resuscitation outcomes. Once all the software evaluation processes are completed, patient outcomes should be measured to demonstrate whether the handheld represents a step forward in newborn care.

Summary

Central to educational software evaluation tools are a facilitated dialogue between developers and users, permitting use of a feedback loop allowing continued improvement. Thus software evaluation is a constructivist process, enhanced by the three steps: an effective brief, an interaction with the tool, and facilitated reflection thereafter.

This chapter proposed that the "brief" be prepared by exposure of the end-users to the tools; the "interaction" to be documented by questionnaire, focussed interview, or Delphi process; and the reflection by reviewing that documentation. The ultimate long term evaluation of the device is whether its use contributes to improved outcomes in real-life. An initial evaluation phase (a pilot test) is described in the next chapter.

CHAPTER SIX

EVALUATING THE PROTOTYPE DEVICE

This chapter describes a pilot test of the proposed NRP PDA device. Results of preliminary testing and observations by expert users (NRP instructors) will be presented, followed by discussion of future directions.

Introduction

As we have seen in previous chapters the Neonatal Resuscitation Program (NRP) is the educational program of choice for the resuscitation of newly born babies in North America. Practitioners who train in NRP (also known as NRP "providers") are required to take an exam called the NRP Megacode that involves observed performance of a simulated resuscitation. Instructors who oversee this exam use a validated evaluation tool (the Megacode Assessment Form (basic or advanced)).

Constructivist principles suggest that a significant part of learning occurs as a result of reflection during a debrief of a simulation. The premise of this thesis is that a handheld device, programmed with the steps of NRP and the Megacode checklist, may facilitate reflection, and therefore learning, by providing feedback on provider performance.

The handheld device uses a graphical user interface that gives information on the timing and sequence of actions – this information may be viewed by the instructor and learner immediately after the simulation, either on a computer screen or as a paper printout. The information will be saved on the computer for later review. Software has been developed to run on this device that requires the initial evaluation of experienced NRP instructors before being used and evaluated with NRP providers on a much larger scale. This chapter outlines an initial evaluation process.

Methods

Four experienced NRP instructors were invited to provide feedback on the handheld device with preinstalled software and connectivity to a laptop computer. As this was a preliminary test of the software and interface for its face and content validity, the experts were not asked to install software or use the device in the classroom.

A checklist (Appendix H) was developed, adapted from Kerr (2004), which asked questions in three specific, but interrelated domains: education value and pedagogy; ease of use; and effectiveness of use. Responses were noted using a Likert scale where responses ranged from "excellent" scoring "5" to "poor" scoring "1". The instructors had the opportunity to provide comments on each question, as well as overall comments on the device and the test.

In addition, the experts were asked to answer three questions: "What do you like about this device and its interfaces (PDA and computer)?" "How might you improve this device?" "How might you use such a device in your classroom?" To ensure anonymity, expert names were not recorded, and results were aggregated for presentation.

Results

Three NRP instructors with several years of teaching experience and one new NRP instructor (less than 2 years' as an instructor, but with current clinical experience) agreed to a demonstration of the functionality of the handheld device and GUIs. The questions and scores are outlined in tables 4, 5, and 6.

Looking at the response to all the questions, 18 out of 22 statements were given an average Likert score between 4 and 5, indicating "very good" or "excellent" to be the most common responses, whether in the context of educational value and pedagogy, ease of use, or effectiveness of use.

The respondents found the device to be flexible for its intended use (average response 4), although one expert added "would like ability to add other parameters". It was appropriate for use during a course (average response 5), and met the needs of their student (NRP providers) (average score 4.5). One respondent commented that it "allows instructors to give accurate visual feedback". The language and terms used were appropriate for NRP (average score 5). The comments expressed that much of the value lay in the reliable documentation of events and the ability to feed these back in the classroom. A later comment stated "the visual part is very helpful". Respondents repeatedly made suggestions to include teamwork evaluation in the device.

The respondents expressed some concerns about the ability to troubleshoot the device and address incorrect entries (average scores 1.8 and 1.5, respectively, in the range of "poor" to "fair"). Although one respondent felt the interface was simple and no troubleshooting was required, the others made a number of suggestions for improvement, such as use of colour to code events, and more thorough orientation.

Although all respondents felt that the device presented options clearly (average score 4.5), they also suggested improvements to the interface, such as colour coding and tick boxes to explain reasons for participants taking incorrect actions.

The device was considered flexible for use in different scenarios (average score 4.8) and provided feedback in the classroom (average score 4.7). One respondent commented, "The device speaks to the steps of NRP but not necessarily the teamwork, communication, etc". It allowed recording of complicated scenarios (average score 4.8). Some concern was raised regarding software compatibility with institutional computer systems.

The users considered the device as being similar to current methods of recording (average score 5, two respondents), or verbally indicated that it was superior. They felt that the output reflected what happened in the scenario (average score 4.8), with the comment that the quality of the output may be dependent on the proficiency of the recorder.

The respondents felt that the device was easy to use from both the instructor's and the learner's point of view (average scores 4.3 and 4.5, respectively). It was particularly useful to have both a visual and temporal representation of the events that occurred. Again, some comments indicated concern about the ability of instructors, indicating that they may need assistance.

Lower scores occurred when describing the hardware functionality. They implied that simple operations like switching on and off and printing may represent a challenge as they had not been adequately oriented to the device. The respondents felt that careful instruction was required, and that more exposure to the tool, particularly for less computer-savvy instructors: "Anything can be learned, but it will take a little time."

The verbal comments to focussed questions were largely positive. The respondents liked the reliability and availability of feedback as well as the simple interface for data entry. They proposed its use to evaluate instructors.

A number of improvements were proposed. Colours could be used to clarify NRP steps, perhaps in a larger, tablet-sized screen. Video recording could be added. Bullets indicating types of errors could drop down from each entry.

Some comments indicated the need to simultaneously evaluated teamwork activities. Others indicated the benefit of sharing the output with groups of learners, or collating responses from whole classes.

When asked how they might use the device in the classroom, in addition to the above suggestions, a potential use was in quality improvement training to reduce sentinel events during resuscitation.

One instructor stated "would like to be part of a trial", another that there were "immense options".

Discussion of results

This pilot describes feedback from expert users with respect to a handheld device designed to collect and subsequently present the temporal sequence of events that occur during a neonatal resuscitation simulation (or Megacode). The purpose of the exercise is to improve the prototype prior to testing in the classroom.

The responses are largely positive and constructive, with respondents' suggestion that the device has promise. They suggest a number of domains for improvement.

Before discussing the benefits, it may be worthwhile exploring the anxieties expressed by the instructors with respect to the hardware. There were a number of comments that related to whether difficulties may arise in use, for example starting up, shutting down, printing, etc. Some of this related to the varying familiarity of the instructors with computer technology, and some to the quality of the orientation. It should be recognized that, as with any constructivist learning environment, teaching instructors to use educational tools requires an adequate brief, an opportunity to interact, and facilitated debriefing: these instructors are clearly expressing this need.

The interface was well accepted by the instructors, both for input and for output. They unanimously described it as being as good, if not better, than existing methods. They even suggested improvements, such as drop-downs and colour-coding. They were technologically aware enough to realize that the iPAQ® could be replaced with an iPad®, removing the need to have a second computer to display output (and introducing the possibility of video recording).

Another computer functionality that they felt was missing were help and troubleshooting screens. These could be added to the next prototype.

The output was perceived as beneficial for teaching and learning, even though they did not discuss or mention constructivist learning principles. One might accept that experienced instructors are intuitively aware of the benefits of facilitated reflection on a learning experience such as a simulation.

It is interesting that the instructors repeated commented on the benefits of this device for group learning. We are becoming increasingly aware of the importance of teamwork and human factors in healthcare (Halamek, 2008). The facilitation of competencies, such as, leadership, communication, and resource utilization may be enhanced by recording events that were either effective or deficient in these respects.

The instructors proposed interesting and exciting additions such as video recording, and projection for group feedback. They postulated a repository of electronic data that would allow both class and instructor evaluation. One instructor suggested using the device as a quality improvement tool to detect deficiencies in training that could be reinforced to prevent adverse events.

Conclusion

In conclusion, the device was constructively evaluated by four experts (NRP Instructors) who were largely positive about the utility and benefits of the device. They were anxious about the use of the hardware, but appreciative of the interface. They had a number of suggested improvements that need to be included in the next version. They felt that the technology needed updating. They were excited about the prospect of using this device, both as a research tool and to facilitate learning. I conclude that they gave the device a pass, conditional on a number of upgrades and subsequent evaluation of its utility in the classroom.

Table 4. Results section A: Educational Value and Pedagogy. Results of questionnaire administered to four expert users following a demonstration of the functionality of the handheld device.

A. Educational Value and Pedagogy	Average score (range)	Comments
1. The device is flexible for your intended use (recording Megacode performance)	4.0 (4)	Would like ability to add other parameters. It is a major improvement from having to quickly scribble a not on the testing sheet.
2. The device is appropriate for use in an NRP course	5.0 (5)	Yes, it is more than appropriate as it will help us give more appropriate feedback. Allows the instructor to give accurate visual feedback.
3. The device meets relevant educational needs of NRP providers	4.5 (4-5)	Ideally the final report would have axes reversed so more intuitive and be modifiable. Would like more than tasks recorded. Communication Teamwork etc.. Comment box to give record to participant
4. The language and definition of terms is appropriate for NRP	5.0 (5)	
5. The device allows you to correct erroneous data entry	1.8 (1-4)	Device allows you to correct or change data. Difficult to know why correction made? – perhaps tick boxes beside to remind why, i.e. inadequate ventilation (overdistension, or poor seal, or wrong pressure)
6. The device has help or troubleshooting options	1.5 (1-3)	Simple interface, none required

Table 4 (continued). Results section A: Educational Value and Pedagogy. Results of questionnaire administered to four expert users following a demonstration of the functionality of the handheld device.

A. Educational Value and Pedagogy	Average score (range)	Comments
7. The device presents options clearly	4.5 (4-5)	Would like options colour coded so initial steps yellow, next orange, etc
8. The device provides feedback in the classroom (*3 responses only*)	4.7 (4-5)	Allows instructor/student to discuss and give feedback. The device speaks to the steps of NRP but not necessarily the teamwork, communication, etc. Yes, if healthcare institute has software capability.
9. The device is flexible for use different types of scenarios	4.8 (4-5)	Yes, from simple to complex. Ideally there would be tap for special manoeuvres (gastroschisis, bag, etc.).
10. The device allows recording of complicated scenarios	4.8 (4-5)	Yes – with clear identification of what requires attention.
11. The input is similar to methods of recording that are currently used (*2 responses only*)	5 (5)	Simulation has a hard copy which allows you to chart, including exactly what problems there were. No it isn't; it is much better. Simulation has ability to record and print on hard copy
12. The output reflects what happened during the scenario	4.8 (4-5)	Yes. Would give clear data to participants of requirements. But also allow them to see improvements as new scenarios are performed. Needs a proficient recorder to observe and record at the same time.

Table 5. Results section B: Ease of Use. Results of questionnaire administered to four expert users following a demonstration of the functionality of the handheld device.

B. Ease of use	Average score (range)	Comments
1. The device is easy to use from an instructor's point of view	4.3 (3-5)	Depending on ability of instructor. I would need some assistance.
2. The device is easy to use from the learner's point of view	4.5 (4-5)	The visual part is very helpful. Nice it is anonymous for the learner. Yes, visual data with accurate timing. Excellent visual for learners.
3. Detailed or prolonged instruction is not required (*2 responses only*)	3.3 (3-4)	Would need more exposure. Unsure as not instructed from beginning. Depends on age of instructor!
4. It is easy to get to the start point (*2 responses only*)	3.7 (2-5)	Anything can be learned, but it will take a little time. Not demonstrated.
5. It is easy to shut the program down (*3 responses only*)	5.0 (5)	Not demonstrated Unsure

Table 6. Results section C: Effectiveness of use. Results of questionnaire administered to four expert users following a demonstration of the functionality of the handheld device.

C. Effectiveness of use	Average score (range)	Comments
1. The device is effective/efficient compared to the paper method	4.8 (4-5)	Allows you to review timing. New learners. Younger learners enjoy technology.
2. The handheld display is pleasing and functional	4.3 (4-5)	Could be larger video and display together. Would like on an iPad larger print. Ideally the tabs are colour coordinated.
3. The computer display is pleasing and functional	4.0 (4)	Would reverse the X and Y axes. Would like ability to enlarge written documentation. Like colour coded for each phase of NRP.
4. The printout was effective/efficient compared to the traditional checklist	4.3 (4-5)	May not remember issues: would be able to keep electronically and e-mail to participants
5. The saved computer file would be a useful tool for records or teaching	4.3 (3-5)	Only if used in combination with video recording. Yes, could tabulate data. Good for comparison, start to finish.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

This thesis outlines the theory behind, and development of, a handheld computer designed to aid instructors and learners record the sequence of events during a simulated (or real) neonatal resuscitation. The device is an instructional aid, providing immediate feedback on learner performance in the form of a time-stamped graphic. The hypothesis is that a handheld device that specifically targets and measures relevant learner performance and feeds it back to the learner and facilitator, encouraging reflection, will support learning during simulated and real-life neonatal resuscitation.

The Neonatal Resuscitation Program (NRP) is the educational program of choice for the resuscitation of newly born babies in North America. Practitioners who train in NRP (also known as NRP "providers") are required to take an exam called the NRP Megacode that involves observed performance of a simulated resuscitation. Instructors who oversee this exam use a validated evaluation tool (the Megacode Assessment Form (basic or advanced)).

The software developed for the handheld device was designed to measure and record the key steps required during a neonatal resuscitation simulation or Megacode. It is recognized that the NRP Megacode is a simulated immersive learning environment (ILE) that fits the concept of a constructive learning environment, characterized by an initial brief, a subsequent action, and eventual feedback through dialogue and reflection.

Central to this thesis is the constructivist learning environment, whose clinical correlate is the "immersive learning environment" (ILEs) that health care learners and practitioners are exposed to, both in the classroom and in real-life.

ILEs may be found in both the real and the virtual world. A schema has been proposed to describe the various forms of ILE as well as to describe their approximation to reality, measured as their "fidelity". Three types of fidelity were proposed: technical fidelity describes the physical aspects of the ILE and the reality of cues; contextual fidelity applies to the rational and logical and temporal steps as they present during an ILE; and psychological fidelity ("psychofidelity") describes the reality perceived in the mind. Is it a high gain of psychofidelity that permits suspension of disbelief? This is most probably the case, as, anecdotally, we are all aware, as instructors, of low technical fidelity scenarios that elicited both anxiety for the manikin during the action and relief that the doll "lived" at the end!

The NRP Megacode is a very special type of ILE, and the focus of this thesis. Constructivist principles suggest that a significant part of learning occurs as a result of reflection during the debrief of a simulation. Tools that facilitate reflection may enhance learning.

A review of the literature reinforced the pervasiveness of constructivist learning principles in simulated and real neonatal resuscitations, as well as in the processes of software development and evaluation. Other educational concepts that apply to these processes include those of design-based research (DBR) and user-centred design (UCD).

The literature review confirmed that handheld computers and smartphones are being used increasingly by health care professionals for a wider range of purposes, including communication, data entry, and evaluation. In most cases they are used to access data and libraries or for communication. In the minority of cases they are used to log or evaluate learning experiences. In this case a handheld device was developed to log neonatal resuscitation events, and present them during the debrief process of learning.

A software prototype was described that resides on a Pocket PC handheld computer. It allows an instructor to record events during a simulated neonatal resuscitation in real time. The time-stamped data can be uploaded to a desktop or laptop computer for display or printing. The output, a time series chart, reflects the course of the resuscitation. A preliminary evaluation of the software by expert users was very positive and recommended changes to enhance the functionality of the device and software.

As a next phase in the development of this prototype, a sequence of software and hardware evaluations is proposed that blends qualitative and quantitative instruments, and uses focus groups, questionnaires, and a modified Delphi process to refine the prototype tool.

It is proposed that the ultimate test of this device is its effect on real-life resuscitations, either with respect to practice (performance) or clinical outcome. Through the lens of design-based research, there is potential to discover new knowledge relating to individuals and teams performing neonatal resuscitation. The handheld device may play a role in this process of invention and discovery.

The principal messages of this thesis support the value of a handheld device as a tool to facilitate neonatal resuscitation training, at least in theory. However rigorous evaluation is required to confirm the benefits of the instrument, both in the classroom and in real-life neonatal resuscitations.

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EPILOGUE. APPS (APPLICATIONS) AND SMARTPHONES

Five years ago, when this project was conceived, smartphones were increasing in use. Today, it is rare to find a health care professional who is not familiar with a handheld device. In addition, thousands of software applications have become available for use with these computers. Larger, more flexible GUIs have become available, in the form of tablets and touch-screen laptops. The processing power of these devices now allows real-time video recording and playback to be added to a time-sensitive checklist. Clearly these advances could be integrated into an evaluation tool.

The Pocket PC and its operating system are the no longer appropriate vehicles for a handheld electronic recording and evaluation tool for NRP simulation. In addition to the hardware and operating system, wireless communication and audiovisual programs could enhance the educational software.

However, although there are new technologies available, the principles of a constructivist learning environment remain unaltered. One still needs tools to assist in recording and feedback in simulated and real ILEs. The potential of such tools has been greatly enhanced by these new technologies and the ability to download them as "apps" (applications).

The evaluation of this handheld device and its software and interfaces will always to lead to the conclusion that the device and platform should be revised in the light of new and improved technologies. While doing so, the premise that knowledge is constructed through interaction with the environment and reflection on that interaction will be sustained.

ROLES AND CONFLICTS OF INTEREST

This thesis is the sole intellectual property and work of the author. There are no financial conflicts of interest for the author or the author's immediate family.

Mark Brophy, the software engineer, was employed to write the handheld device software according to the writer's specifications. He played no role in initial concept development or authorship of this manuscript.

Intellectual conflicts may arise include the following:

Co-authorship. The writer is a co-author on 3 studies evaluating the NRP Megacode.

Administrative Responsibilities. The writer is Chair of the Canadian NRP Steering Committee and contributor to the NRP Megacode Assessment Form.

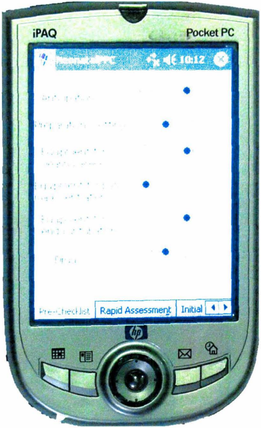
APPENDICES

APPENDIX A. Template for electronic checklist (programmed into handheld): items such as evaluation of heart rate, endotracheal intubation, instillation of epinephrine, can be entered repeatedly.

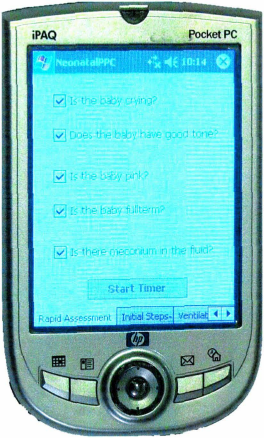
	ITEM	START TIME	STOP TIME	NOT DONE	PERFORMANCE			DONE IN SEQUENCE
	Birth	**0 seconds**			**poor**	**adequate**	**good**	**yes/no**
INITIAL STEPS OF RESUSCITATION	Place under radiant warmer							
	Clear airway							
	Intubation (meconium)							
	Provide free flow oxygen							
	Dry and remove towel							
	Tactile stimulation							
VENTILATION AND CHEST COMPRESSIONS	Evaluate HR1							
	Provide PPV							
	Evaluate HR2							
	Provide CPR							
	Evaluate HR3							
	Intubation							
MEDICATIONS AND VOLUME EXPANSION	Instil epinephrine							
	UV placement							

	Volume expander							
	Sodium bicarbonate							
	On-going care							

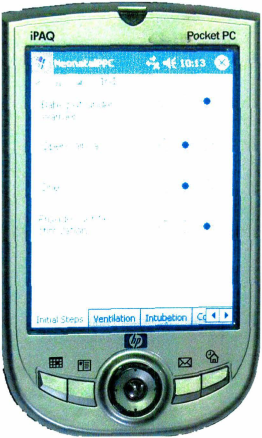
APPENDIX B. Pre-Checklist screen: The instructor observes the learner checking essential equipment.



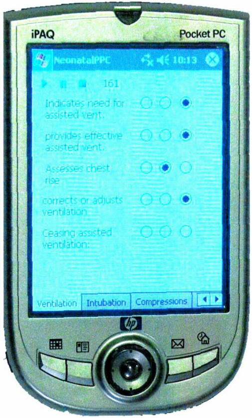
APPENDIX C. Rapid Assessment screen: The timer can be activated when the baby is born; after which the learner must evaluate whether resuscitation is required.



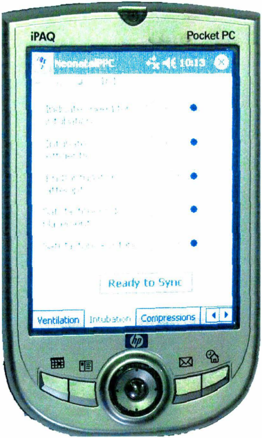
APPENDIX D. Initial Steps screen: The learner should normally spend up to 30 seconds drying the baby and making sure the airway is clear and open, while observing for normal or abnormal signs.



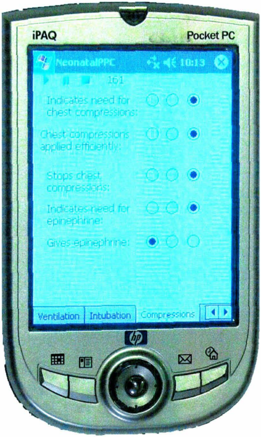
APPENDIX E. Ventilation screen: If the scenario requires the learner to demonstrate assisted ventilation, this screen permits recording of the events. It includes the essential steps required to ensure effective ventilation and correct for ineffective ventilation.



APPENDIX F. Intubation screen: This screen allows the instructor to record how well an endotracheal tube is placed, as well as assessing the roles of an assistant.



APPENDIX G. Chest Compressions screen: This screen records the use of chest compressions and cardiac medications.



APPENDIX H: Software and user interface evaluation checklist

A. Educational Value and Pedagogy	Poor	Fair	Good	Very good	Excellent
1. The device is flexible for your intended use (recording Megacode performance)	1	2	3	4	5
Comments:					
2. The device is appropriate for use in an NRP course	1	2	3	4	5
Comments:					
3. The device meets relevant educational needs of NRP providers	1	2	3	4	5
Comments:					
4. The language and definition of terms is appropriate for NRP	1	2	3	4	5
Comments:					
5. The device allows you to correct erroneous data entry	1	2	3	4	5
Comments:					
6. The device has help or troubleshooting options	1	2	3	4	5
Comments:					
7. The device presents options clearly	1	2	3	4	5
Comments:					
8. The device provides feedback in the classroom	1	2	3	4	5
Comments:					
9. The device is flexible for use different types of scenarios	1	2	3	4	5
Comments:					
10. The device allows recording	1	2	3	4	5

of complicated scenarios					
Comments:					
11. The input is similar to methods of recording that are currently used	1	2	3	4	5
Comments:					
12. The output reflects what happened during the scenario	1	2	3	4	5
Comments:					

B. Ease of use	Poor	Fair	Good	Very good	Excellent
1. The device is easy to use from an instructor's point of view	1	2	3	4	5
Comments:					
2. The device is easy to use from the learner's point of view	1	2	3	4	5
Comments:					
3. Detailed or prolonged instruction is not required	1	2	3	4	5
Comments:					
4. It is easy to get to the start point	1	2	3	4	5
Comments:					
5. It is easy to shut the program down	1	2	3	4	5
Comments:					

C. Effectiveness of use	Poor	Fair	Good	Very good	Excellent
1. The device is effective/efficient compared to the paper method	1	2	3	4	5
Comments:					
2. The handheld display is pleasing and functional	1	2	3	4	5
Comments:					
3. The computer display is pleasing and functional	1	2	3	4	5
Comments:					
4. The printout was effective/efficient compared to the traditional checklist	1	2	3	4	5

Comments:					
5. The saved computer file would be a useful tool for records or teaching	1	2	3	4	5
Comments:					

"What do you like about this device and its interfaces (PDA and computer)?"

"How might you improve this device?"

"How might you use such a device in your classroom?"

APPENDIX I: Mapping of scenario-based and user-centred design of a visualization software tool using a team of domain experts and health care users (Sutcliffe, Thew, De Bruijn, Buchan, Jarvis, McNaught & Procter, 2010). ©2010 by The Royal Society.